Appendix A: TECHNOLOGICAL ADVANCEMENTS AT MIT
and Potential Impacts in the Broader Transportation Industry
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The MIT-UIC Technology Scanning Project has the broad goal of identifying new and emerging technologies as applied to the railroads, in a generalized search for technologies. To gain an understanding of what technologies are currently emerging and what they are capable of, we conducted a survey of MIT’s over 200 labs, research centers and programs. The new technologies can be grouped into different “Areas of Enabling Technologies” (El Alj, 2001) or areas that are key to scientific advances. Out of the twenty areas examined, we found that MIT has active and interesting research projects in twelve areas. In addition, we identified a different area of research not previously examined: Asset-Life Extension technologies, where a great deal of work is currently ongoing at MIT. These areas were:

- A.1 Advanced Manufacturing Technologies
- A.2 Advanced Materials Technology
- A.3 Computer Research
- A.4 Electronics Research
- A.5 Environmental Technologies
- A.6 Energy Research
- A.7 Human/Machine Interaction
- A.8 Miniaturization
- A.9 Nanotechnology
- A.10 Propulsion Systems and Turbomachinery
- A.11 Sensor and Data Processing Technologies
- A.12 Information and Telecommunications Technology
- A.13 Asset-Life Extension Technologies

For each of these areas, we found one or more ongoing research programs at MIT’s research labs. In this appendix, they are itemized, along with a detailed explanation of what the proponent of the technology claim that it would be capable of, if the development proceeds successfully. With our collective expertise in operating rail systems, we attempted to systematically identify applications for railroads and for potential rail competitors, even if a railroad organization or a current railroad supplier did not originally sponsor the research. The emerging technologies are itemized in the rest of the appendix. In addition to these areas, the other key areas identified by El Alj, which were outside the scope of our generalized technology search at MIT, were:

- A.14 Cooling Technologies
- A.15 Display Technologies
- A.16 Alternative Fuel Technologies
- A.17 Imaging Technologies
- A.18 Laser Technologies
- A.19 Quantum Technologies
- A.20 Safety Technologies
- A.21 Security Technologies
In other research institutes, universities, and private-sector laboratories around the world, there are definitely other ongoing research which addresses these key areas (and perhaps other yet-unforeseen key areas). The rail industry would perhaps benefit from a continuing technology outreach program, in order to ensure as little as possible of the emerging technologies with important implication are missed.

A.0 Organization of This Report

For each of the group of technologies, we reviewed many websites and research publications. A summary of the report, website, or other published material is provided under the heading “What is it?”. The quoted portion is show in smaller type. In the case of online sources, a hyperlink to the original documentation is provided, to enable the reader to download more information and evaluate the technology if necessary. Our quick and simple evaluation of the aforementioned technology, based primarily on industry experience, is then given under the heading “How is it relevant to railroads?”. Evaluation of technologies is a complex affair. Some of the technologies were duplicated, since they are immediately relevant if used in a particular manner, but also have more potential in the longer term as further research & development allows deployment in other ways. Some of the technologies are more likely to be successful than others, in either reducing revenue or increasing costs. Some require additional investment, while others are ready-to-market. To simplify matters, we give a “Verdict” to each application of technology for summary purposes, which will be drawn from the following list:

1. Immediately Relevant to the Railroad Industry
2. Applicable to the Railroad Industry with Further Research or Adaptation or in the Longer-Term
3. May not be Directly Relevant to the Railroad Industry in the Foreseeable Future
4. Technology May Cause Secondary Impact through a Railroad Customer or Supplier

In our analysis, we found that 13 technologies were Immediately Relevant, 20 technologies were Applicable with Research, eight technologies May not be Directly Relevant, and 14 technologies would have Secondary Impacts. The technologies in each category are summarized below, in no particular order:

A.0.1 Immediately Relevant

- Automated Cost Estimation for Advanced Composite Materials
- High Performance Visualization of Urban Scenes
- Video Communications Research
- Optimizing Scientific Computation
- High Speed Rail Simulator/Human Factors for Central Artery Tunnel
- Ultrasonic Sensors for Nondestructive Evaluation
- Low-Cost Portable Telediagnostic Devices
- Vibration Suppression in Flexible Structures
- Active Networks
- Innovative Railroad Information Displays
- Evaluation of Decision Aids and Displays for High Speed Trains
- Fundamental Aspects of Underfilm Corrosion
- Equipment Gerontology: The Study of Equipment Aging and Prediction of Residual Life

A.0.2 Applicable with Research

- Automated Cost Estimation for Advanced Composite Materials
• Modeling of Deposit Solidification in Droplet Based Manufacturing
• Recycling Research Project
• Technologies for Unifying Multi-scale Computing
• Video Communications Research
• Combustion Pollution Research
• Photonics Research Programs
• Smart Aero Engines
• Numerical Investigation of Unsteady Blade Loads
• Active Tip Leakage Flow Control Using MEMS Technology
• Design of High Performance, Low Emission Gas Turbine Engines
• Aerodynamic Performance of a Scaled Turbine Stage
• Propulsion Systems Research
• Sensor Chair
• Electronic Product Code: A Naming Scheme for Physical Objects
• Visual Surveillance and Monitoring: A Forest of Sensors
• Unsupervised Audio Scene Analysis
• Wireless Networking
• Microbially Influenced Degradation of Polymer-Coated Metals
• The Electronic Structure of Thin Anodic Passive Films

A.0.3 May not be Directly Relevant

• Rotary-Linear Hybrid Axes for Meso-scale Machining
• Natural Fiber Reinforcement of Large-Scale Composite Polymer Panels
• Smart Fiber Network in a 3-D Fiber Textile Composite for Remote Structural Monitoring
• Computer Graphics Rendering Research
• Visualization of Light and Sound
• Framework for Automation Using Networked Information Appliances
• The Ring Sensor
• Mercury and Pegasus -- Telephoned Based Conversational Interface

A.0.4 Technologies with Secondary Impacts

• Implementing Lean Manufacturing with a Combination of New and Existing Facilities
• Automotive Propulsion Engineering Research Programs
• Human Performance Simulation
• Automobile Connectivity Research
• E-Automotive
• Magnetic Random Access Memories
• Smart Aero Engines
• Numerical Investigation of Unsteady Blade Loads
• Active Tip Leakage Flow Control Using MEMS Technology
• Design of High Performance, Low Emission Gas Turbine Engines
• Aerodynamic Performance of a Scaled Turbine Stage
• Propulsion Systems Research
• Low-Cost Portable Telediagnostic Devices
• Sensor Chair

Our analysis and the assumptions on which these verdicts are based, are contained in the remainder of this appendix.

A.1 Advanced Manufacturing Technologies

A.1.1 Automated Cost Estimation for Advanced Composite Materials
MIT Advanced Composites (http://web.mit.edu/lmp/www/composites/)

What is it?

This project concerns the development of a fabrication cost model which can be used by designers for advanced composite materials. In general the substitution of advanced composite materials for metals has been based upon a cost-performance trade-off. In spite of many public claims to the contrary, manufacturing cost premium for aerospace advanced composites versus aluminum is around 100%. Strategies to reduce cost generally involve the introduction of new automated fabrication techniques along with design modifications, in particular, integration of parts to reduce assembly. Evaluation of these cost reduction strategies is difficult due to a lack of realistic cost models. The goal of this project is to develop realistic cost models, verified by industry and available in the public domain. A key element of these models would be the easy ability to modify results for new developments in process technology. Such a model, combined with factory simulations and structural evaluations would enable the realistic assessment of alternate design strategies for the reduction of cost, and the development of design for manufacturing guidelines for industry.

More details on this project is available from Sascha Haffner’s paper, “Automated Cost Estimation for Advanced Composite Materials”, found at http://web.mit.edu/haffner/www/ResearchPaper1.html. The research is carried out by the MIT Laboratory for Manufacturing & Productivity.

• MIT Laboratory for Manufacturing & Productivity http://web.mit.edu/lmp/www/

How is it relevant to railroads?

The major sponsors for this research, unsurprisingly, are the users of high-performance, low-weight structures – the aerospace industry, and the auto industry to a lesser extent. How advanced composite materials will affect the railroad scene is not clear at present. Advanced composite materials have not traditionally been used on the railroad, but it is unclear whether this is due to a lack of research supporting railroad applications or whether the performance of advanced composites will simply never withstand the vibration-ridden rigours of the railroad environment.

Some of the initial, more mundane uses for advanced composites may be for the “non-moving” parts of the railroad: signal heads, relay huts, passenger car interior. Signal technology is already on the way to be replaced by communication-based train control (CBTC) where lesser wayside equipment would be required; the advanced composites may nonetheless reduce the costs of signal erection and maintenance areas where CBTC cannot be justified. Marginal changes to passenger car interiors may result in lesser maintenance or slightly lesser weight, but may result in deterioration of the perceived quality of interiors and service quality. Transit authorities competing on the basis of price rather than service may find this an attractive solution.

For the more demanding uses for advanced composites, such as load-bearing parts, doors, window panes, lining for tank cars and other goods carriers, coupling devices, presumably requires further targeted research and rigorous testing of the resulting material. The use of composite materials for freight cars may result in a higher weight-to-payload ratio for a given axle load. As passenger cars are not constrained by weight,
passenger trains may not see significant improvements, although safety may be improved perhaps at a cost. For high speed rail, if composite materials could be constructed with similar strengths as steel, it may allow higher speeds to become possible on existing tracks. So far, lightweight high-speed train service has resulted in a series of economic as well as catastrophic structural failures, beginning from GM’s bus-bodied Aerotrain of the 1950s to the aluminium-bodied British Rail Networkers which performed poorly in accidents. Notwithstanding, technological advances may permit much better crashworthiness characteristics in future, provided the focus remains in maximizing structural performance and not in minimizing costs.

Obviously, this research may be highly significant in the aerospace industry where the weight-to-payload ratio is a lot more critical than it is in the freight rail industry. However, so far composite materials have only resulted in marginal increases in productivity in the aerospace industry. The Airbus series of aircrafts have certain load-bearing parts made from carbon-fiber composites, but the fuselage itself and most of the wing is still made from metal alloys. This suggests that composites are currently unlikely to achieve widespread deployment except in very specialized areas, due to its cost compared with traditional materials. Composites were used for constructing bicycles, thus it is conceivable that it may be used for trucks or high-performance load-bearing parts on light-rail vehicles, but again much research would be required before its feasibility and economics could be established.

For electrified railroads, composite materials may be used for overhead structures and perhaps for insulators. Stronger and more effective conductors may result from a blend of highly conductive metal with composite fibers. However, the likely constraints are related to cost and conductivity in the case of the wire. As demonstrated by the state-of-practice, catenaries other than simple steel I-beams are not used except in environmentally sensitive areas. This suggests that cost, not performance, is driving the choice of catenary supports.

A.1.2 Modeling of Deposit Solidification in Droplet Based Manufacturing
MIT Droplet Based Manufacturing Laboratory (http://web.mit.edu/dbm/)

What is it?

Common techniques of droplet-based manufacturing (DBM) combine production of a molten alloy spray, usually by gas atomization, and its deposition on a substrate to form dense, rapidly solidified bulk alloys with fine, equiaxed microstructures. Although such processes have been used to make relatively simple near-net shapes, such as cylinders, disks and sheets, control of the deposit microstructure and, hence, final part properties is difficult due to the complexity and inherent variation in the atomization process used to produce the molten droplets.

In order to overcome these problems, we have constructed systems capable of producing and depositing uniform metal droplets. The uniform droplet spray (UDS) forming process has been developed to enable precise control of droplet thermal states and the resultant material microstructure of the deposit. By having a uniform droplet size throughout the spray, all the droplets deposited onto a substrate will have the same thermal state upon impact, allowing for precise control of the solidification process within both the droplets and the deposit. Uniformity of the sprayed droplets simplifies both investigations of basic process mechanisms and control of resulting microstructures to a much higher degree than has been previously possible. Research opportunities in this project cover all areas of the process including investigations of uniform droplet formation, process modeling and control, and microstructural evolution of the sprayed deposits.

(from the webpage of Prof. Jung-Hoon Chun: http://me.mit.edu/people/research/jchun.htm)

How is it relevant to railroads?
Material properties are vital to the life cycle costs of many railroad parts. Through a droplet-based manufacturing process, parts that are more durable can perhaps be made for railroad cars. Possible applications include: brake shoes, wheel-tyre, rail, switches and crossings, couplers, and other maintenance-intensive parts. Most of the advancement will probably occur within the truck, although there are other moving parts in the locomotive which may benefit from finer control of microstructure, such as engine blocks, cylinder heads, and pantographs for electric locomotives. In terms of alternative forms of propulsion, maglevs have high costs due to the precise alignment required from the infrastructure. With the hybrid maglev, it is likely that parts exist where high dynamic forces will be experienced due to an approach to building the infrastructure focused on keeping the infrastructure costs low relative to vehicle costs. Use of precisely engineered parts with microstructure giving rise to properties such as anti-cracking (for instance, an immediate application might be yaw-dampers for high-speed trainsets, and other high-performance parts) would lower the tolerance required hence substantially lower the cost of the infrastructure.

A.1.3 Rotary-Linear Hybrid Axes for Meso-scale Machining
MIT Precision Motion Control Laboratory

What is it?

The project aims at designing and building a prototype hybrid machine tool axis as a key component of new manufacturing machines for meso-scale parts. Hybrid means that the two axes of motion are compounded in a single moving component. Meso-scale parts are defined as having a size on the order of centimeters and thus falling between the domains of microfabrication and standard machining. Such parts include dental restorations, molds, dies, and turbine blades. Currently a prototype rotary-linear axis has been built. It consists of a central shaft which is driven in both rotation and translation. This hybridization minimizes machine inertias and thereby maximizes accelerations allowing for the production of complex parts rapidly and accurately. The minimization of inertias also increases the frequency of structural resonances allowing for control at higher bandwidths.

More details on this project, and others on similar topics, is available from the MIT Precision Motion Control Laboratory.

- MIT Precision Motion Control Laboratory: [http://web.mit.edu/pmc/www/](http://web.mit.edu/pmc/www/)
- List of past projects: [http://web.mit.edu/pmc/www/Projects/index.html](http://web.mit.edu/pmc/www/Projects/index.html)

How is it relevant to railroads?

The majority of projects currently undertaken by the MIT Precision Motion Control Lab are funded by the National Science Foundation under a variety of grants. This suggests the technologies developed there should have widespread applications in a variety of industries. At this point, it is hard for the authors to see how meso-scale (up to about a centimeter) parts could be used in the traditional rail industry, since track and vehicle components have sizes between a few thousand feet long to about a few inches long. In the next-generation guideway systems such as maglev, the ability to manufacture small parts quickly and precisely may allow a higher tolerance to be achieved than otherwise possible. However, smaller tolerances may tend be more expensive than a solution that requires less precision. The aerospace industry, which is used to working with tolerances a lot tighter than those in the railroad, are likely to be the first benefactor of this technology, if ever.

A.1.4 Implementing Lean Manufacturing with a Combination of New and Existing Facilities
Production System Design Laboratory

What is it?
The objective for this project is to help develop a plant-wide lean manufacturing system for producing front and rear axles for a variety of Ford vehicles. Because hundreds of millions of dollars worth of facilities already exist at this plant, it would be infeasible to design an entirely new system from the ground up. In some cases, obsolete equipment is being replaced and the opportunity exists to replace it with entirely new facilities. In many cases, however, recently purchased equipment exists and a new, lean system must be constrained to use this existing equipment. In all cases, it is desired to design a lean system to achieve reduced throughput time, flexibility to product design changes, and the ability to respond to changing customer demand on a monthly, weekly, or even daily basis.

How is it relevant to railroads?

The Lean Manufacturing Technologies could have one of two possible impacts. Firstly, the increased competitiveness in the cost of auto production could conceivably make rail a relatively less attractive mode for passenger travel. Secondly, the ability to respond to changing customer demand on a frequent basis may mean that parts will arrive in smaller batches, consistent with the truck’s business advantage over railfreight, leading to a decline in railfreight traffic.

A.2 Advanced Materials Technology

A.2.1 Natural Fiber Reinforcement of Large-Scale Composite Polymer Panels
Building Technology Program

What is it?

Recently, natural fibers have been investigated as filler materials for constructing buildings, capable of serving as localized tensile reinforcement and volume fillers within several types of polymer matrices. A number of natural fibers have been under continued investigation for use in natural fiber reinforced polymer composites (NFRC); including wood fiber, jute, sisal, kenaf, flax, wheat straw and bamboo. These fibers have been coupled in a matrix primarily composed of two commodity plastic matrix materials: polyethylene and polystyrene. While specific mechanical properties of natural fibers vary according to the particular fiber, the overall performance of natural fibers lies within a relatively tight range as a result of similar molecular composition. An increasing amount of interest has developed over the past few years for NFRCs because of their ease of production, subsequent increase in productivity, cost reduction, lower density and weight and use of renewable resources. The automobile industry has begun to apply NFRCs in a variety of exterior and interior panel applications. The significant weight savings and the ease and low cost of the raw constituent materials have made NFRCs an attractive alternative material to glass and carbon fiber reinforced polymer composites. However, further research needs to address significant material and production obstacles before commercially available NFRCs are widely used in architectural and civil works.


How is it relevant to railroads?

The research synopsis specifically mentions the auto industry, which is somewhat rare for MIT projects. However, its impact on the auto industry may be incremental rather than revolutionary – the cost of automobiles is not usually driven by the cost of the interior but the cost of the engine and the bodyshell; the cost of the highway mode is mostly driven by infrastructure and land requirements, especially in urban areas. The builder of transit vehicles and intercity-rail vehicles are presumably also able to use the advanced properties developed for these materials for vehicles interiors, for incremental benefits such as lower costs, higher durability or just swish looks. Some of the technologies may have a marginal impact since it may become easier for rail operators to maintain an attractive vehicular interior, to generate more revenue.
However, the driver behind vehicle interior cleanliness and maintenance standards could be an asset utilization and labor cost issue more than the actual materials cost of replacement interior décor.

In light density operations, wooden trestles are often used – the decision more often based on cost grounds and availability of materials locally. The research synopsis did not indicate whether this fiber/polymer matrix technology is in fact scalable, such that the techniques may be applied to constructing light density lines either at lower cost or are less maintenance intensive. It seems unlikely, however, that the high technology can reduce cost to the extent of beating the very low opportunity cost of local lumber.

A.2.2 Smart Fiber Network in a 3-D Fiber Textile Composite for Remote Structural Monitoring

Building Technology Program

What is it?

Three-dimensional fiber textile composites (3DFTC) have resulted from a search for viable alternatives to 2D composite (2DC) laminates. As a result of increasing concern regarding the difficulty with which 2DC have been able to address delamination from impact, in-plane shear stresses and transfer of axial and bending stresses between adjacent composite elements, 3DFTCs have recently received greater attention. For many reasons, the industrial application of 3DFTCs has lagged far behind the use of 2DC in high-performance industries such as aerospace and large-scale marine structures. However, several isolated yet noteworthy applications have been implemented in less demanding performance scenarios for civil and architectural structures. The lower level of performance requirements makes the use of 3DFTCs a possible way in which to lighten and strengthen typical structural and non-structural components used in civil and architectural structures.

3DFTC allows for the inclusion of a variety of fiber types within a three-dimensional near-net preform network. The inclusion of monitoring “smart fibers” within the architecture of the woven material allows for the through-member permeation of a fibrous sensor material. Typical fiber materials used for stress and strain monitoring are optical glass fibers linked to a central processor. In this way it is possible to gather important information regarding the health of a structure during construction and during its lifetime from a remote location. The study proposes to evaluate fibers for inclusion within a 3DFTC structural member as well as propose various sensor network architectures most productive for the applications listed. The materials chosen need to conform to the stresses inherent in the pultrusion and weaving processes during the production of the standardized structural forms.

How is it relevant to railroads?

Again, it is unclear this technology is applicable to the heavy-duty nature of the railroad environment. If used on an experimental basis, inclusion of some high-tech beams may help us understand stresses in trestles better and perhaps design them more cost-effectively. However, many traditional railroad trestle designs are already well understood. For light density operations, it may help us monitor the “weakest link” in the trestle such that the structure could be left standing for as long as possible before it has to be replaced. If such technologies could be adapted to monitor stress levels in state-of-art reinforced concrete and steel construction, it may be more applicable to the rail industry.

Better still, if a cheap version of the technology could be developed for use on existing structures, it may enable us to leverage much more productivity from an existing structure; for instance, a structure that has been designed for 25mph maximum speed may be uprated if the sensor fibres show that the structure could take much more strain without failing. Albeit, it seems unlikely that the technology could be developed for retro-fitting at reasonable cost, because the weaving of the fibres is an integral process of the construction of the structure. Perhaps replacement load-bearing members could be made using sensor composite material, presumably only a few key members will require monitoring in a discrete structure to predict the stress that the entire structure is likely to capable of supporting.
A.2.3 Recycling Research Project  
Materials Systems Laboratory

What is it?

A central requirement of successful sustainability efforts is effective recycling. Toward this end, pending European Union recycling guidelines will require the auto industry to recycle 95% of vehicle mass by 2010. This increase in the auto recycling rate will require significant changes in what is recycled in a car, how it is recycled, and how the recovered materials are actually employed. Additionally, given that reducing the automobile’s negative environmental impact requires manufacturers to use a greater diversity of materials, the automobile recycling industry is going to have to work very hard simply to maintain its current level of efficiency.

Together with colleagues in the Materials Systems Laboratory, the researchers are analyzing and evaluating alternative strategies for materials recycling. The key questions are first, what are the advantages of the different processing routes; and, second, what changes in the structure of the industry are necessary to implement the most effective options.

- The Material Systems Laboratory is at: [http://msl1.mit.edu/msl/](http://msl1.mit.edu/msl/)

How is it relevant to railroads?

Presumably, if the recycling movement is affecting the auto industry, it is likely to affect the rail industry also. Fortunately, materials used in the railcar – steel, wood, and glass – may be somewhat easier to recycle than those in an auto. Moreover, the infrastructure components (ties, rail, ballast and anchors) remain fairly discrete and are therefore also relatively easy to recycle. One perspective derived from this research project is that perhaps railcar manufacturers should consider the cost of recycling the materials as part of the total costs of constructing railcars. As more and more alloys are used in railcar construction, the recycling of metals in different composition may become more problematic. Even though composites may be attractive from a construction cost or railcar weight point of view, the cost of recycling the material ought to be considered a part of the total life cycle cost of the equipment. The cost-performance tradeoff evaluations should thus include the cost of recycling.

A.3 Computer Research

A.3.1 Technologies for Unifying Multi-scale Computing
MIT Laboratory for Computer Science

What is it?

Multi-scale computing refers to the diverse set of computing environments that scale over a wide range of engineering parameters, including cost, size, power, and reliability. Unfortunately, the software problem for multi-scale computing is compounded by this rich diversity of computing platforms, including networks of workstations, servers, multiprocessors, and MPPs. The goal of this project is to develop technologies necessary to unify computing across these different platforms.

Three promising technologies have been identified to achieve this goal. In the area of architecture, a user-level communications unit (UCU) provides efficient and protected communication across multi-scale platforms. In the area of operating systems, an exokernel interacts with the UCU and provides mechanisms for applications to define their own operating system abstractions. In the area of applications, a multithreaded runtime system provides unified resource abstractions for programming multi-scale computers.
The MIT Laboratory for Computer Science is at: http://www.lcs.mit.edu/research/research.php. Clearly, development of computer science technologies is one of MIT’s many strengths. A large number of research projects are currently being carried out, some are more germane to railroad applications than others. Only the most interesting has been selected for inclusion in this report.

How is it relevant to railroads?

Potentially, this technology is a double-edged sword for the railroad industry. There is no doubt that it will have a major impact on the industry – the question is whether it is good or bad. On the plus side, unifying technologies will allow transactions and systems integration across different parts of the railroad industry not previously considered possible. For instance, the embedded on-board computers in locomotives, passenger railcars, etc. are probably very different from systems in depots that are in charge of maintenance work orders, inventory of parts, and other depot management functions. If these systems were able to talk to each other, not simply from a data communications perspective but communicating useful information – for instance, a traincar which is suffering from a broken seat (entered by the traincrew) will send a message to the relevant depot via a wireless link, which will automatically check if the replacement part is available, and if not, place an order for the relevant part and puts the defect on the work-order. This will allow maintenance operations to be carried out with a greater degree of automation and probably more efficiently. Of course, some kind of auditing system is necessary – if you like, a paper-trail of such messages must be available. The technology is not necessarily cost-effective, although it will almost certainly lead to better levels of service – traincars will be out of service for lesser amounts of time, and when it is in service, instances of cracked windows, broken air conditioning or substandard seating will decrease.

However, with such wider system integration, problems are inevitable, because (a) the system will become too complex to debug, and (b) the different subsystems have different design criteria, thus opening data flow between them can have unintended consequences. For instance, interlocking and signal systems are designed to be completely fail-safe and extremely reliable. But if an engineer implements a data communication channel between the signalling system and other non-life-critical system without thinking through the implications, the results could be disastrous. One could imagine a scenario in which a signalling computer realizes that it has a burnt out bulb, thus dials the maintenance computer and asks for a replacement; the maintenance computer encounters an error (no more bulbs left) and sends a message back saying so, instead of dialling inventory control to get more bulbs. The signalling computer interprets this as a fatal error and shuts down its own operations, as a result the signals go dark and are missed by a less-than-alert engineer… Of course, this is never supposed to happen, but given a large enough set of linkages and complex interactions between systems, it’s a matter of time before a life-critical link gets forgotten, and accidents happen.

Even if interlocking logic were designed into the signalling equipment to prevent this type of accidents, other problems can still occur that are perhaps not life-critical but business-critical. For instance, if technologies are available to enable computers to talk to each other, it is a matter of time before railroad freight shippers will request an open communication channel between their inventory management systems and the railroad’s scheduling system. The railroad’s freight car scheduling system is business critical. It’s not difficult to envisage that disgruntled shippers may attempt to disrupt the railroad’s network by swamping the scheduling computer with shipping requests, or to attempt to block a competitor’s shipping requests. Although experience with the computerized reservation systems (CRSs) in the airline industry has suggested that integration of large complex systems is possible and it can work, it has taken some twenty years and a lot of development work for the system to evolve to the state-of-practice today, and a number of problems still exist in the CRS.
The value in applying these complex technologies may not exceed the costs of its implementation in many scenarios – for instance, Southwest Airlines has stayed out of the CRS system and consumers appear to have indicated that they are quite happy to fly Southwest despite the fact that they are unable to book a seat through a CRS-connected travel agent. The risk in applying these integration technologies is always that somebody will enter the market without these technologies and achieve a lower cost base for substantially the same service than you are able to offer.

A.3.2 High-Performance Visualization of Urban Scenes
MIT Computer Graphics Group

What is it?

This project aims at the development of new visualization techniques allowing the interactive manipulation of urban data. Efficient visualization of 3D urban scenes is important for a number of applications such as: the evaluation of construction and renovation projects (site planning and visual impact studies); civil and military simulators (flight, drive, combat); navigation helpers for automobiles; virtual tourism and education; climate and environmental studies (plant growth in urban areas, detailed visualization of a number of simulations such as the diffusion of pollutants etc.); and city development planning.

The visualization of urban scenery is a very challenging problem because of the great complexity of these environments. Typical views of urban scenes contain very rich visual details at a fairly small scale, while the extent of the model is often very large (at least several square kilometers). Therefore the geometric and visual complexity of the models easily exceeds the memory and processing capacity of most visualization systems. However, we observe that while urban scenes are extremely complex, they are also heavily structured. This structure is a consequence of the artificial nature of the built environments and reflects the spatial, social, and historical organization of these scenes (for instance in the form of the network of streets). The goal of this project is to exploit the structure of urban environments to offer interactive visualization techniques as well as efficient simulation tools tailored to urban scenery. To achieve this goal, efficient image caching and interpolation techniques will be combined with traditional 3D techniques. In particular, specific level of details will be associated with urban objects based on the underlying structure, and appropriate criteria will be devised for the generation and usage of cached images.

How is it relevant to railroads?

This technology could be relevant to the railroads on two different levels. Firstly, a more transit-like application would be for the modelling of station improvements – or more importantly, convincing policymakers and the customers that the station improvements they are paying for is actually worthwhile. Secondly, a more mundane application is for that of rail operator training. Instead of training operators on actual trains, visualization technology could be used to train operators in simulators rather than in the field, with lesser expenses.

The first application is likely to remain important in the future, even though it is only of tangential interest to the railroad industry since nice urban scenery does not usually directly generate profit for the passenger rail carrier (although if coupled with a real-estate arm, it can be potentially very important). The requirement for the second application is likely to decrease as the industry migrates towards automatic or computer-assisted train control, when the requirements for the operator to “know the road” will decrease.

A.3.3 Interactive Control of Rigid Body Simulations
MIT Computer Graphics Group

Physical simulation of dynamic objects has become commonplace in computer graphics because it produces highly realistic animations. In this paradigm the animator provides few physical parameters such as the objects’ initial positions and velocities, and the simulator automatically generates realistic motions. The resulting motion, however, is difficult to control because even a small adjustment of the input parameters can drastically
A novel interactive technique is described for intuitive manipulation of rigid multi-body simulations. Using this system, the animator can select bodies at any time and simply drag them to desired locations. In response, the system computes the required physical parameters and simulates the resulting motion. Surface characteristics such as normals and elasticity coefficients can also be automatically adjusted to provide a greater range of feasible motions, if the animator so desires. Because the entire simulation editing process runs at interactive speeds, the animator can rapidly design complex physical animations that would be difficult to achieve with existing rigid body simulators.

A.3.4 Motion Capture, Analysis, and Synthesis
MIT Computer Graphics Group

Modeling human and animal motion is a fundamental scientific objective, with applications in computer graphics, robotics, and medicine. Graphics applications include education, training, and visualization, as well as animation in art, film, and entertainment; in robotics, robot design and the design of controllers for legged locomotion; in medicine, the diagnosis of medical problems and the design of prosthetic devices. In all these applications, a predictive physical model of locomotion is essential. The success of each application is contingent on the simplicity of this locomotion model: models of great complexity are difficult to simulate, analyze, and optimize.

A.3.5 Modeling and Rendering of Metallic Patinas
MIT Computer Graphics Group

An important component that has been missing from image synthesis is the effect of weathering. This research presents an approach for the modeling and rendering of one type of weathering—metallic patinas. A patina is a film or incrustation on a surface that is produced by the removal of material, the addition of material, or the chemical alteration of a surface. Oxidation, sulphidization, and painting are examples of phenomena that produce patinas.

How is it relevant to railroads?

Other than as a feeder technology to the High-Performance Urban Scene Simulator, it is difficult to see how these particular types of research will assist the railroad industry.

A.3.6 Visualization of Light and Sound
d'Arbeloff Laboratory for Information Systems and Technology

What is it?

Recent advances in computer graphics hardware and techniques have made it possible to visually render and explore geometrically-modeled settings in real time or at interactive rates. Computer simulations can generate significant spatial and temporal data describing three-dimensional environments. Computer graphics visualization techniques provide the means to display this multidimensional data, allowing substantial amounts of information to be communicated to the designer. This research concerns the development of simulation techniques to improve the accuracy of lighting and acoustic space evaluation, utilizing theoretical and interactive techniques. In addition, new interaction paradigms are under consideration.

How is it relevant to railroads?

Again, other than as a feeder technology to other railroad-related technologies, primarily for design and training purposes, it is difficult to see how this particular types of research will assist the railroad industry.
A.4 Electronics Research

A.4.1 Video Communications Research
Advanced Telecommunications and Signal Processing Group

The MIT Advanced Telecommunications and Signal Processing Group carries out a variety of research which will support telecommunication and data transmission in future. There are a number of research projects with very specific application to certain types of video transmission needs currently in progress:

- **Representation of Multi-Dimensional Signals with Arbitrarily-Shaped Regions of Support**: For example, a 3-dimensional medical image may contain a map or model which targets an arbitrarily-shaped region of detail. Several promising wavelet representations have been developed for high performance with low complexity.

- **Realtime Source Multiplexing of Variable Bitrate Encoded Video**: Realtime video is most efficiently encoded using a variable bitrate to accommodate the variable nature of video information. In source multiplexing, the bitrate fluctuations of various sources are effectively averaged, allowing multiple video streams to be efficiently transmitted on a single constant rate channel.

- **Non-Causal Processing of Pre-Recorded Video for Compression and Multiplexing**: By using information obtained from pre-processing of a video source, improved quality can be achieved in compression and multiplexing.

- **Very Low Bitrate Coding for Underwater Images**: Video transmission from an unmanned undersea vehicle must take place at a very low bitrate. This requires novel methods of video compression which exploit unique characteristics of underwater video images, such as slow motion, low contrast, and bluriness.

- **HDTV Format Conversions and Resolution Enhancement**: The HDTV standard allows for transmission in several different formats, requiring methods for converting between formats. This project also investigates the possibility of broadcasting at higher resolution under current bandwidth through the use of enhancement information transmitted with the images.

- **Speech Enhancement Systems**: Current study is of an algorithm, developed by the ATSP, which segments speech into nearly stationary regions using filtering and adaptive windowing and enhances the signal of each region through linear prediction modeling and Wiener filtering. Recent improvements have been achieved by taking into consideration the signal-to-noise ratio of each region as it relates to the sonic frequency.

How is it relevant to the railroad?

In general, application of video or image transmission technologies to the railroad are somewhat limited. A few obvious ideas have been floated, some of which are listed below:

- Remote Monitoring of Grade Crossings (Safety)
- Remote Monitoring of Stations and other Facilities (Security)
- Remote Control of Equipment (Locomotives, Switchers)

Each of these technological opportunities has yet to prove their worth. The most immediately applicable is perhaps the Monitoring of Grade Crossings – indeed, such closed-circuit television monitors, using conventional high-bandwidth video transmission technologies, have been installed at many grade crossings in Britain where train speeds exceed 110mph. The video image is not really used for real-time incident monitoring – rather, it is used as a deterrent, in case of accident for investigation, and enable prosecution of violators, due to firstly to the rare frequency of a situation and also the near impossibility of intervention.
from a remote site once a hazardous situation has been detected. For the Station Monitoring, a similar problem exists. The issue has consistently been the fact that personnel who watches these monitors tend to allow their attention to wander, and even if something is amiss, it is usually too late for the railroad personnel to raise alarm from a remote location. A local security guard or even just a token clerk may be a more effective security option. Obviously, enhanced video encoding technologies will allow monitoring to become more ubiquitous and cheaper, but the debate is not over as to whether video surveillance is really part of the solution, and whether there are privacy issues associated with continuous surveillance in general.

The Remote Control of Equipment is an entirely different idea, for which better video communications would be much more useful. The idea is that an operator could remotely control a locomotive, whether this be in the yard, or out on the mainline, while being able to see everything in the cab from a remote location. This would include the instrumentation panel, as well as the view out of the cab window. Since wireless bandwidth is very expensive, there is a much more pressing case for lower-bandwidth video transmission. However, Remote Control of Equipment itself may be problematic beyond the confines of the yard, for a number of reasons:

(a) The mainline is an open environment – in addition to lesser control over grades and right-of-way exclusivity, there are simply many more hazards out there. Thus, to control a locomotive effectively on the mainline, input beyond the instrument panel and the view from the cab may be required – for instance, dynamic forces in the train (i.e. how the train “feels”), and the ability to lean out the cab window to inspect an obscured signal or a misaligned switch.
(b) With short-formation passenger trains, those inputs are not so vital and remote-control could be seen as a possibility, although it may not be publicly acceptable as demonstrated by the fact that San Francisco’s Bay Area Rapid Transit (BART) was designed to be computer-controlled and operatorless, but operators were reinstated after the opening of the system.
(c) Railroad equipment are not intervention-free pieces of kit; frequently, mainline-running trains will encounter hot axleboxes, brake pipe leaks, and other simple operational problems that will require a very simple operator intervention before the trip could continue. At some level, you’re attempting to balance the increase in productivity by allowing crew-less trains with the decrease in productivity because every time there is a problem, a crew would still need to go out and meet the train. Current reliability statistics suggest that the cost of keeping standby “thunderbird” crews plus the technology may well be higher than the cost of simply manning the trains.
(d) Even with remote control, the locomotives would still need to be equipped with local control mechanisms, thus no savings are possible on the in-cab equipment.

A.4.2 Optimizing Scientific Computation
Research Laboratory of Electronics

What is it?

The use of supercomputers and massively parallel computer systems is essential to solving large-scale scientific and engineering problems that need extensive amounts of memory and rapid speed. Data-intensive calculations run much faster when parallel processing is combined with significant amounts of memory on a single chip, typically a digital signal-processing (DSP) chip. Parallel processing involves the simultaneous use of more than one central processing unit (CPU) or engine to execute a program. The CPU contains the circuits for interpreting program instructions and executing arithmetic and logic operations in proper sequence. A DSP chip is a special-purpose programmable CPU placed on a single chip. It provides ultra-fast instruction sequences used in math-intensive signal-processing applications. A major research activity in this area is the development of parallel processing algorithms and software, where programs are divided into components that are executed simultaneously by the separate processors. Dividing a program in such a way can make it run faster. To use a parallel computer effectively, an algorithm must have parallelism. That is, it must require the simultaneous performance of certain mathematical operations and determine the number of non-overlapped
operations that are needed. In this way, the number of arithmetic operations needed to solve a problem reliably is minimized, thus minimizing the computational cost and solution time associated with large-scale scientific computation.

How is it relevant to the railroad?

One of the most demanding computing problems in the transportation industry today is solving large-scale optimization problems. As railroads merge and systems grow ever larger, finding the optimal solution (or in fact, a probabilistically optimal solution – with the in-built assumption that the operating plan would not be executed, and that recovery moves would be necessary) is increasingly challenging. Obviously, any additional computing power which will allow faster or cheaper solutions to the problems is good news. Faster solutions will enable real-time operations planning to be possible where it isn’t previously possible, while cheaper solutions will enable ever larger systems to be optimized and more variables considered.

There are two possible perspectives to this optimization technology. Firstly, as some optimization experts will point out, raw computing power is not leveraged with respect to the size of the problem you can solve, but algorithms are. Clever algorithms in the past has reduced computing power required to solve a given optimization problem by several orders of magnitude, making previously infeasible problems solvable. The key is to reformulate a problem whose computing power requirement varies exponentially with the number of variables as one whose computing power requirement varies as a polynomial function of the number of variables. Many techniques are already available, and continuing research occurs at places such as MIT’s Operations Research Center. The reduction in runtime available from algorithm improvements will most likely outstrip any reduction in runtimes through sheer brute force – previous computer research has demonstrated that while computers struggle to double in speed, halving the number of operations required to solve a problem is not really a significant achievement in algorithmics.

The other perspective becomes more and more important as we implement the rudimentary optimization methodologies. When optimization is first implemented, the gains are big, and the investment is relatively small. However, a point of diminishing returns is reached – as we get closer and closer to optimal, the gains diminish while the investment required skyrockets. It is conceivable that for a given level of investment, say $1 million, there are better places to invest that money than in optimization of operating plans. Many railroads may already be running an operating plan which is so close to optimal that it’s better to invest the funds in other areas. While it is true that the investment in optimization will generate significant gains even for a 0.1% reduction in say crew costs, it is likely that some other technology would achieve a much higher saving than that, simply because it has never been implemented – the “slack” hadn’t yet been taken out of that part of the system, as it were.

There are uses of raw computing power other than optimization of network flows. In the case of optimization, algorithmics could be used to reduce the runtime to solution dramatically, but this is not the case with all problems in transportation – especially ones that are data-intensive. Frequently, transportation systems require a relatively simple operation to be performed on a vast array of data (as opposed to an optimization problem which is a series of complex operations performed on a small array of constraints). The attention should then be focused on increasing raw computing power and reducing the size of the dataset, if possible. It is here that parallel processing is likely to make the largest impact on transportation systems. Relative to ad-hoc, undispatched and distributed modes such as the automobile, the railroad is likely to gain a big advantage from increased central processing power. Unless the users of the automobile are willing to give up the flexibility of individualized decision-making, it is unlikely that the research in large-scale computing power will enhance the automobile experience significantly.

A.5 Environmental Technologies
Although various research labs perform work on Environmental Technology, these appear to relate more to the deployment of environmentally-friendly technologies rather than actual technologies themselves. As a result, the programs we discovered under this category was not included. Discussion of alternative fuel technologies will be found under the category “Energy Technologies”. Other environmentally-friendly technologies, such as recycling technologies, is found under “Materials Technologies”.

There is an Environmental Technology and Public Policy Program at MIT’s Department of Urban Studies and Planning. MIT also has a Technology and Policy Program, which also examines implementation of environmentally-friendly technologies. At Harvard, the Kennedy School of Government also addresses these issues, in greater depth than at MIT. The MIT Laboratory for Energy and Environment addresses some of these issues, focused mostly on evaluation of environmental technologies rather than their deployment.


### A.6 Energy Research

#### A.6.1 Automotive Propulsion Engineering Research Programs

**Sloan Automotive Laboratory**

##### A.6.1.1 Spark-Ignition Engine Program

This program, established in 1981, focuses on combustion and emissions in spark-ignition engines. Investigators are conducting parallel research programs ranging from development of a knock-prediction model and examination of pollutant-formation mechanisms to application of new practical combustion-diagnostic tools for studying parameters affecting engine performance.

##### A.6.1.2 Lubrication in Internal Combustion Engines

This program, formed in 1989, focuses on understanding how lubrication affects engine fuel consumption, component wear, oil consumption, and emissions from internal combustion engines. The primary goals are to develop and apply advanced diagnostics to describe lubricant-film behavior and to develop theoretical models that relate detailed lubricant-film measurements to engine performance parameters.

##### A.6.1.3 Engine/Fuel Interactions in Spark-Ignition Engines

Current and future air quality regulations have motivated oil and automotive companies to pursue new fuels and new strategies for controlling emissions. This program, started in 1991, explores how changes in fuels anticipated during the 1990s will affect the combustion process and emissions. Projects examine the effects of fuel composition changes on the fuel-air mixture preparation, hydrocarbon emission behavior, and engine performance during the start-up period.

**How is it relevant to the railroad?**

The Sloan Automotive Laboratory carries out much research which are directly related to current concerns and issues in the automotive industry. Much of its research is fuels and environment related. The focus is on solving current problems rather than developing genuinely novel technologies that change the status quo.
As such, the research is highly specific and affects the automotive industry only marginally. This research is therefore unlikely to significantly increase the dominance of the private auto and also unlikely to be applicable to the railroad industry. Other auto industry research also occurs at MIT, and these could have longer-term effects on the balance of modes and the structure of the transportation system.

A.6.2 Combustion Pollution Research
MIT Energy Laboratory

What is it?

This research includes detection and measurement of short-lived free radical intermediates important to how fast and how completely combustion occurs, kinetics experiments and prediction of rate coefficients and thermodynamic properties, and mathematical modeling of combustion reaction networks such as the growth and destruction of polycyclic aromatic hydrocarbons and soot particles. Health effects of combustion emissions are being studied in collaboration with analytical chemists and toxicologists. Combustion engineering researchers are now developing design strategies for modified or novel combustion processes that will permit fuels with higher contents of nitrogen and aromatic hydrocarbons to be burned more efficiently and with less pollution. Their approach involves both experimental studies and computer modeling.

Other research has emphasized fundamental and more applied studies of high-temperature reactions, for example, pyrolysis, combustion, and gasification of various fuels including coals, biomass, natural gas, liquid petroleum products, and their derivatives. Topics of interest include mechanisms and kinetics of gas-solid reactions, gasification of carbonaceous solids, deposition of solids from gas-phase products of combustion or gasification, reactions of fuel-bound and exogenous mineral matter, and reactions for control of sulfur oxides (SO\textsubscript{2}) and nitrogen oxides (NO\textsubscript{x}). Other projects are extending understanding of high-temperature gas-phase reactions. Of special interest are the fuel-rich oxidation of hydrocarbons and the role of mixing in chemical reactions in gasification and combustion systems.

In fuel conversion research program, focus is on transforming fossil and biomass fuels into higher-quality products better suited to clean burning in conventional combustors or in advanced, high-efficiency direct conversion devices such as fuel cells. Conversion research also examines transformations that facilitate the storage and transport of fuels. Much of the fundamental research in the last decade has focused on understanding high-temperature chemical reactions important for converting fuels or removing pollutants. Other fundamental work investigates industrially important reactions that involve catalysis or that occur in a thermal plasma, an energetic gaseous electrical discharge that generates high temperatures and reactive chemical intermediates. These techniques allow reactions to occur at much higher rates and can permit increased yields while limiting the production of undesirable by-products.

How is it relevant to the railroad?

The MIT combustion research appears to be focused on the needs of the auto industry, although the research is conducted at a very fundamental level thus could potentially be applicable to the railroad. It is likely that stricter environmental regulations will be extended to the railroad sometime in the near future, therefore it is important that suitable follow-on research is conducted by locomotive suppliers or the rail industry to ensure the continued compliance of the railroad with environmental regulations. This research, however, is unlikely to enhance the rail industry’s bottom line, and should not receive priority unless legislatively mandated – or if the resulting positive externalities could be captured by the industry.

A.7 Human/Machine Interaction Research

A.7.1 Human Performance Simulation
The Human-Machine Systems Laboratory

A.7.1.1 High Speed Rail Simulator
The high-speed rail simulator at the U.S. Department of Transportation’s Volpe National Transportation Research Systems Center is a human-in-the-loop simulation of a train locomotive. Currently, the simulator consists of two monitors which display the out-the-window view and dashboard display to the train engineer. A central traffic dispatcher can interact with the simulation remotely. The train engineer reacts to data and scenarios shown on the monitors by entering control commands through a traction/brake lever or the computer keyboard. The simulation software, which was developed entirely by MIT students, is portable to any SGI machine running the IRIX operating system at Rev. 3.3 or higher. The software is modular to the point that any number of trains can be running on the system at once; the number of available machines only limits the number of trains.

A.7.1.2 Human factors for Boston’s Central Artery/Tunnel

The main objectives of the human factors research in the Central Artery/Tunnel Project are to carry out the task analysis for operators in the Operations Control Center (OCC), and to develop an operator-in-the-loop simulation of the OCC for incident management scenarios.

How is it relevant to the railroad?

Simulation research, like the research for High-Performance Rendering (see A.3.2 – Urban Scenes), is useful to the rail industry on a limited basis. The obvious application, as has already been developed, is the high-speed rail simulator which would be used in operator training. Although operator training on simulators does cut costs and allow operators to “drive” through scenarios that would be impossible to replicate in practice (such as crash conditions), there is still a need for field training for issues such as “feel” of the train and how you would actually deal with a hot axlebox (e.g. where it is a safe place to stop the train, and being safe when walking backwards along the train). Ideally, operator training should not form a large proportion of the carrier’s costs – if that is the case, it implies a high turnover rate and thus relative lack of experience generally amongst the operators. Thus, reducing the cost of training through simulations is presumably not as leveraged as for example investing in technologies that will retain operators better, such as an optimization system which outputs reasonable operator schedules.

The Central Artery project demonstrates that the simulation research can also be applied to other modes of transportation, such as highways and airlines, provided that the users accept a central-dispatching as a way forward. In dispatching disciplines, simulations are much more useful than operating disciplines, since it is possible to reproduce the conditions exactly in a simulator, with the same instrument panels and same phones. The development of the technology will facilitate re-training, which is vitally important in many dispatching disciplines, but this is more of a management issue than a technology issue. The cost of the training technology is usually much less when compared with the cost of dispatcher non-revenue time spent in training.

A.7.2 Automobile Connectivity Research

MIT Media Lab

A.7.2.1 Detection and Analysis of Driver Stress

Driving is an ideal test bed for detecting stress in natural situations. Four types of physiological signals (electrocardiogram, electromyogram, respiration, and skin conductivity related to autonomic nervous system activation) were collected in a natural driving situation under various driving conditions. The occurrence of natural stressors was designed into the driving task and validated using driver self-report; real-time, third-party observations; and independently coded video records of road conditions and facial expression. Features reflecting heart-rate variability derived from the adaptive Bayesian spectrum estimation, the rate of skin-conductivity orienting responses, and the spectral characteristics of respiration, were extracted from the data. Initial pattern recognition results show separation for the three types of driving states: rest, city, and highway, and some discrimination within states for cases in which the state precedes or follows a difficult turn-around
or toll situation. These results yielded from 89-96 percent accuracy in recognizing stress level. We are currently investigating new, advanced means of modeling the driver data.

A.7.2.2 Automobile Connectivity Research

The Automobile Connectivity Research Special Interest Group (CC++) looks at cars in the digital world. It explores the implications and applications of human-machine interface research, advances in personalized information technologies, the increasing interconnectivity of automobiles, new design technologies and methodologies, and the attitudes of drivers to their vehicles. It includes: autos that interface with the driver’s information environment; cars with connections; implications and applications of highly dense, high-bandwidth communications among nearby automobiles and the surrounding areas; design and concept studies, including novel input and output modalities for automobile development and use; and studies of individual drivers and communities of drivers, examining how their experiences are shaped by automobiles.

How is it relevant to the railroad?

The first part of this research appears to be focused on applying neurological and psychological research on stress indicators to a specific application in the auto industry. There is follow-up research to this which examines the impact of connectivity in the automobile is more generally and widely applicable. It is conceivable that if automobile drivers can benefit from certain communication technologies, subway riders and rail passengers can also benefit from similar communications. On the other hand, if it became much more possible to communicate while driving, this could be detrimental to the competitive advantage of chauffeured transportation systems such as rail and air. It is at present unclear where this research will lead, although passenger rail interests should be watching this area with great caution, especially for systems which rely predominantly on short-distance, auto-substitutable trips such as the Nederlandse Spoorwegen system.

A.7.3 E-Automotive
International Motor Vehicle Program

What is it?

As we enter the auto industry’s second century, we see powerful signs of change that could foretell the next dominant production paradigm. Central to all these changes is the internet, which is already transforming how information is used and how coordination is managed in this most complex of industries. E-business offers tremendous potential for reducing waste and inefficiency, redistributing activities along the value chain, and providing new means for collaboration. These e-effects will be evident in product development, procurement, manufacturing, and distribution separately, but the greatest impact will result from end-to-end integration of the value chain, from the final customer back to initial product planning.

While consolidation in the industry and plans for an industry-wide internet exchange suggest a continuation of strong and centralized control by the dominant automakers, it is believed that e-automotive developments will ultimately speed the move away from the old vertical model. As key vehicle functions move from mechanical to electronic controls, and as the vehicle becomes a platform for computing and telecom applications (telematics), the IT and electronic sectors will affect (and infect) auto’s competitive dynamics. Consumer desires for customization will challenge the industry’s long-established push approach to distribution and sales. As expectations are raised by New Economy experiences in other parts of their lives, e-powered consumers will be drawn towards build-to-order models where they play a co-design role and production is pulled by real-time information about their preferences.

Ultimately it is predicted that this will be a transitional stage – what is now identified as e-business initiatives will someday be the norm for how business is done in this industry. By focusing on e-business now, it is hoped to catch the inflection point in the trajectory of change – the point where the continued evolution of mass and lean production gives way to a new emergent logic, a new way of thinking about making things.
How is it relevant to the railroad?

This piece of research is particularly interesting despite the apparent demise of the so-called e-revolution. The researchers apparently believe that the factors which made the auto industry successful at the turn of the last century – Ford’s mass-production approach – is likely to fall out of favour as customers demand increased level of customization in an e-enabled age. Of course, it is not clear whether customers will demand sufficient customization that the auto industry’s economics of scale would be entirely lost, or whether customers would demand customization to the extent that many will abandon the private auto in favour of a less-customizable but cheaper mode – collective public transportation. As with most consumer-driven pieces of research in the auto industry, the passenger rail industry ought to be following its developments closely. Information about what the auto industry is planning, and what the currently auto-captive consumers want, could potentially be key for the passenger railroad’s competitiveness in future.

A.8 Miniaturization Technology

A.8.1 Photonics Research Programs
Microphotonics Center

A.8.1.1 Photonic Crystals

Photonic crystals are an exciting new class of materials which has emerged over the past few years. These materials are periodic composites of macroscopic dielectric and/or metallic media designed to possess a complete (or omni-directional) photonic band gap, i.e. a range of frequencies for which photons are forbidden to propagate in the crystal. The photonic band gap (PBG) is analogous to the electronic band gap in traditional semiconductors, and permits unprecedented control of the confinement and propagation of light at very small dimensions, thereby enabling the design and integration of a large variety of optical micro-devices on a single chip. One area for investigation is the fabrication of highly efficient micro-LEDs, high-Q micro-cavities and micro-lasers, fast optical switches and modulators, tunable sources and filters, and channel add/drop micro-filters for wavelength-division multiplexing and demultiplexing. PBG materials may also be designed as highly sensitive optical coatings, paints capable of controlling the light transmission and emissivity of an underlying surface for all angles of propagation and polarization of incident light. Infrared-reflecting coatings could have a host of commercial applications in home appliances (efficient ovens), heat-retaining windows, and heat-retaining lightweight clothing.

A.8.1.2 Micro-resonators

Micro-resonators that control, filter, and enhance optical interactions will be key elements in a wide range of micro-photonic devices, circuits, and sensors. By confining light to very small dimensions they make it possible to control emission properties and to enhance the efficiency of active devices. The concentration of optical intensity in micro-cavities can be used to enhance optical nonlinearities and reduce the power required for all-optical switching devices. Devices may be optimized for the desired speed, and functionality can be further enhanced by coupling the confined optical mode to other electronic, optical phonon, and acoustic resonances. New structures for increasing the effectiveness of similarly coupled interactions will be investigated.

A.8.1.3 Photonic Micro-cells

One of the most challenging problems in integrated photonics is power transduction between electronic and optical signals at the micro-scale. The power efficiency and speed of interconnects in a device depend on the length of the inter-connect. The ultimate device density is limited simply by the power input into each device. At high levels of optoelectronic integration devices must operate at nW power levels. Unless power transduction efficiencies approach 1, the maximum density of devices allowed by the thermal limit does not change significantly with efficiency. We will utilize high dielectric contrast materials in microphotonic circuits that do not expand the optical mode to a greater scale, so that light is generated, manipulated, and detected at the micro-scale. Photonic micro-cell, rather than device, design will optimize efficiency. We will study photon
bus architectures employing an external photon power supply to cells comprised of modulators, routers, filters, and detectors. At this scale, the photonic micro-cells should operate at nW or less, permitting high levels of integration.

A.8.1.4 Input/Output Coupling

A major issue in high-level micro-photonic integration is input/output optical coupling; coupling is the most costly aspect of discrete optoelectronic interconnection. Monolithic micro-photronics is a promising solution, but effective optical junctions for these highly confined optical systems require innovative design and materials selection. The key performance factors are coupling efficiency and noise. Coupling efficiency for guided-wave microphotronics is dependent on optical mode matching; changes in refractive index, mode symmetry and size, and junction alignment are critical issues, with tradeoffs between performance and processability. We will explore new bonding materials and novel means of focusing photolytic cures along the desired optical transmission path; precision alignment by fiduciary patterns for placement and attachment will be developed. The goal is the creation of specific coupling methodologies for in-line transmission in monolithic circuits, and efficient hybrid waveguide-to-fiber connections.

A.8.1.5 Novel Integrated Optical Circuits

The fabrication of optical waveguides, resonators, and filters with structures of high index contrast has made great progress in the last decade. As the bandwidth of signal processing elements increases, the control of center frequency becomes less critical and the required Qs becomes lower. With decreasing Q, the structures are less sensitive to radiation loss. Resonators can be constructed at sizes only a few optical wavelengths in dimension, whose radiation Q can be kept within acceptable limits. These devices offer the possibility for the integration of multi-component optical systems on small chips using structures of high index contrast. By proper coupling of optical resonators one may design for specific transmission characteristics; spectral responses can also be synthesized using interference of traveling waves, rather than the coupling of resonances. We will design, fabricate, and test these novel microphotonic circuits to establish building blocks for integrated functionality.

How is it relevant to the railroad?

Photonics Research is definitely a long-term piece of research with potentially huge payoffs. Photonics is a basically novel way to process information; instead of using silicon chips and electric voltages to represent information, photons and light streams are used. The research outlined above are basic research that are needed to enable photonics-based devices to replace the integrated circuits of the 80's as the next-generation information processors. As the research outline hinted, there are applications other than information processing, although obviously the information processing aspect of this technology is the most interesting and perhaps carries the widest possible potential.

The photonics revolution, if it is ever to occur, would presumably change the high-end computer industry first before it will filter down to embedded systems that are used within the railroad – such as terminals, on-board diagnostic computers, and signal controllers. Since the same technology would be available to everyone – just as the electronics revolution affected all industries – the impact are likely to be felt across all modes of transportation, and not just railroads. Because of the fundamental nature of the industry, it is likely to benefit all industries that choose to deploy it, in the same way that integrated electronics helped replace maintenance-heavy and failure-prone mechanical relays both onboard aircrafts and in railroad signalling installations.

It is conceivable that the photonics revolution would never occur: electronics research is some sixty plus years ahead of photonics research, and the growth in speed and capability of electronic devices may continue to outstrip the growth in photonic devices except in very specialized high-bandwidth applications. However, this does not mean that systems would not evolve towards more and more specialized photonic components for tasks for which they excel. For instance, a future circuit board may be predominantly
electronic but have various packages soldered in-line which are photonic-based. Again, because the technology is widely applicable, if the photonics “evolution” occurs, it will benefit all industries, including railroads and their competitors.

In terms of how it will affect the market, since electronics components are currently carried by truck due to their high value-to-weight ratio, it is unlikely that a photonics evolution, where photonic devices will replace electronic devices, would affect the railroad freight market immensely. In fact, the even higher value-to-weight ratio may well push photonic components onto aircrafts and away from trucks.

A.8.2 High Power Microfabricated Electro-Mechanical Systems
Gas Turbine Laboratory

What is it?

A major new project in the laboratory is aimed at the development of high power microfabricated electro-mechanical systems (MEMS), or “microengines”, such as gas turbine engines with flow path diameters of one to several millimeters and rocket engines which look like a computer chip. The gas turbine engines have the potential, when coupled with a micro electric generator, to provide a compact device with power density considerably higher than current battery sources. The ultimate goal is the design and construction of a working micro gas turbine generator. Intermediate objectives are to develop a microfabricated motor-driven compressor and also a micro turbine-generator. These devices, along with microcombustors, allow the development and testing of the major components forming the gas turbine generator. In parallel, the micro rocket engine is being developed, which will use the turbomachinery and bearing expertise from the other devices for its fuel pressurization.

How is it relevant to the railroad?

This project appears to be one which aims to replace small-scale batteries with turbine-generator sets. On the scale that they are currently talking about, the invention is probably of limited value to the railroad industry, except in specialized applications such as providing power needs for remote field equipment such as warning lights and radio transponders. The rail industry has a need for a number of low- to medium-current, continuous power needs that are one step larger than available from a battery. For instance, lighting in subway and passenger cars, refrigeration in reefers, etc. If the microengines could be scaled up to become miniengines – to provide between 20 and 100 amps of steady current flow at 115 volts, with a minimum maintenance and fuel requirement, the impact could be substantial. The current diesel generator technology is highly efficient, but maintenance-prone. The MEMS technology may not be any less maintenance-prone, but technological breakthroughs to overcome that are conceivable.

A.9 Nanotechnology

A.9.1 Guiding Light Through Sharp Bends Using Two Dimensional Photonic Crystals
NanoStructures Laboratory

What is it?

Small scale optical signal processing requires waveguiding an optical signal around sharp bends with a radius of curvature on the order of an optical wavelength. Conventional waveguiding is the result of total internal reflection at the interface between the high-refractive index guiding layer and its low-index surroundings. However, waveguide bends in the conventional index-contrast waveguides may cause large optical losses depending on the radius of curvature of the bend. These optical losses due to radiation can be avoided by using a two-dimensional (2D) photonic crystal. The 2D photonic crystal consists of an array of cylindrical rods of high dielectric material above a low dielectric material. Waveguides are created by introducing a line defect
of smaller radius cylinders into the 2D photonic crystal. The line defect allows guiding of light around sharp corners, including even a 90-degree bend with low optical loss.

How is it relevant to the railroad?

This particular line of research is obviously basic research supporting the photonic devices already discussed in Section A.8 (Miniaturization Technologies). Photonic crystals by themselves are probably not particularly useful to the railroad industry, but next-generation control and computation devices built using photonic components could have potentially major impacts. On the other hand, basic research into optical properties of materials can have important uses for the rail industry. If some coating or material could be developed that indicates error conditions (such as excessive stress) optically, for instance with a change in color, many maintenance/inspection procedures could be simplified. This idea is examined in more detail in the working paper under “Track that Changes Color”.

A.9.2 Magnetic Random Access Memories

NanoStructures Laboratory

What is it?

Magnetic Random Access Memories (MRAMs) are solid-state non-volatile magnetic storage devices in which each bit of data is stored as a small, elongated magnetoresistive sandwich element. A typical magnetoresistive sandwich consists of two magnetic layers of different coercivity, one hard and one soft. The direction of magnetization of the hard layer is used to represent the data bit. To write data, a magnetic field is applied by passing a current through a conductor line (word line) adjacent to the element, such that the field is large enough to change the magnetization of the hard layer. To read, a smaller current is passed, which can change the magnetization of the soft layer only. The resistance of the element depends on whether the hard and soft layers are magnetized parallel or antiparallel, hence changes in the resistance resulting from the reversal of the soft layer can be used to probe the magnetic state of the hard layer. Elements are arranged in a rectangular array and connected with conductor lines, allowing individual elements to be selected.

How is it relevant to the railroad?

Electronic data storage is used in all industries, not just the railroad or transportation disciplines. A faster way to store data in a non-volatile fashion would enable data-intensive industries, such as logistics, to benefit tremendously. While access speeds of MRAMs would obviously be a lot better than discs, it is not clear that a revolution is waiting to take place. Non-volatile storage medium other than discs have been available for a long time, for instance, sdRAM, tape, EEPROM, punched cards. sdRAM and EEPROM have not managed to replace the ubiquitous disc because the unit costs are too high, while tape and punched cards have been replaced because the disc’s unit cost became sufficiently low. Whether the magnetic disc would be replaced would largely depend on the cost of MRAM when mass-produced. It is conceivable that MRAM would not be widely deployed except as specialized storage in high-end systems – perhaps as non-volatile disc caching systems.

In terms of logistics, if MRAM cost/performance ratio begin to exceed that of magnetic discs, it is conceivable that much more database functions would be available to customers, since the time it takes to write data to disc is a known constraint in all kinds of database systems. This is certain to benefit shippers and logistics companies as they are able to exchange greater amount of data at faster rates, but it is not certain whether transportation companies would be able to leverage higher freight rates for the higher level of service. It is feared that this type of technology change would require transportation firms to invest in technologies for which they have very little return – simply to remain competitive with the others.
A.10 Propulsion Systems and Turbomachinery

A.10.1 Smart Aero Engines

Gas Turbine Laboratory

What is it?

The MIT Gas Turbine Laboratory embarked on the ‘Smart Engines’ research program in the mid 1980’s, to investigate the benefits of advanced control on aeroengine performance optimization. The program’s hallmark has been repeated demonstration that engine component performance limitations can be fundamentally altered through collaborative application of fluid mechanics, control theory, structural dynamics, and experimental methods. These technological advances motivate a new concept in engine control, which we term ‘smart’ engine technology. Through active feedback control (which involves the incorporation of new sensors, processors, and actuators) component level performance can be enhanced. This enhancement takes the form of either adaptation to off-design conditions for better performance, or stabilization of previously unattainable regimes, which allows either higher performance or less restrictive component matching requirements. In either case, active control technology allows the engine designer new degrees of freedom for optimization of overall engine performance.

How is it relevant to the railroad?

It is quite clear that this research has immediate applications in the airline industry. It is likely to make the airline industry incrementally more competitive, although no revolution can be expected for some time. Experience shows that incremental improvements can add up substantially over time, however. Its implications on the passenger rail industry, other than making a competitor stronger, are not yet clear.

There have been spotty attempts to build high-speed, light-weight gas-turbine trains over the past forty years, but none have become successful as a standard. Union Pacific’s attempts at making express-freight locomotives with gas-turbine technology were killed by soaring fuel prices, while USDoT’s passenger TurboTrain demonstration project failed on the grounds of heavy maintenance required for the turbine engine. It is conceivable that with research in advanced material technology, the start-stop cycle problem for applying gas-turbine technology to the railroad could be overcome – for instance, a thermal-shock proof glass was developed for coffee makers, and perhaps a similar thermal-shock proof material could be developed to make turbine blades and other engine components. However, even if this were true, it is likely to benefit the airline industry more than the railroad, as engine technology is in fact that limiting factor in much of what airlines do, while propulsion technology is rarely the limiting factor in the railroad environment. The limiting factor is usually the infrastructure.

If the cost of high-speed infrastructure could be reduced, building an engine that would go that fast is a secondary concern, since the existing state-of-the-art diesel technology exceeds the performance of the infrastructure that could currently be economically justified. Nonetheless, it is conceivable that the infrastructure costs could be reduced through innovative vehicle design – for instance, a lighter low-profile high-speed locomotive may allow trains to traverse curves at increased speed without incurring extra track maintenance costs and without derailing. Historically, high-maintenance solutions for the railroad such as the ‘Deltic’ engine in Britain and the Fairbanks-Morse Trainmaster in North America, have not been received favourably. However, if performance-increase from a high-maintenance solution is so high that a change in maintenance practices could be justified (for distance, diesels are a lot more maintenance-heavy than steam locomotives, nonetheless the railroads mostly switched by the 1960’s), it is conceivable that the railroad industry could be elevated to a new level. The premise, of course, is that railroads need to be able to make money off the passenger business. So far, this has not been demonstrated to be the case, which may explain in part the stagnation of gas-turbine express passenger locomotive research.
A.10.2 Numerical Investigation of Unsteady Blade Loads Generated By Conveeting Density Non-Uniformities

Gas Turbine Laboratory

What is it?

The demand for greater efficiency in turbomachinery has resulted in higher temperature and higher pressure ratio operating conditions. As a consequence the mean stress levels of turbomachinery components have increased and high cycle fatigue failure has become an important issue. Conveeting density wakes generated by temperature non-uniformities (e.g., hot streaks from the combustor, ground ingested air, hot boundary layers etc.) have recently been identified as possible 'new' sources of high cycle fatigue failure. The purpose of this research is to quantify the fluctuating blade loads generated by these density wakes. The effects of density wakes on blade flow separation and heat transfer is also addressed. A two-dimensional, unsteady, viscous flow solver is used for this study.

How is it relevant to the railroad?

Research related to the temperature-stress cycles in turbine engines will help the railroad industry more than the airline industry, since the railroad environment is likely to call for more start-stop cycles on turbine engines. However, even marginal improvements will greatly benefit the airline industry, because the extent to which turbine-based technologies are deployed. An engine that is less likely to fail due to start-stop cycles can perhaps make it finally possible to adapt gas-turbine engines for railroad use reliably. Nonetheless, in general propulsion has not been the constraining factor for railroads to win a share of the passenger market – the infrastructure is the more important constraint.

A.10.3 Active Tip Leakage Flow Control using MEMS Technology

Gas Turbine Laboratory

What is it?

In a gas-turbine engine, the tip leakage flow through the gap between the rotating blades and the surrounding casing, rolls up into a tip vortex which enters the main flow in the passage, resulting in substantial blockage and subsequent performance loss. Casing treatments have long been studied to passively reduce tip leakage and shown to be beneficial. The two goals of this project using microfabricated electro-mechanical systems (MEMS) devices are to improve understanding of the dynamics of the complex flow field associated with tip vortex flow, and to improve performance and stability of turbomachinery system. The test bed will be a low-speed single stage compressor, and the MEMS sensors and actuators will be place around the casing.

How is it relevant to the railroad?

This project, distinct from the other MEMS projects, aims to use MEMS devices as sensors to study existing large-scale turbomachinery. (Contrast with Power MEMS in Section A.8.2). The performance increase appears most likely to benefit the aviation industry, which is a major user of conventional gas-turbine aero engines. Any specialist railroad gas-turbine engines are likely to substantially differ in design from the aero engines, thus would require further investigation for efficiency enhancements. Some experimental and mathematical techniques developed in this project could potentially contribute towards that effort.

A.10.4 Design of High Performance, Low Emission Gas Turbine Engines

Mechanical Engineering

What is it?
Computational modeling of combustion processes in modern high performance, low emission, dual gas turbine engines. Results are used to investigate the impact of very fast turbulent mixing approaches, such as combined high swirl and shear on combustion dynamics.

The next generation of military and civilian aircraft engines will be required to meet strict emissions regulations, particularly in nitrogen oxides (NOx) and soot, without sustaining performance penalty. Supercomputer-based models are used to evaluate the performance of several design options, like lean premixed, quick-quench lean, etc., and investigate the necessary modifications to ensure stability, reliability, etc.

A series of research, including the projected discussed in the preceding section and many more, are being carried out by the Mechanical Engineering department for a variety of sponsors – most from within the aviation and auto industries. More information about this series of research is available from: http://web.mit.edu/ctl/www/research/research01-02/re_motor.html

How is it relevant to the railroad?

Since this set of engineering research projects are applied in nature, it is unlikely that there are immediate applications to railroads. Some of the likely impact is that it would make the other modes marginally more competitive against the railroads. The environmental research for low-emission engines, however, is a double-edged sword. The resulting design may incur higher costs than the traditional, highly-polluting designs, thus may in fact hinder the competitiveness of the other modes (if environmental regulations are mode-specific).

The longer term effects are likely to be beneficial. It is a matter of time before the environmental regulations will catch up with the rail mode. However, the computational tools developed here could be adapted for performance fine-tuning for railroad locomotives, without having to re-invent the proverbial wheel of engineering. The environmental-compliance learning curve is likely to be less steep for the railroads if the others have “gone before it”.

A.10.5 Aerodynamic Performance of a Scaled Turbine stage in a Short Test Duration Rig
Gas Turbine Laboratory

What is it?

This work is an effort to experimentally investigate the aerodynamic performance of a single stage turbine using the MIT Blowdown Turbine facility, a short-duration (~0.3 sec. test time) facility which provides rigorous simulation of the aerodynamic and thermal environment of an engine. To measure the aerodynamic efficiency of the scaled turbine in blowdown test environment, two approaches were applied. One approach is to measure mass flow and shaft torque delivered by the turbine rotor. The other way is to measure total temperature and total pressure at the inlet and exit of the turbine. Due to the short test time and unsteady nature of the blowdown environment, performance measurement in a short-duration test facility places especially demanding requirements on the accuracy and response of temperature and pressure sensors. Throughout the performance measurement the new version of temperature sensor demonstrated high reliability and greatly contributed to the accurate efficiency measurement.

How is it relevant to the railroad?

The main focus here is in building sensors that are good enough to take measurements from inside gas-turbine engines to help better understand the dynamics inside the engine. The same technique, presumably, could also be applied to understanding traditionally railroad-type prime movers such as diesel power plants and perhaps heavy-oil engines. However, the dynamics of the diesel power plant may be already well understood. As has been previously stated, the breakthroughs in railroad technology is likely to occur on the infrastructure side, and not the propulsion side, although if a significantly lighter engine could be
developed for the rail locomotive which have similar maintenance characters as a standard diesel, that would be a great help.

A.10.6 Other Propulsion Systems Research

A.10.6.1 Ion Beam Assisted Deposition of Zirconia Thermal Barrier Coatings
Ceramics Processing Research Laboratory

Ion-beam assisted deposition of zirconia is being used to produce thermal barrier coatings for advanced gas turbine engines. The gas turbine engines found in modern commercial aircraft are typically composed of Ni-based superalloys that have melting points of ~1300°C. The combustion gas temperatures though can exceed 1370°C during typical application. Thus, advanced turbine engines require complex cooling processes and thin thermal barrier coatings. These ceramic coatings are 100 microns thick and in combination with an underlying intermetallic bond and oxidative resistant coating, have proved to be most effective thermal barrier and oxidation resistive coatings. Plasma sprayed coatings are being replaced with e-beam evaporated films because of their better adhesion and spalling resistance. Columnar structures are produced by e-beam deposition that accommodates the thermal expansion mismatch between the substrate and the film. This research focuses on the role by which low energy ion beams modify the film orientation and density.

A.10.6.2 Micro Gas Turbine Engines: Bearings
Gas Turbine Laboratory

Efficient high-speed turbomachines require low-friction bearings. Research and development of gas (air) lubricated bearings is ongoing for use in the turbomachinery devices developed in the microengine project. Experimental and analytical investigation is necessary to design and understand the operation of the bearings since they operate in a design space yet unexplored. Issues such as stability of the coupled rotordynamics and fluid system, and thrust balance are currently being addressed.

A.10.6.3 Micro Gas Turbine Generators
Gas Turbine Laboratory

One particular problem is the performance of the gas bearings that must operate in an extremely unconventional parameter regime. Current work is on analytical, numerical and experimental issues associated with the design and analysis of these bearing flows and other fluid mechanical aspects of the micro engine. The goal of the MIT Micro Gas Turbine Engine Project is to create a fully microfabricated gas turbine engine, complete with combustor, compressor and turbine, with an electrostatic generator mounted on the shroud of the compressor. This project is concerned with the design and fabrication of the electrostatic generator. The primary focus of the generator project is fabrication: devising fabrication flows and techniques for the generator, and constructing the actual device. The main goal of this development effort is the fabrication of a two-level interconnected metal structure for a low-resistance electrical stator. Because the stator must survive high temperatures during both fabrication and operation, it uses a two-level platinum structure with deposited oxides for the interlayer dielectric.

A.10.6.4 Compressor Performance Enhancement Using Suction
Gas Turbine Laboratory

Research is focused on the design and construction of a fan/compressor stages that takes advantage of boundary layer removal on the blade to achieve higher blade loadings along with increased efficiencies. The first stage to be designed is a low speed fan stage. The higher loadings achieved through the removal of the boundary layer will allow the same pressure ratio to be reached at much lower tip speeds. The second stage to be designed is a high speed, high pressure ratio core compressor stage. This stage will be designed to achieve the highest possible pressure ratio with a tip speed of 1500 ft/s. The ultimate goal of this project is to develop a computational technique for design of compressor stages with boundary layer removal and demonstrate their feasibility through the construction and testing of these two designs in the MIT Blowdown Compressor.

A.10.6.5 Electric Propulsion of Ships
Laboratory for Electromagnetic and Electronic Systems

Studies done in conjunction with colleagues in the Ocean Engineering Department at MIT and active duty United States Navy officers doing graduate study at MIT. Advanced propulsion systems for naval ships, including electric propulsion and integrated propulsion and ship service systems. Simulation, stability, survivability and control studies for shipboard electric power and propulsion systems.

A.10.6.6 Computational Model for Multistage Axial Compressor Design

Gas Turbine Laboratory

Traditionally, axial compressor blades are designed with methods that neglect the fact that these blades will eventually function in multistage environments. Thus, discrepancies exist between the expected performance of blades (obtained from isolated blade row design and analysis) and the actual performance of blades in a multistage compressor. This study seeks to look at how the multistage environment affects blade row performance. Through the use of CFD, flow field and performance comparisons will be made between blade rows in isolation and in multi-blade row environments. Specifically, focus will be on the effect of neighboring blades on the behavior of wakes and endwall flows. The mechanisms responsible for the differences observed will be investigated. The end-goal is to understand how the multistage environment impacts blade performance, and to develop design guidelines which account for multi-blade row turbomachinery environment in a rigorous manner.

How is it relevant to the railroad?

It is relatively easy to come up with fairly direct application to railroads when all those propulsion technologies are at your disposal. However, none of the technologies mentioned here are likely to fundamentally change the face of the rail industry. I would argue train control technologies, communication technologies, and infrastructure construction technologies would have a much higher impact on the rail industry than propulsion alone will.

A.11 Sensors and Data Processing Technologies

A.11.1 Ultrasonic Sensors for Nondestructive Evaluation

Nondestructive Evaluation Laboratory

A.11.1.1 Laser-Based Ultrasonic Sensors for Detection of Rail Defects

Over the course of this century, the increasing service demand of the rail industry has not been offset with the amount of new rails laid; existing rail infrastructure must cope with heavier loads and increased traffic. As we continue to increase axle loads and to expect longer service life from rail and accumulate increasing amounts of tonnage, rail fatigue life will certainly continue to decrease. Detection of rail flaws is one of the critical missions in a track management system. The primary goal is to develop a non-contact system for detecting defects in rail tracks, with an emphasis on improved reliability and higher probability of detection.

A.11.1.2 Ultrasonic Phased Arrays for Nondestructive Evaluation

A fundamental property of a phased array is the ability to focus the propagating waves to a specific point within the load material by inducing a spherical plus linear delay. Focusing becomes a critical issue as the near field of the array becomes significant, because the directivity while steering is only stable in the far field. Focusing, on the other hand, has the ability to decrease the “effective” near field length, thereby enabling excellent directivity in a region not previously stable. The major drawback of focusing is that it is inherently expensive in terms of time, as every point must be analysed one at a time, while steering can be analysed linearly per steered angle. Focusing will enhance the capabilities of an array, by enabling better directivity, without sacrificing it usefulness in this enlarged near field. It will also be shown that in the far field, the directivity of focusing converges to that of steering.
A.11.1.3 Railroad Track Condition Assessment through Ultrasonic Nondestructive Evaluation

This project deals with possible enhancements to ultrasonic inspection and monitoring systems with a focus on the feasibility of ultrasonic array sensor systems. This effort may offer clues to developing a faster, more accurate and more cost-effective approach to rail condition monitoring and defect characterization.

How is it relevant to railroads?

These research are clearly railroad-focused, to a certain extent. However, ultrasonic crack detection is used in inspecting many service-critical metal parts in the construction, railroad, marine, aviation, and other industries. There is a very short-term, immediate pay-off for the railroads since it will enable more efficient crack-detection or assist in avoiding potential catastrophes. In the longer term though, a paradigm shift in the rail industry is required; instead of periodically inspecting equipment, a maintenance regime which relies on preventative maintenance, preemptive replacement of life-expired parts, and smart parts that tell you when they’re about to fail (perhaps through a non-critical failure mode that is easy to detect or through an active system which does not require the maintainer’s polling) is needed. Obviously, in the near term, the technique could also be applied to the aviation industry to stem catastrophic failures and make inspection procedures more efficient, which may have short-term consequences on the cost-base. Also in the shorter term, more efficient maintenance procedures or better asset life-cycle prediction in the construction industry and in metal structures may allow railroad infrastructure to be built more cost-effectively thus lowering the cost-base of the rail industry in the medium term.

A.11.2 Low-cost Portable Tele-Diagnostic Devices
Media Lab Digital Nations Consortium

What is it?

Low-cost, portable tele-diagnostic devices can achieve widespread use in rural areas of developing countries. By implementing modern sensor technologies, this diagnostic device will allow local health practitioners to easily capture a large range of basic patient medical information. This information (which will be in the form of text, graphics, audio and video) can subsequently be sent via the internet to health centers for diagnosis. In addition to medical data, the device will be capable of forwarding local environmental and meteorological data from remote areas to central locations, where it can be monitored and analyzed. We are also adding wireless extensions to various common medical devices, enabling them to be used in this system without being tied to the host computer with a wired connection.

How is it relevant to railroads?

These devices are very much relevant to the transportation industry, especially the railroad industry, if they could be produced at sufficiently low cost. Efficient operation of a guideway-based ground-transportation system requires communication from wayside devices to a central computer (or at least individual vehicles). If the cost of the information transmission could be lowered, cost saving could be obtained if existing state-of-practice was carried forward – or the system could be made more efficient if new practices developed. The cost is particularly critical since frequently railroads operate over vast areas where there is little or no development, where low-cost wireless links could really help. Even in high-density areas, in some cases it is cheaper and more reliable for the railroad to provide its own communication architecture than to rely on the general infrastructure. However, none of these technological advances will mean anything if the fully-allocated costs are higher than what could be achieved with wayside twisted-copper or fiber-optic cables.

In terms of its effect on competitors, the portable devices are likely to affect both the highway and the aviation industries, but in different ways. Central control is of little use to automobiles, but enhancing
communication from within the auto may increase the level of service by allowing passengers to query tourist information and road conditions on the move. In the aviation industry, remote weather sensors are often required, but only at locations proximate to the air terminals. Even so, lowered wayside-to-control communication costs will lower total cost base, although probably not sufficiently significantly to enable large scale changes to state-of-practice.

A.11.3 Sensor Chair

Media Lab

What is it?

The MIT Media Lab is developing a system based on pressure sensors on a chair. This system will be designed to detect affective states in learning such as interest, boredom, confusion, and excitement, which are accompanied by different patterns of postures. Leaning forward towards a computer screen might be a sign of attention (on-task) while slumping on the chair or fidgeting suggests frustration/boredom (off-task). The goal of the project is to detect the surface-level behaviors (postures) and their mappings during a learning situation in an unobtrusive manner so that they don't interfere with the natural learning process. Through the chair, one can see the associated patterns with the different postures. It can track the joint positions of the lower body and detect swinging of the feet. They are in the process of further refining the sensors and algorithms to detect affective cues in posture. Pattern recognition techniques will be used on the data gathered by the sensor chair to determine the posture in real time.

How is it relevant to railroads?

The seat is a really big part of any passenger transportation system. As outlined in the working paper, a sensor chair could potentially give rise to a more comfortable ride, although the sensor chair that the Media Lab is developing is obviously inappropriate for this purpose, and more development work would be necessary. Given past experience with technologies that enhance the in-vehicle environment, they are most likely to be deployed in automobiles first, followed by airlines and then the railroad. In other parts of the project, we have argued that deployment of such technologies are actually more critical to the railroad because of the relative lengthy periods of in-vehicle time. As to the potential of this technology being actually deployed, much of it would depend on its cost effectiveness. The current assessment is that even if such chairs were only provided in a select number of “premium” seats, the utilization of these seats would be so low that it would be difficult to recover the costs of the technology. In the private auto environment, where customers are less concerned with capital cost recovery, the technology may be deployed, which would necessarily lead to a defensive response by at least some rail carriers. Thus this technology is potentially destructive to the industry’s bottom line.

A.11.4 Vibration Suppression in Flexible Structures

Department of Mechanical Engineering

What is it?

Flexible structural systems are high dimensional and lightly damped, and invariably contain significant uncertainties in their dynamic behavior. Adaptive controllers, which are capable of overcoming such uncertainties and delivering high performance by providing a time-varying compensation on-line, are therefore desirable for such systems. A new adaptive controller has been proposed that can globally stabilize a class of flexible structures. This controller is applicable whether position measurements, rate measurements, or combinations thereof are available, as well as for co-located and non co-located actuator-sensor pairs. The superior performance generated using such controllers was verified in the simulation studies of two practical structural systems.

How is it relevant to the railroad?
The adaptive controllers, when suitably modified to deal with lateral motions not just in the structure but also in the foundation on which it is anchored, could be potentially valuable to both passenger and freight transportation business. Highly sensitive goods previously impossible to transport by train could now be transported aboard special freight cars that have adaptive controllers which limit vibrations and other dynamic behaviour. The adaptive controllers could also be fitted to passenger vehicles to reduce the kinematic envelope and improve passenger ride comfort, thus allowing vehicles to travel at higher speeds (similar to a tilting-train type concept) on inferior infrastructure.

This technology, interestingly, if developed successfully for railroad applications, would have limited use for other transportation modes – except perhaps trucking, where a better ride could also be achieved with improved suspension utilizing adaptive controllers. In the freight industry, this is likely to be a niche market. In the passenger rail industry, if the demand for high speed rail continues to rise, the adaptive controllers could turn out to be an extremely important piece of technology if it succeeds in reducing the kinematic envelope for trains running at high speeds.

A.11.5 Electronic Product Code: A Naming Scheme for Physical Objects
Auto-ID Center

What is it?

For over twenty-five years, the Universal Product Code (UPC, or “bar code”) has helped streamline retail checkout and inventory processes. As one of the most successful standards ever developed, UPC coding and labelling methods has grown to include numerous elements of the supply chain. The emergence of the internet, the digitalization of information and the globalization of business offer new possibilities for product identification and tracking. To take advantage of this network infrastructure, a new object identification scheme, the Electronic Product Code (ePC) is proposed which uniquely identifies objects and facilitates tracking throughout the product life cycle. The ePC is a short, simple and extensible code designed for efficient referencing to networked information.

The vision is to create a “Smart World,” that is, an intelligent infrastructure linking objects, information and people through the computer network. This new infrastructure will allow universal coordination of physical resources through remote monitoring and control by humans and machines. The objective is to create open standards, protocols and languages to facilitate worldwide adoption of this network – forming the basis for a new “Internet of Things.” One of the first activities in the creation of this new network infrastructure is the design of a naming scheme to enumerate and identify physical objects. Termed the Electronic Product Code (ePC), this standard will serve not only as a next generation Universal Product Code (UPC), but also as a method to identifying components, assemblies and systems.

How is it relevant to the railroad?

This technology is one whose future implications are not clear. There are several components to this item of emerging technology. Firstly, there is the concept of the object identification scheme. Secondly, the hardware required to implement the concept (i.e. radio frequency tags, or other “smart” tags, either active or passive). Then there is the notion that the these tags would talk to each other in a network, either by being interrogated, via a transponder or directly. Lastly, the implementation of a standard that is sufficiently open but yet secure is a technological development in itself. There is little doubt that the technology, if fully implemented, will have not only major impacts on supply chains but also everything that relies on some kind of a supply chain or logistics within the railroad company, including mundane activities such as train maintenance and restocking the dining car, as well as key activities such as vehicle fleet management and major construction projects. What is not clear is whether the technology would ever develop to the extent so that the ePC can be as ubiquitous as the barcode. Simply “extrapolating” to the future is not sufficient –
for instance, rechargeable batteries never penetrated the market the extent that its makers envisaged. Just as there is still a role for disposable batteries, in the future a role for barcode may still remain.

The concept and the hardware implementation are both helpful to the rail industry, although frequently in the rail industry it is the state of these objects that are vital and not the identification of the objects themselves. A maintenance supervisor knows a wheelset is a wheelset, because it looks like a wheelset; what is vital is not the fact that it is a wheelset but which particular wheelset, and what condition it’s in (repaired, cracked, has flats, etc.) This clearly requires individual identification for specific objects, plus perhaps some ability to store item-specific information, and not the supply-chain oriented “counting” type technology that will signal stockouts or low stock, but not track individual stock items. In terms of hardware, there is doubt that the radio tags will survive the rigours of the railroad environment, if applied to absolutely every piece of hardware. A disposable radio frequency identification tag will probably not survive being stuck on a wheelset for very long, but a more permanent and sturdy tag may upset the wheel balance and require wholesale re-engineering of what constitutes a wheelset. It seems that in those circumstances, a tracking number written in paint is a much better alternative.

The idea of a smart world is difficult to imagine at present, and if implemented, much of the technological innovation that will take place will depend on people finding new ways of using the technology beyond what the technology was designed for. The replacement of one procedure with the same procedure using a different technology will not yield much efficiency gains; the real difference is made when the procedure changes given the impact of the technology. In the rail environment, as has already been mentioned, this may take the form of an automated system for logging maintenance faults, ordering extra food for the café car service, or better seat- and capacity-inventory control. Nonetheless, fundamentally, trains still have to move, passengers do not like trains without conductors, and freight trains continue to interface with real people at grade crossings and other locations such as yards. It’s possible to envisage a railroad which acts like a giant automated conveyor belt which dispatches itself through smart equipment talking to one another over radio links, but that vision probably won’t be realized for a good while – there are simply too many “exceptions” in the railroad environment to imagine full automation in the next 20 years.

A.11.6 A Framework for Automation Using Networked Information Appliances
Laboratory for Computer Science

What is it?

It is proposed to automate information transfer, exchange and management tasks through the synergistic use of computers, intelligent software and sensors or appliances. There are many varieties of information automation problems and new ones arise every day. For example, an intelligent navigation system tells a driver the fastest way of getting from point A to point B, which takes into account current traffic and weather conditions, as well as accommodating driver preferences. A smart thermostat regulates temperature within a home predicting human presence or activity so as to minimize energy consumption. Work is conducted for building a framework of computers, sensors and intelligent software that allows for the rapid deployment of information automation problems.

The approach is based on the (idealistic) notion of composable computing. Composable computing have a single interface for all of the black boxes which could be computers or peripherals, and the user can plug-and-play with these devices to suit the needs of his application. Ideally, this is independent of the processor or the operating system or the network type. As an example, the user may put together a computer block, a network block, and a camera block to create a networked digital camera. If he adds image recognition software, downloads it via the network and runs it on the computer, he can create an intelligence surveillance system. Another important feature of a composable computing platform is modularity. Modularity allows the user to upgrade any component of the system, be it hardware or software or appliance-specific components, independent of other components.
How is it relevant to the railroad?

This technology is somewhat different to the other proposals for communication and connectivity. Most propose some kind of communication link between devices, some proposes a common standard for such communications, and all proposes devices that are in one way or another, “smarter” than current versions. (See also Section A.3.1 – Technologies for unifying multi-scale computing.) This technology proposes a level of abstraction beyond simple device-device communication; it proposes that the network itself should be abstracted. Using composable computing, it is conceivable that you can drag together a wheelset, a coach body, a motor and a power source to form a tracar. We consider this future scenario unlikely except in a computer-simulated reality.

### A.11.7 The Ring Sensor

d’Arbeloff Laboratory for Information Systems and Technology

**What is it?**

The next wave information technology revolution will take place when the information infrastructure interacts with diverse equipment that people use in their daily lives. Rather than merely providing internet access services, the utility of wearable computers will be extended dramatically when they are hooked up to various devices and systems. The ring sensor developed at the d’Arbeloff Laboratory, for example, monitors the physiological status of the wearer and transmits the information to the medical professional over the internet. This ring sensor allows for continuous, long-term monitoring, which opens up new possibilities of preventive medicine and long-term care. Other health monitoring devices, such as the vestibular-ocular test apparatus, the glucose counter, and the insulin delivery system, can all be hooked up to a wearable computer without wiring the patient body. In turn, a medical professional carrying a wearable computer would be able to access all the data, clinical protocol, and operational procedures whenever and wherever needed.

**How is it relevant to the railroad?**

The basic idea of the ring sensor is very simple. It is similar to the ideas proposed in Section A.11.2 (low-cost tele-diagnostic devices) and other miniaturization and communications technologies. The question for the railroad industry (and the high-tech industry in general) here is: why should the devices be wearable? A device that is portable, but not wearable, can perform many of these tasks perfectly adequately, and its cost base is likely to be much, much lower. In certain limited applications, wearability may be desirable (e.g. when the particular employee is likely to work extensively in the field with much physical movement) – but even a device as big as a railroad radio can be carried with relative ease. The medical application may be a niche market for this type of sensors.

### A.11.8 Visual Surveillance and Monitoring (VSAM): A Forest of Sensors

Artificial Intelligence Laboratory

**What is it?**

Visual Surveillance and Monitoring is a concept that takes advantage of time-varying data from multiple cameras to obtain point correspondences and perform robust calibration. This system tracks a moving object in the scene and uses its location at every time step as a single point correspondence among multiple cameras. At every time step, the system stochastically samples the correspondences from the last $n$ frames and recomputes relationships among cameras. Since the system is continually recalibrating itself, it responds to changes in sensor locations by stabilizing after several frames.

**How is it relevant to the railroads?**
This technology appears to be a software engineering project which takes time-series inputs from multiple sensors and performs continuous recalibration, so that if the location of the sensors are changed (or as new sensors are added, other taken offline), the system adapts and keeps track of its “understanding” of the system despite the shock to the system. The sensors do not necessarily have to be visual. Potentially, the system can allow the engineering of a very robust network of distributed sensor mechanism that monitors a system, similar to the internet, where the failure of part of the system would not unduly hinder the monitoring function as a whole.

In terms of the rail industry, this technology can be used to create “the resilient railroad”, where all the detection mechanisms are replaced by sensors. It is conceivable to have a railroad where instead of having track circuits that all have to be functioning correctly to control rail operations, the track circuits are replaced by a bank of “train sensors”, which may take different forms (e.g. track circuits, axle counters, treadles, video surveillance, towerman reports). If any particular component goes down, rail operations continue with the limited available information, and the central computer continues to monitor train movements as best it can using the information sources still available. For example, if a track circuit suddenly fails, but a video camera further down the line “sees” the train and the computer was able to check that it had the correct number of cars, then the following train could be authorized to pass the section as if the track circuit had cleared.

There are trade-offs between a deterministic system and a probabilistic system such as the one currently proposed. The above paragraph will make those in the signalling profession extremely nervous. Rightly so, since it is almost impossible to understand analytically a system which has so many moving parts (and thus just as many different failure modes). So although the railroad is perhaps more resilient, it would no longer be possible to analytically guarantee safety and ensure fail-safe operation. For instance, if a train was misrouted as the result of a track-circuit failure, the system could potentially “lose” the train – and an unrelated image of another train could be mistaken for the “lost” train and operations continued on that basis. The result is an accident when the train shows up where the system did not expect it. The other main issue with a probabilistic system is that signal maintenance staff (and managers) may no longer maintain the infrastructure to the level of workmanship we’re accustomed to if it is understood that track circuits are not vital to the continued operation of trains. Where there is redundancy built into the system, there would be less incentive to maintain the seemingly redundant features (for instance, where the track circuits duplicated image-recognition based “train sensors”) to a service-critical level of standard. For the same reason that “double-checks” in human operating procedures can lead to one party tacitly relying on the other to do the checking, redundancy in service-critical systems can sometimes have unexpected consequences. Another issue is how the computer would determine which sensor is at fault if conflicting information is received – especially when the sensors do not necessarily work in parallel at the hardware level.

If the technology does indeed become mature and develop to an extent where it could be used for safety-critical control operations, it is conceivable that it will benefit the rail industry more than the others, due to the necessarily centralized operation of the railroad. Importantly, if the technology was implemented but does not work, it is also most likely to disrupt business-critical operations on the railroad. Air traffic control to a certain extent relies on centralized control, but less on sensor data and more on operator reporting. It is conceivable that air traffic control may combine radar data, pilot reports and other data sources from sensors and models such as weather data and use this type of technology to assist air traffic control, but the same technology would benefit the rail industry (which is faced with much more dispatching constraints than the airline industry) much more. This technology could also have applications in intelligent vehicle-highway systems, where many sensors are required to gather data on traffic conditions and the “best guess” dispatching decisions could be made based on data sources without 100% reliability. The fundamental difference between dispatching requirements in the highway mode versus the rail and the air mode is that the highway dispatcher does not have the ultimate responsibility for ensuring safety. Thus, the technology is
most easily applied to a highway system but will probably not have a major impact beyond what the currently proposed intelligent vehicle-highway systems are capable of.

A.11.9 Unsupervised Audio Scene Analysis
Artificial Intelligence Laboratory

What is it?

Unsupervised Audio Scene Analysis addresses the problem of robustly monitoring a “scene” using a microphone or microphone array. Rather than concentrating on human speech, the system attempts to model the general sounds that occur in a particular scene and looks for long-term contexts of those sounds and looks for anomalous sounds. The goal is create a system that will work in any sparse audio environment. A current difficult is that the system is unable to take advantage of domain specific knowledge without limiting the domains where the system can be used.

How is it relevant to the railroad?

Some of this work will directly address some safety concerns in the railroad operating environment. For instance, experienced tower operators will tell you that they can “hear” trouble – in some circumstances, this is as mundane as a leaking brake pipe; in other circumstances, a tower operator might hear a dragging brake (which can sometimes cause derailments). More often than not, the maintenance anomaly heard at the trackside is a flat wheel – which is potentially a track-condition issue since a flatspot causes permanent damage to the infrastructure if left untreated. The other things that a tower operator might spot include burning axleboxes (which requires a visual inspection) and a break in the train (which again requires visual inspection), although there are alternate technological solutions for addressing these problems already.

In the traction environment, there are also tell-tale signs that can be “heard” which might signal trouble. A malfunctioning Turbocharger or one that is about to blow over has a particular sound, as does other prime-mover related problems (knocking, coughing etc). A mechanic will sometimes be able to diagnose the repairs needed by simply listening to the prime mover. The more experienced train operator may also pick up on problematic engine sounds, although they usually do so after experiencing a loss of power. Usually, the crew stays in the lead unit, thus a problematic prime mover further down the consist would not be “heard out” unless a loss of power or other problems signal to the headend crew that someone needs to walk back and investigate.

It is debatable whether any of this sensor technology will generate any value for the rail industry. It is conceivable that one day these automatic audio (and probably also video) sensors would be as ubiquitous on the railroad systems as axle counters, out-of-gauge detectors and hot-axlebox detectors. Of course, these multi-function detector devices are much more intelligent than the current generation of detectors, but even with the current generation of detectors, some form of technology-forcing by the government was required to persuade the railroads to make what is predominantly a safety-related investment (although, obviously some of the investment has been recouped in the form of derailments avoided, etc). Nonetheless, the systems must become more reliable and a lot less expensive before it will see widespread use.

On the other hand, it is arguable that the rail industry already has these sensor systems. Many operating personnel do record and report these problems: wet spots, locomotives susceptible to power loss, flat wheels, but the rail industry has found it on the whole more economical to keep the equipment in service in a semi-faulty condition to fulfill immediate operating needs. Even a well-managed railroad will occasionally run a fleet of older locomotives into the ground (which can sometimes be the correct economic decision). If the rail industry in general are already receiving early warnings reports of potential fault conditions, but
are slow to act on them due either to budget, strategic or maintenance-capacity constraints, what are the chances of their investing in technology to detect more of the same conditions?

A.12 Information and Telecommunications Technologies

A.12.1 Wireless Networking
Telemedia, Networks and Systems Group

What is it?

The SpectrumWare project is applying a software-oriented approach to wireless communication and distributed signal processing. Advances in processor and analog-to-digital conversion technology have made it possible to implement virtual radios that directly sample wide bands of the downconverted radio frequency spectrum, and process these samples in application software. The elimination of dedicated hardware introduces tremendous flexibility into a wireless communications system. However, the present approach goes further than the software implementation of traditional signal processing functions. Processor and network memory are used to temporally decouple the sample streams from the software modules so that the bulk of the processing can be realized within virtual time programming environments. Decoupling relaxes the temporal constraints on the processing algorithms and their execution. The testbed will be used to implement a wireless communication system and to experiment with other forms of transducer-based information appliances.

How is it relevant to the railroad?

This technology is basically concerned with implementing a traditionally hardware function (converting radio waves into audible sound) in software. The “flexibility” element mentioned in the technological brief in fact comes at the expense of tremendous cost – in the same way that an e-Book costs a lot more than a printed and bound book, if the cost of the computer equipment used to access the book is not considered a sunk cost. In the rail industry, it is difficult to see under what circumstances would a software decoder fast enough to handle direct radio-frequency wave inputs be useful.

One possible tangential application of this is in communication-based train control, where many high-frequency devices are used to either generate “overlay” waveforms on top of traditional track circuits or for transmission over the airwaves. Obviously in the current vision, much proprietary hardware electronics is used to handle the communications between the dispatching system and the vehicles, and software replacement might make the systems more flexible – for instance, if signals at 2,100Hz, 2,325Hz and 2,550Hz represent three different aspects, then a software system would allow the addition of a 2,775Hz signal for a fourth aspect, provided that the software at the central dispatching computer and onboard the vehicles are both upgraded.

However, experience has shown that software implementations are error-prone and difficult to prove. Most propulsion systems of today have some software-driven components, and software bugs has led to problems as diverse as brakes freezing and locked, doors spontaneously opening and the train generating excessive electromagnetic interference. In general, because of its flexibility, it is relatively more difficult to prove the correctness of software components. There is a discipline which is involved in proving correctness in software, but it is evident that the industry state-of-practice with respect to software driving railroad devices (such as locomotives and braking systems) are not quite at that level. It is feared that implementation of software-based decoders in signalling systems (which already relies on a great deal of complex software, and not without the associated problems) will lead to more problems and more failure modes which ultimately results in little or no materialized cost savings, service disruptions, and giving rise to flexibility that was not needed in the first place (and subject to attack by errant individuals).
The real trick here for the railroads, or indeed any other industries with long asset lives and relatively fixed demand patterns, is to engage in life-cycle engineering. There is little or no point in making the signalling system flexible in terms of number of aspects if no capacity upgrade is anticipated in the next (say) 40 years, during which time the hardware components would have become life-expired anyway. Much of the capacity problem faced by the railroad industry today does not originate from bad decisions made at the time when signals were installed, but more because of intense capacity rationalization in the 1980s (on railroad systems) and asset-life extension or like-for-like replacement schemes during which future capacity provision was not adequately planned for and addressed.

There is potential for this kind of software technology, if signal makers of today are able to agree on a common platform on which the software should be developed. It is conceivable that the same transceivers can be installed onboard locomotives, and at the wayside, regardless of the specifics of the system. The transponders could then be dynamically re-programmed to talk to the wayside devices, and depending on the signal aspects available in that territory, and frequency spectrum available in that territory, to talk differently to the wayside devices. If a critical wayside device is broken, a device could be pulled from a locomotive and an immediate replacement made (along with the necessary software changes to convert a vehicle-bourne device to a track-bourne device). Although that level of abstraction is theoretically possible, and some of this emerging technology would address such needs, at present it is difficult to imagine that sufficient work could be done that the benefits of these systems will outweigh its costs – in the same way that most of us would probably prefer a $2 transistor radio to a $2,000 personal computer which also happens to read radio spectrum and play it back as audio.

A.12.2 Active Networks
Telematic, Networks and Systems Group

What is it?

Active networks allow individual user, or groups of users, to inject customized programs into the nodes of the network. “Active” architectures enable a massive increase in the complexity and customization of the computation that is performed within the network, e.g., that is interposed between the communicating end points. Many degrees of customization have been identified. The (extreme) case, in which we are most interested, replaces conventional packets with “active messages” that are executed at network routers/s switches. These “packets” are analogous to Postscript fragments, which embed page contents within programs.

Architecturally, the level of abstraction at which inter-operability is achieved is increased: today’s routers support the agreed syntax and semantics of internet protocol (IP), i.e., they all perform equivalent computations; active switches execute many programs but must all support an equivalent and inter-operative computation model. The control over network functionality (and innovation) is moved to the end users, rather than the router vendors (or operators).

The Active Network is a result of both technology-push and user-pull. The push is the emergence of active technologies, compiled and interpreted, supporting the encapsulation, transfer, inter-position, and safe and efficient execution of program fragments. The idea is to extend these technologies to function within the network itself rather than just using the network as a medium to transmit the active content. The pull comes from the ad hoc collection of firewalls, web proxies, multicast routers, mobile proxies, video gateways, etc., that perform user-driven computation. The active network architecture will support the diversity and dynamic deployment requirements of these inter-posed services being used in the marketplace today.

(from David Tennenhouse and Dave Wetherall, at http://tns-www.lcs.mit.edu/publications/sospwip95.html)

How is it relevant to the railroad?
An active network, if implemented, can be beneficial to the rail industry in more ways than one. The rail industry, and the transportation industry in general, have sought solution for customized communications for a long time. Even today, Nextel remains the cell phone provider of choice for truckers, because they are closest to providing for the specific needs of the industry. If the rail industry is able to take the operations of networks into its own hands, it is presumably able to do many things which conventional networks would find difficult to accomplish, for instance, instead of sending out a packet bound for a specific IP address (i.e. computer terminal), the control center is perhaps able to send out a packet bound for “CNIC 5297”. In a conventional solution, if the computer terminal physically onboard CNIC 5297 was changed, then some centrally-held routing table needs to be changed to reflect that. Historically this has been a problem as radio and communications modules are often swapped in and out all over the country for maintenance reasons. In an active network solution, the network routers themselves are able to locate CNIC 5297, perhaps by sending out broadcast messages if the terminal that was formerly attached to that locomotive (now sitting in a maintenance shop) reports that it is no longer onboard.

However, one cannot help but wonder if there are cheaper solutions to this problem. For instance, some maintenance discipline would ensure that the centrally-held routing table is indeed updated when a radio swap-out is performed. Surely labor costs have not escalated to the extent that the cost of the active network infrastructure is less than the 30 seconds it takes to update a central routing table when performing a swap-out? Of course, active networks have purposes other than locating locomotives, but unless it becomes as ubiquitous as the internet for non-railroad related reasons, it is difficult to justify applying the technology to railroads specifically for the purpose of locating personnel and locating equipment. Already, methods to perform these tasks exist (for instance, via cell phone instant messengers) – indeed, many locomotive engineers have subscription to these services so their family can find them! The fact that railroad managements have not found it necessary to implement these technologies suggests that expected productivity gain is insufficient over the current state-of-practice to justify the costs.

A.12.3 Mercury and Pegasus – Telephone Based Conversational Interface
Spoken Language Systems

What is it?

Mercury is a telephone-based conversational interface that provides information about flight schedules and pricing. It enables users to book and price complex multi-leg travel itineraries to over 200 cities with the United States and around the world. Created in June 1999, Mercury offers information on over 200 major cities worldwide, and recognizes a vocabulary of approximately 1,000 words. Spoken Language Systems (SLS) members have used the system to make actual travel arrangements using naturally spoken English – eighteen group members all successfully completed a variety of three city travel problems in a recent evaluation. The successful transactions took an average of 36 queries and 12.5 minutes to complete.

Pegasus is a conversational interface that provides information about flight status. It enables users to obtain flight status information over a telephone line. Pegasus can provide information about flights within the United States, and can answer questions about departure and arrival time for flights that have taken off, landed, or filed a flight plan on the day the user queries the system.

How is it relevant to railroads?

Freight railroads have traditionally dealt with a small number of specialized customers. Mercury, which is basically a customer-interface designed to replace the call-center operative, is clearly not the suitable technology for this group of customers — instead, electronic data exchanges (or their modern equivalent, xml) and web-based booking systems are likely to the ways of the future.
In the passenger market, there is perhaps a need to reduce the costs of call centers as more passengers transition to web-based booking (and sometimes receiving a discount), but an automated speech recognition system is hardly the way to do it. Usually, web-aware customers will try booking on-line, and when difficulties are encountered (e.g. a seemingly valid debit card number is not accepted, or when a refund is required and the website does not allow it), they will call the call center. If the call center spoken-language system is unable to handle any more exceptions than the website, you’ll have a very irate customer! On the other hand, if a computer is able to handle all those exceptions, why not program them into the web interface to begin with? Of course, it is alright to charge the customers for the privilege of talking to a real operator, if a cost-recovery scheme is required. Those who are having problems with the website or automated systems will still call.

A.12.4 Innovative Railroad Information Displays
Center for Transportation Studies

What is it?

A useful information display system must be able to maintain the user’s sense of context by keeping the important information clearly viewable and conserving important relationships, while subduing information not currently relevant. The Visible Language Workshop (VLW) of the MIT Media Laboratory has developed unique methods to interconnect different user views of dynamic transportation events by managing spatial information. Some VLW displays can interactively sense and learn about the user’s real world context or about events occurring beyond the user’s environment. VLW has demonstrated that displays can provide alerts or decision support based on digital “expert” knowledge. The objective of the work is to develop and demonstrate a novel railroad information management and display approach which may lead to improved productivity and safety. The VLW will investigate how its methodologies can be adapted to enhancing information management tasks facing dispatchers and train engineers. Assumptions about near-term railroad operations, such as use of physical and communication or GPS will be considered. Using software rapid prototyping techniques, one or more concepts will be investigated in VLW’s advanced graphics environment and modern PC-based advanced graphics systems.

How is it relevant to the railroad?

This technology is essentially an active dashboard which will select information most relevant to the user in a space constrained environment. Great strides was made in the aviation industry when “glass cockpit” was made possible by condensing many analogue dials onto a few cathode ray tube displays, and it is easy to imagine that what even smarter information displays will do for any sector of the transportation industry where an operator needs to learn about the status of a machine through a visual display.

Of course, there are safety issues in the railroad environment associated with expert systems that make decisions on behalf of experienced operators. What if the in-cab system decides the train brake pressure gauge does not need to be visible while the train is coasting down the hill with dynamic brakes on full (but malfunctioning), either because it has never been in this situation before, or perhaps because previous experience has wrongly taught it that engineers tend not to watch the train brake pressure gauge when using dynamic brakes. It is conceivable that details about why the dynamic brake is not functioning would fill the display, while the engineer would never realize that the conductor in the rear car has applied the emergency train brake in anticipation of a runaway and all of the train’s wheels are dead locked and sliding down the hill except those on the locomotive!

There are two paths from which this technology would lead. First point of view suggests that visual displays are inherently passé and the future is in automatic train control, so there would be lesser and lesser needs for information displays on a real-time basis in future. Another point of view suggests that information displays would become such a vital part of the control system (and for humans to monitor the controls) that the
research that is being done now is invaluable to any industry that involves an operator monitoring the operation of a sophisticated “smart” machine. Which scenario would turn out to be more accurate would depend on the pace at which automation technologies progress and the degree to which operators need to intervene to override potentially problematic situations.

A.12.5 Evaluation of Decision Aids and Displays for High-Speed Trains
Center for Transportation Studies

What is it?

Three levels of preview display are proposed as decision aids for the control of future high-speed trains. The first level provides speed limits, signal aspects, grades, and minimum stopping distance previewed for up to 12.5 miles ahead. The second level provides additional full-service and emergency braking curves, as well as the predicted speed profile for the current control level. The third level provides an additional optimal speed profile and corresponding control levels to advise the driver on producing the optimal control. These displays are experimentally compared with a basic display that shows only the conventional information in a cab. A human model will be developed to investigate the impact of smaller block length (much smaller than 1.25 miles) on system performance under the basic display and the first level of preview display.

How is it relevant to the railroad?

Is locomotive operation really a black art? In high-speed passenger rail, perhaps not. There is a definite braking curve, there is a fixed consist, there are highly predictable and repeatable conditions. Thus, I would argue, decision aids are not necessary – high-speed trains could be entirely computer controlled, just as an aircraft has an autopilot function. Human research generally suggests that the control should remain with the human operator, with the computer monitoring human performance and intervene if the computer determines that the human is about to commit a fatal error. Thus, it is not clear why the human operator needs to know about the speed profile and the braking curves – the human learns that through experience, not through looking at a diagram. The braking curves and speed profile could be used to intervene if the human deviates outside the safety envelope, but there is no need for the human to see that information.

At some level, the right technology to develop is one that would abstract train operations into a series of different commands – possible commands might be, “proceed normally”, “stop as quickly as possible”, “back up 50 feet if it is safe”, similar to the commands that an examiner might give to a trainee driver. The human judgment involved is not in judging braking curves etc., but in coming up with the best course of action when faced with an exception that the computers are unable to deal with – for instance, a truck stuck on a grade-crossing, or a piece of misaligned track ahead.

In freight service, many technological solutions that sought to replace the locomotive engineer has failed. The braking curve depends on the location of loads with respect to empties in the train, the terrain, the curvature, the type of brake gear used, the weather and railhead condition, the weight and capabilities of the locomotive consist (e.g. availability of dynamic braking) amongst other things. There is no reason to believe the current technology under development will be any better than the earlier versions. Unless the train came with sensors to detect all those conditions (or has it transmitted to it via all types of information systems), the locomotive engineer remains the best judge of how to run the train. Running a freight train really is a black art.

A.13 Asset-life Extension Technologies

A.13.1 Fundamental Aspects of Underfilm Corrosion
Uhlig Corrosion Laboratory

What is it?

Advances in areas such as transportation, aerospace, data requisition, information processing, and communications are dependent on the development of advanced components and systems. Reliability often depends on the extent of corrosion of metallic materials in device structures. Corrosion reduces reliability by: (i) degrading the structure, (ii) introducing undesired products, and (iii) reducing performance. Preventing corrosion phenomena, which affect new materials, is fundamental to successful operation of such systems. Many corrosion problems are overcome by using organic coatings, often without a full understanding of the basic phenomena involved. The corrosion rate of a metal protected by an organic coating is related to the transport of ionic and nonionic species, charge transfer processes at the interface, delamination and changes in the composition of the organic matrix. The performance of a coated metal depends on the metal, polymer, interfacial adhesion, environment, as well as the integrity, continuity, thickness, and composition of the coating. The long-term research will be directed toward achieving the ultimate objective of developing a procedure for making reliability estimates and for lifetime prediction, along with a test-structure that can be used in the industry. In addition, the influence of various processing and physical variables on the protective properties of coatings will be evaluated.

How is it relevant to the railroad?

Corrosion is a major problem in many parts of the transportation industry, but especially for the railroad whose infrastructure stretches across the most remote parts of the continent, some of which are used so infrequently that the bulk of the maintenance burden is associated with corrosion. Fundamental research about the mechanism of corrosion could ultimately lead to not only life-cycle predictions and more accurate evaluation, but new possible ways of mitigating the corrosion damage. Nonetheless, the corrosion-preventing technologies are only useful if the results can demonstrably prolong the life of railroad equipment, thus a different focus may be necessary in a railroad-sponsored program.

A.13.2 Equipment Gerontology: The Study of Equipment Aging and Prediction of Residual Life

Uhlig Corrosion Laboratory

What is it?

Due to economic constraints on new product development in many industries, increasing importance is being placed on safely extending the service lives of existing components and systems. Unfortunately, extended operation of an engineering system can lead to the emergence of unanticipated problems, especially when the original design life is surpassed. Generically categorized as “aging”, such problems may be evidenced as advanced stages of “normal” failure mechanisms (e.g., wear, fatigue, corrosion) or may appear as previously unobserved mechanisms. For the aerospace industry, aging-related failures can be catastrophic (e.g., Aloha Airline Flight 243 – the in-flight structural failure of a 19-year old Boeing 737 in 1988, TWA Flight 800 – the 1996 explosion and crash of a 25-year old Boeing 747-100 possibly linked to wire aging). Contrary to popular belief, aging is not necessarily a terminal, degenerative condition whose onset occurs only after some discrete length of service. Aging issues can be addressed in their early stages through the implementation of an aging management approach. Aging management embodies three concepts: designing for graceful aging, health monitoring, and life prediction.

How is it relevant to the railroad?

The study of Equipment Aging will have widespread consequences throughout many parts of the transportation industry. In the railroad industry, where failures are not usually fatal but can lead to catastrophic cost consequences, this research can potentially save the rail industry a significant amount of money in accidents avoided but also in maintenance safely deferred or strategically brought forward. The rail industry have not traditionally been highly vigilant about an effective maintenance strategy, however, and
maintenance have often been standards-based rather than performance-based. The management of maintenance activities would require changes before the result from equipment aging studies can be most effectively applied.

A.13.3 Microbially Influenced Degradation of Polymer-Coated Metals
Uhlig Corrosion Laboratory

What is it?

Microorganisms are ubiquitous and have been linked to corrosion since 1910. However, microbially influenced corrosion, especially for polymer-coated materials, is still not fully understood. There are, nevertheless, an increasing number of reports on direct degradation of polymeric materials by bacteria and fungi. Electrochemical Impedance Spectroscopy (EIS) is well established as the technique most suitable for assessing the degradation of polymeric materials; however, there is currently no conclusive evidence showing that EIS is capable of distinguishing between classical and biologically-induced degradation. The current project seeks, in the short term, to increase understanding of microbially assisted degradation of polymer-coated metals. While it is encouraging that the onset of degradation can be monitored by EIS, the ultimate long-term goal of this project is the deconvolution of EIS data to reveal the microbial contribution.

How is it relevant to the railroad?

There are various known problems on a number of railroad systems where microbes have been implicated in contributing to infrastructure degradation. The problem is not limited to subway tunnels, where the problem is most pronounced and degradations can lead to structural failures, but also in signal wiring and other mission-critical components where a failure can have temporarily disastrous effects on the level of service. This type of degradation also leads to premature replacement of parts which can be costly, especially when the parts concerned are complex and require specialist labor (signalling systems being a prime example). The technology may have immediate applications, although obviously other type of degradation occurs and microbes may not be the only problem.

A.13.4 The Electronic Structure of Thin Anodic Passive Films
Uhlig Corrosion Laboratory

The remarkable corrosion resistances exhibited by metals (e.g., titanium, chromium, iron, nickel and their alloys) make them industrially significant materials. The corrosion resistance in many of these metals and alloys is usually related to the formation of thin passive films on the metal surface that exhibit semiconducting or insulating properties. The passive films are interesting because they ensure protection from the very process responsible for its formation. An examination of the nature of these passive films is, therefore, of prime importance to the understanding of corrosion behavior and for devising measures for corrosion prevention and control. The chemical composition and structural properties of passive films obtained from surface analytical techniques that are ex-situ measurements are subject to considerable ambiguity. However, Photoelectrochemical (PEC) and Electrochemical Impedance Spectroscopy (EIS) techniques have proven to be attractive techniques for probing the passive films in-situ, for identifying the films chemical composition and obtaining useful information regarding their electronic and optical properties which may significantly influence the film’s behavior.

How is it relevant to the railroad?

This research is fairly basic, but it has wide-ranging applications in the transportation industry. A better understanding of the mechanisms that give rise to corrosion resistance will assist us in developing coatings and other materials that will give rise to even better performance. However, any development is likely to be long term. Metals are not used in the railroads simply for their corrosion resistance, but also for their structural strength and the relative ease to machine, as well as other properties. Any replacement or substitute material would need to address these issues as well as corrosion resistance.