IDENTIFYING CRITICAL TECHNOLOGIES
FOR THE INTERNATIONAL RAILROAD INDUSTRY

Technology Scanning: Focus on New and Emerging Technologies
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1. INTRODUCTION

1.1 Overview of Performance-Based Technology Scanning

The transportation industry, like other industries, has historically benefited from advances in technology, although the types of technologies, categories of benefits, and patterns of implementation are remarkably diverse. New technologies may allow cost savings or service improvements, and they may provide incremental or revolutionary benefits. Certain “enabling” technologies may create a basis for significant changes that affect all industries as well as the way that we live, while other technologies may target quite narrow needs and opportunities. Benefits from technology can be immediate – or highly illusive; and it may be better at times to be first to implement but at other times to let others take the time and expense to prove successful applications.

In an era of rapid technological change, technology scanning is a critical strategic activity for railways and for any other industry. Understanding what opportunities might become available is important to rail companies, whether those opportunities benefit rail or competing transport modes. Using a structured approach to technology scanning will help a company or an industry sift through the myriad possibilities and formulate a coherent strategy for research and for investment.

This working paper is one of a series prepared for the UIC on the general topic of “Performance-Based Technology Scanning” (Exhibit 1). The emphasis on “performance” is intended to focus technology scanning on applications that will ultimately have the greatest payoff for the rail industry. Rail market share and financial performance are driven by the industry’s ability to compete with other transportation modes in terms of service, cost, safety, comfort, and convenience. To the extent that existing technologies constrain performance, it is possible to identify needs and opportunities for improvements. To the extent that technologies have differing possibilities for improving performance, it is possible to evaluate and rank them in terms of their potential for the rail system.

Exhibit 1: UIC/MIT Working Paper Series

Phase I:
- Identifying Critical Technologies for the International Railroad Industry: Phase I Executive Summary, UIC/MIT-WP-2001-01, August 2001

Phase II:
- Identifying Critical Technologies for the International Railroad Industry: Phase II Executive Summary, UIC/MIT-WP-2002-01, available July 2002
PBTS encompasses five steps:

- **General Search for Technologies** - Conduct a very broad review of new and emerging technologies that might be beneficial to the industry

- **Technology Mapping** – Conduct structured investigations into the performance capabilities of the system and identify the points of leverage for technological developments related to cost, reliability, safety, or capacity (for all competing modes)

- **Transportation Systems Modeling** - Develop and maintain a set of models that can be used to evaluate technological improvements as they affect specific aspects of transport systems performance

- **Customer Requirements Analysis** - Investigate the requirements of selected groups of customers and identify new ways of doing business; estimate the benefits to customers that will result from improvements in cost, speed, reliability, safety or capacity

- **Analysis of Specific Technologies** - Examine specific technologies identified as having potential for improving system performance

This paper is concerned with the first activity, the general search for technologies, building upon work of Phase I of the research program (WP 2002-2). Other working papers have addressed the other elements of PBTS, including applications to containerizable freight (WP 2001-4) and intercity passenger service (WP 2002-2).

### 1.2 General Search for Technologies

In Phase I of the UIC/MIT Technology Scanning Programme, Schofield identified a number of methodologies with which technology scanning is conducted (WP 2001-3). El Alj followed two of the broadest approaches, “General Search for Technologies” and “Technology Mapping” and identified twenty areas of emerging technology currently being developed in laboratories throughout the world, which may have substantial impact on the railroad industry and its competitors (WP 2001-2, p.4-10). This is a continuing activity of use to UIC and its member railroads.

In Phase II, we created a framework with which emerging technologies could be classified, to assist the technology mapping exercise, and to provide a structure within which experienced railroad personnel may systematically identify their requirements and how technologies could assist them. It was determined that there are three mutually exclusive orientations along which the sphere of technologies could be divided: by impact, by fundamentality, and by functionality. The impact dimension allows us to assess if the technology is likely to produce a positive return-on-investment and whether this is accomplished through increased revenue or decreased costs. The fundamentality dimension assists us to differentiate between very fundamental research that improves our understanding of the world at large from those which are immediately applicable to the rail industry. The functionality dimension tells us which market segment the technology is likely to benefit and helps us address distributional issues in technological investment. For a more detailed discussion, see Section 2.

Sections 3-5 cover results from three different approaches to technology scanning, as described below:
1.2.1 University Research

One approach to finding possible technological applications is to look at what is going on at major research centers. University research (Section 3) is driven by a variety of forces, as there are numerous of research possibilities and many semi-autonomous research groups. The research underway at any major university therefore indicates the range of interests of researchers as well as the pressures and funding opportunities promoting new technologies. A review of research underway at MIT confirmed that there continues to be great interest in all of the areas identified in Phase I. Some research is directed at the transportation industry, as there is considerable public interest in new fuels, cleaner automobiles, and more efficient auto and air travel. However, there is little research directed at the needs of the rail industry. This means that it is essential for the railways to be aware of on-going research efforts and to seek possible adaptations of new technologies as they become available.

1.2.2 Emerging Areas of Technology

Another approach is to look for entirely new areas of technology that are emerging based upon fundamental advances in science. MIT’s School of Engineering has identified four such areas: information technology, engineering systems, bio-technology, and nanotechnology. Information technology is well known and acknowledged by most observers to be critical for transportation and in fact most industries. Control techniques, optimization strategies, automation and other elements of engineering systems are also well understood to be critical for improving the performance of transportation and other complex systems. The other two areas are newer and less well understood. Bio-technology is extremely important for medical and agricultural purposes, but does not yet seem to have critical transportation applications. Nanotechnology is a term applied to technologies that operate at a very small scale, either to produce tiny, inexpensive machines or to create extremely consistent materials with unusual strength or other characteristics.

Since nanotechnology is unlikely to be well understood by transportation professionals, we conducted a more extensive review of on-going research in this area. While immediate applications are unlikely, the long-term potential is very great. It appears that it will be possible to design highly specialized materials with properties tailored to particular needs. For example, metals could be designed that change colors in different stress states, which would have many potential applications for railways. Another possibility is that new manufacturing techniques will be developed for producing many kinds of articles; instead of cutting pieces out of sheets of metal, pieces of any shape or size could be built up from “nano-dots”. If this became a significant form of manufacturing, there would be important implications for the location of manufacturing, materials requirements, and freight transportation.

1.2.3 Technology Vignettes

Any prolonged consideration of technological opportunities will uncover numerous possibilities and suggest potential applications of technology. Without further study, it is unclear how much potential these ideas might have or when they might become applicable. We believe that there is some merit in describing a few of these ideas, if only to facilitate further brainstorming concerning technological applications. We therefore have included a series of what we call “technology vignettes” as a separate section of this paper.
The paper concludes with some observations concerning technological innovations. An appendix provides considerable background information concerning research underway at MIT, including comments regarding possible applications to rail systems.

2. CLASSIFICATION OF TECHNOLOGIES – THREE FRAMEWORKS

To understand how technologies will affect railroads, it is important to have an organizing principle for the vast array of technologies that are currently undergoing research. Thus, we created a framework with which emerging technologies could be classified, with a view to better understand its impacts. Instead of taking a traditional “classification” approach that attempts to categorize like-technologies in the same bin (somewhat similar to the classification system for the living world), where new “species” of technologies could occasionally be found, we took the set of all possible current or future technologies, and divided them along several dimensions, which are intended to be orthogonal. Within each dimension, the coverage is intended to be exhaustive and mutually-exclusive. These dimensions are often related to the inherent properties of the technology or the technological idea, so even if a new “species” of technology is invented, it should still fit within the framework without the requirement to add additional categories. There are three major dimensions along which the sphere of technologies could be divided: by impact, by fundamentality, and by functionality.

2.1 Classification by Competitive Intent

The competitive intent dimension allows us to assess if the technology is likely to produce a positive return-on-investment (provided that the costs can be accurately projected), and whether this is accomplished through increased revenue or decreased costs. The basic idea is that all possible technologies could be assessed in terms of their potential impact on revenue and their potential impact on costs. The technologies that are primarily designed to reduce costs are termed “Type A” technologies, and those that are designed to enhance revenue are termed “Type B”. Type A technologies seek to reduce costs of providing service, whether through track, equipment, signals & communications, or stations. Type B technologies seek better market share through higher speed & frequency of operations, better on-board service, greater accessibility, and superior stations.

![Figure 2: The Two Fundamental Types of Technologies, and Lemons.](image-url)
2.1.1 Revenue Enhancing and Cost Cutting Technologies

Type A technologies tend to share certain characteristics, which are generally necessary for it to be successful at reducing costs. They are likely to be (1) mass produced, (2) cheap, (3) omnipresent, and (4) standardized. These innovations are likely to be introduced through a normal process of what might be called “steady state renewal”. Over time, the system becomes more efficient. This type of technological development could be useful for cross-country systems, low cost commuter services, or high capacity services, where they can be applied across the board. For these markets, attempts to drive up market share with B-type technologies are likely to fail because competition is based upon cost, not service.

Type B technologies are more likely to be (1) specialized, (2) expensive, (3) custom-built, and (4) proprietary. Where there is potential for attracting substantial new customers, then it is possible to consider capital enhancements and upgrades. These technologies may be best for high-margin corridor systems or leisure services, where better service is needed to compete with other travel and leisure options.

The two types of technologies are shown on a revenue/cost plane in Figure 2. These technologies are the only ones the railroads are likely to be interested in. The other technologies, which have positive cost implications and either zero or negative revenue implications, are technically known as “Lemons”.

2.2 Classification by Maturity of Technology

While the impact dimension looks at technology from a consumer’s point of view – what are its effects on the railroad, if implemented, the maturity dimension looks at it from a technologist’s point of view – how applicable is this technology? How close is it to being turned into a product? Is the product directly useful to a consumer, or is it just an intermediate product or part destined for another producer? Is it a technology that a consumer can apply, or is it only useful to an intermediate producer? The fundamentality dimension assists us to differentiate fundamental research that improves our understanding of the world at large from research that is immediately applicable to the rail industry.

It has long been known in the natural sciences that there are different levels of basic science research which contribute towards understanding at different levels. Work in set theory and number theory allows scientists to build mathematical models of physical phenomenon, which in turn allows us to describe the atoms that ultimately make up living things. In the world of technology, the same distinction could be made between different levels of technology, as well as the underlying work to understand “how it works” which may enable further development of different technologies. In light of this, we divided technological research into three tiers fundamentality:

- **Tier 1**: Fundamental Research
- **Tier 2**: Application Research
- **Tier 3**: Application Engineering

2.3 Classification by Functionality

The competitive intent dimension considers the needs of the railroad, while the fundamentality dimension considers the dreams of the technologist. The third framework, classification by functionality, deals with the requirements of the ultimate customer – the railroad passenger, and the railfreight shipper. The functionality dimension tells us which market segment the technology is likely to benefit, and helps us address distributional issues in technological investment. In addition, it can be useful for evaluation of competing technological investments for their investment-return potential, since the larger the target market segment, the more it is able to generate return-on-investment per unit of utility increased.
To assess functionality of technologies in a railroad environment, we divided technologies into four categories. This was the most difficult of the three frameworks, since it is not always clear that the categories are indeed mutually exclusive. Frequently, the application of one technology would have a multitude of effects, depending on the manner in which it is applied. Nonetheless, dividing technologies into categories according to the predominant effect (or intended effect) of the technology upgrade is a good way of addressing distributional issues. Are particular market segments disadvantaged because a new technology is being implemented? Does a particular technology benefit one market segment more than the others? These are important questions, and must be addressed. Of course, sometimes the implementation of a particular technology can have unintended effects, and this would mean the category in which the technology belongs is not necessarily stable. Nonetheless, the initial classification during a technology-scan exercise is a valuable exercise, which would may offer insight into possible deployment scenarios not otherwise available. The four categories are:

- **Operational Technologies:** signalling, rolling stock, infrastructure, communications, dispatching – traditional technologies to allow for high speed operations on dedicated rights of way. This would include technologies to cut costs of high speed operation. Fare collection technologies, passenger manifests and the associated information systems; smart passenger tracking.

- **Accessibility Technologies:** e.g. compatibility of HSR with conventional train, diesel versus electric trains, dual mode technologies, bogie changing technology, tilting technology, e-commerce technologies (more opportunities to purchase tickets).

- **Accommodation/Entertainment Technologies for Passengers:** e.g. seat ergonomics, construction technologies to allow for more room and more comfortable beds, technologies to accommodate private autos within a passenger train; other revenue-enhancing technologies such as diners, bars, phone & internet on board, etc; luggage handling technologies. On the freight side, this would include specialist cargo handling techniques, cargo refrigeration, cargo sorting, etc.

- **Consolidation/Coordination Technologies:** equipment or technologies specifically designed to capture the economies of scale or economies of scope, e.g. express freight cars integrated within the passenger train set, logistics information technologies associated therewith, timed transfers (customer information systems technologies associated therewith), other intermodal technologies (transfers from subways, coordinated fare collection).

### 2.4 Technology Outlook for Railroads – Future Technologies and Transportation

The U.S. DOT, through its Volpe National Transportation Systems Center (the Volpe Center) has a technology scanning program for transportation in general. Some of the findings were presented at the Spirit of Innovation Conference in 2000. The Volpe Center believes technological developments over the next 30 years will continue to fundamentally impact the transportation system the way it has done in the past 200 or so years, although it is not clear at this point what the next revolution will be – whether this be Personal Rapid Transit or High Speed Ocean Transport.

Systems, materials, vehicle components, structures etc. are now much safer than just a few years before, and are being continually improved. Communication, information, navigation and control systems have been integrated with various transportation systems to create smart vehicles. The vehicles continue to become cheaper, durable, easier to maintain, more efficient and environmentally friendly. Electronic design, surveillance, control and tracking systems such as GPS and GIS have fundamentally changed the freight and
passenger transportation industry. Despite the increasing level of technical sophistication and development, the costs of many transportation system components are coming down.

The Volpe Center identified seven critical areas of technologies which are considered likely to impact the transportation industry. While slightly different from our framework, the Volpe study confirms that many of the areas we identified as critical are not simply important to the railroads, but to the transportation industry in general. The seven areas were:

- Better understanding of human performance, condition and behavior.
- New computer, information and communications systems.
- Advanced materials and structures.
- Manufacturing methods of various tools and objects.
- Energy and propulsion systems.
- Sensing, detection and measurement technologies.
- Analysis, modeling, design and construction technologies.

It has been noted that in some of the cases, several trends in the technologies reinforce each other. For example, the emergence of “smart structures” and evolution of “intelligent materials” with built-in sensors of microscopic sized will lead to improvements in safety by reducing the possibilities of sudden failures. In fact, some of the technological ideas and concepts that lead to enhancements and developments in a certain sector may be tried for applications in several other sectors and thus new levels of performance, safety and efficiency achieved. Many advances in computers, information technologies, telecommunications, navigation, materials, structures, energy, propulsion, control and navigation systems, sensing and human factors have been occasioned or accelerated by various other transportation applications. These may make feasible new kinds of systems to come into existence that have altogether higher levels of performance and capacity than those in the current generation.

Having presented a Framework for Technology Scanning and Three Frameworks for Classifying Technologies, in the next section we move into the “Technology Scanning Proper” by presenting our findings as we applied the frameworks and conducted a technology scan on behalf of the UIC – keeping it as broadly based as possible so that the solution identified could apply to many railroads around the world.

3. NEW AND EMERGING TECHNOLOGIES RESEARCH AT MIT

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. The approach taken in this section is generally thought of as “technology-push”, where the technologists are attempting to persuade the market to purchase their inventions. Several categories of technologies, identified as having potential in railroad applications, are then fed into the next step of the process which would identify the technologies that are the most germane and promising.

Following El Alj’s approach, we conducted a general search for technologies which are currently under development at over 200 of MIT’s labs, research centers and programs. A general search is functionality-based and technology-oriented, rather than a framework suited for mapping to railroad applications. For consistency, we elected to retain the same key areas used by El Alj and retained the technology-push focus of her work. In addition to highlighting emerging technologies in a “General Search for Technologies”, we also mapped some of the technologies to potential railroad applications, and tried to imagine how the technology would change the railroad business model. We confirmed that the twenty key areas are still
extremely important, by considering the research on-going at MIT, as described in Section 3. In twelve of these key areas previously identified, we found that MIT is conducting interesting basic scientific or engineering research which are potentially important to railroads. In addition, we identified a new area in which research is currently being conducted: Asset-life Extension Technologies, which has its focus not on manufacturing but on extending the life of existing plant and/or manufacturing equipment which will have a longer life-cycle. This further confirms the diversity of technologies which could have railroad applications for railroads and competitors in the long run.

3.1 MIT – Source for Identifying New Technologies

MIT’s press office publishes a number of news and technical publications, including the Technology Review magazine, and the MIT Undergraduate Research Journal (MURJ), all of which carries recent achievements and results from MIT’s various affiliated labs. Some of the publications were scanned for potentially interesting technologies. More information is available directly from the journal websites:


3.2 Areas of Enabling Technologies

The new technologies can be grouped into different “Areas of Enabling Technologies” (El Alj, 2001) or areas that are key to scientific advances. For each of these areas, we examined MIT’s research labs to see what ongoing research is currently occurring. 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. Through a recursive process, we found a number of areas not where the awareness amongst the railroad industry and its suppliers are generally quite low (or, at least, we did not find specific references to these technologies in general rail research program literature):

- Advanced Manufacturing Technologies
- Miniaturization Technologies
- Nanotechnology

Review of various rail industry research reports, including JR East’s e@train (Japan), Railtrack’s Strategic Plan (United Kingdom), and FRA’s Five-Year Strategic Plan for Railroad Research (USA), revealed that the rail industry (and railroad suppliers) as a whole are generally aware of a number of other key areas:

- Advanced Materials
- Computer – Electronics
- Human/Machine Interaction
- Information and Telecommunications

The detailed review of each technological item under many key areas of technology are contained in Appendix A – Technological Advancements at MIT with Potential Impacts in the Broader Transportation Industry.

3.3 Technology Review Methodology and Organization
For each of the group of technologies, we reviewed many websites and research publications. In Appendix A, 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, Supplier or Competitor

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:

### 3.3.1 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

### 3.3.2 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
3.3.3 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

3.3.4 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

3.4 Summaries of Technologies Reviewed

Our analysis and the assumptions on which these verdicts are based, are contained in the appendix. A brief summary of the most important and interesting technologies that we reviewed are presented here:

3.4.1 Advanced Manufacturing Technologies – Advanced Composite Materials

Although advanced composites are most useful in a high-performance, low-weight environment such as the aeronautics industry, low-cost composites could be used in a variety of rail applications, from as mundane to signal heads, passenger car interiors to more heavy-duty uses like load bearing parts, the truck, and coupling devices. More research and development will be needed before such visions can become reality, although such research is much more likely to benefit the airline than the railroad.

3.4.2 Computer Research – Technologies for Unifying Multi-Scale Computing
The rich diversity of computing platforms with different engineering parameters has made it very difficult to enable systems to talk to each other. Interface technologies to enable communication between different computer systems are a double-edged sword for the rail industry. Communication and data-sharing will enable greater degree of automation than is currently possible, and offer better levels of service to customers, but lead to more complex systems with more failure modes, and potentially more serious safety and security issues.

3.4.3 Electronics Research – Signal Processing for Video Communications

Advanced signal processing techniques will support video and data transmissions in future, to enable lower cost per unit of information transmitted. Applied to video transmission, the technique could benefit the rail industry by enabling low-cost monitoring of facilities and a greater degree of remote control through visual feedback. The benefit/cost ratio of either idea is at present unclear, but if proven effective, remote control of equipment within the yard and on short-distance transit lines would certainly be possible.

3.4.4 Electronics Research – Optimizing Scientific Computation

The use of supercomputers and massively parallel systems is essential to solving large-scale scientific and engineering problems. The railroad industry, with its immense computational needs, can certainly benefit from faster computation speeds. For optimization work, improvements in algorithms may well be a more cost-effective method than increasing computational speed, but for data-intensive functions, faster computational processing power may enable far more real-time controls than at present possible. On the other hand, the bottleneck may not be in the processing power – but communications bandwidth.

3.4.5 Miniaturization Technology – Photonics Research

Photonic crystals are an exciting new class of materials that could be used to control light the way semiconductors are used to control electricity. Potentially, instead of using integrated electronics, computation could be performed using photons at much higher speed. Many industries may benefit from this technology, in particular the control, dispatching and optimization functions of the railroad. Initially, photonics research would probably focus on high-cost, high-performance sectors. Eventually, it may be more widely deployed, and may affect the general freight market as components are further miniaturized.

3.4.6 Nanotechnology – Magnetic Random Access Memories

Magnetic Random Access Memories are solid-state non-volatile magnetic storage devices. Storage devices faster than the disc will benefit the logistics industry, and many other data-intensive industries immensely. However, its benefits for non-logistics transportation carriers are unclear, as carriers may be forced to invest in expensive data-exchange technologies and introduce additional security risks from which they are unable to leverage higher freight rates.

3.4.7 Propulsion Systems and Turbomachinery – Smart Aero Engines

The MIT Gas Turbine Laboratory embarked on the ‘Smart Engines’ research program in the mid-1980s. The research has immediate and incremental applications in the airline industry, and is likely to make it a better competitor over time. The technologies developed can potentially lead to better propulsion for high-speed rail, but propulsion technology may not be currently leveraged or constrained in the railroad industry – infrastructure technologies and guidance technologies are. Thus, this research is less likely to benefit rail in the near future.
3.4.8 Sensor and Data Processing – Ultrasonic Sensors for Nondestructive Evaluation

Ultrasonic phased arrays are being developed that allows nondestructive evaluation of a variety of structures. This and other types of ultrasonic technologies have been applied to detection of rail defects recently. However, for railroad infrastructure in the longer term, a paradigm-shift is required; instead of periodically inspecting equipment, a maintenance regime which relies on preemptive replacement of life-expired parts and smart parts that tell you if they’re about to fail.

3.4.9 Sensor and Data Processing – Low-cost Portable Tele-Diagnostic Devices

Low-cost, portable tele-diagnostic medical devices can achieve widespread use in rural areas of developing countries. Wireless extensions will allow devices to be used without being tied to a host computer. The communication element of the technology being developed here is potentially of great importance to the railroad, although it is not clear that costs that are sufficiently low for medical purposes would be considered sufficiently low for widespread deployment on railroad infrastructure.

3.4.10 Sensor and Data Processing – Vibration Suppression in Flexible Structures

Flexible structural systems are lightly damped and contain significant uncertainties in their dynamic behaviour. Adaptive controllers deliver a time-varying compensation to achieve high stability. This technology is potentially valuable for passenger and freight businesses – to offer a superior ride for sensitive consignments, and to reduce the kinematic envelope of passenger vehicles travelling at high speeds, thereby reducing infrastructure cost or increasing speed. Adaptation of the technology will be needed, but this may potentially be a significant advantage for passenger trains that other modes could not replicate.

3.4.11 Sensor and Data Processing – Electronic Product Code

The Electronic Product Code is a standard designed to uniquely identify objects throughout their life-cycle. The technology includes the concept, the radio tag hardware, the “Smart World” notion where the objects communicate with each other, and a robust standard for such communications. This technology is expected to have major impact on supply chains, railroad customers, and all railroad activities that depend on supply chains (such as maintenance). The implications are unclear at present, and it is not clear whether the technology would achieve the ubiquity of the barcode.

3.4.12 Sensor and Data Processing – Visual Surveillance and Monitoring

Visual Surveillance and Monitoring makes use of a “Forest of Sensors” and performs real-time calibration to form a robust sensing infrastructure. Potentially, this technology could be used to create a resilient railroad, where dispatching does not rely on the correct functioning of a particular track-circuit. However, a whole host of safety issues may be introduced with using a probabilistic or inductive artificial-intelligence logic to ensure safety. The safety-efficiency trade-off must be carefully considered.

3.4.13 Sensor and Data Processing – Unsupervised Audio Scene Analysis

Artificial-intelligence research in unsupervised audio scene analysis will create an automatic way of monitoring the environment for anomalous sounds. This is potentially useful on the railroad for additional defect detectors which will spot signs of trouble early on in infrastructure and equipment. However, it is debatable whether this information can be of timely value as staff occasionally report equipment needing attention but there may not be economic incentive or capacity to perform the needed maintenance.
3.4.14 Information and Telecommunications Technology – Software Wireless Networking

The SpectrumWare project applies a software-oriented approach to wireless communication. Analogue-to-digital conversion technology enables signal processors to directly sample the radio band spectrum and convert it to digital sound data. The potential flexibility in this technology will allow easier incremental upgrades for communication based train control, but it comes at the expense of tremendous initial outlay. In addition, software technologies have sometimes not been as reliable as desired in a railroad environment.

3.4.15 Information and Telecommunications Technology – Active Networks

The Active Network allows routers within the network to perform complex and customized computations to determine information routing. Potentially, this technology can be used to construct a wireless and mobile communications infrastructure that does not rely on a central registry of nodes. At present, it is not clear whether the distributed approach is better than the centralized approach in providing mobile communication for railroads. Many of the crew already have private subscriptions to centralized services.

3.4.16 Information and Telecommunications Technology – Innovative Railroad Information Displays

An Innovative Display maintain the user’s sense of context by keeping the information viewable while subduing information not currently relevant. Applied to the railroad environment, it is a potentially valuable valuable tool in a space-constrained environment but may have safety implications. Since fully automatic train control may not arrive any time soon, research in information display may provide medium-term benefits, just as glass cockpits have enhanced the productivity of aircraft pilots.

3.4.17 Information and Telecommunications Technology – Decision Aids for High Speed Trains

The Decision Aid uses a kinematic model to assist the engineer by displaying a calculated braking curve and other relevant information such as grades and signal aspects. While the cab-signal aspect of this technology have existed on the Pennsylvania Railroad since 1923 (14), the braking curves may be of use to inexperienced train operators on fixed-consist lines where the braking behaviour is easily predictable. In freight service, locomotive operation is almost a black art, and no technology will replace experience.

3.5 Conclusions

A generalized search for technologies at MIT is a valuable exercise, as we were able to uncover some technologies which had not been previously mentioned explicitly in some of the world’s railroad technology research program documentation and technology strategies. While the potential of many of the technologies are either currently unknown or unclear, many of the technologies clearly have potential and should be subject to further evaluation.

Having analysed technologies at MIT, we determined that a particular interesting area of emerging technology is that of Nanotechnologies.

4. TECHNOLOGY SPOTLIGHT – FOCUS ON NANOTECHNOLOGIES

Nanotechnology is the study of microstructures in materials on a nanometer ($10^{-9}$ m) scale, which have interesting properties that can be manipulated to produce advanced materials. It is particularly relevant as materials technology can strongly drive the cost of many engineering systems. Materials with properties that are made-to-order could advance engineering systems an order of magnitude or more beyond what is
currently imaginable. Indeed, composite materials on a larger than nano-scale such as carbon fibres have already been successfully used in many structural applications, including those in transportation. Nanotechnology has strong potential to bring about step change in materials, production techniques and machine design. This is definitely not tomorrow’s technology – applications lie far in the future. Nonetheless, it is important, particularly for government entities in a position to make very long-term investment, to be aware of the possibilities.

4.1 Nanotechnology – An Introduction

Nanotechnology basically denotes the wide range of technologies involving the manipulation of the structure of the matter at the molecular and the atomic levels. It can be considered a catch-all description of activities at the level of atoms and molecules that have applications in the real world. It has an enormous capability to offer us the capacity to design materials with totally new characteristics and features. Nanotechnology is geared towards fundamentally changing the things we make and the methods through which we make them. Instead of using, say, steel to make something because steel has certain properties, and then creating a machine that is capable of shaping steel in a way we want, with nanotechnologies we make the raw-material and the product in one step – constructing the product from scratch using the basic building blocks of matter, atoms.

The manipulation here basically occurs on the scale of nanometers (one billionth of a meter or 3-4 atoms wide) and is intended to alter various types of properties of matter, including the physical, chemical, and biological properties – such that we could create designer materials with certain properties. The concept is already well known in alloys, textiles and teas, where mixtures are made with certain recipes to produce products with properties somewhat different from the original. The materials, with the new properties, can then be used to create all kinds of components, structures and systems with capabilities not possible with natural materials. Nanoscale devices possessing extraordinary properties are constructed by using the already known physical properties of the atoms and molecules. These nanodevices can be made in one of two ways: either by machining and etching existing material, or by building organic and inorganic structures atom-by-atom, or molecule-by-molecule. The molecular devices may have a significant impact on the various facets and applications in industry (7).

Another feature of nanotechnology is that it is one area of research and development that is truly multidisciplinary. Research and development at the nanoscale has unified the need to share and explore knowledge on various tools and techniques, and the basic physics affecting atomic and molecular interactions. Material scientists, mechanical and electronic engineers and medical researchers are now forming teams with biologists, physicists and chemists at various levels. The basic aim is essentially to get each and every atom in the right place and make all kinds of useful structures.

4.2 The Applications of Nanotechnology

Our review of information sources and other relevant literature suggests that nanotechnology has applications limited to not only one field but extend to a wide variety of industries that include biotechnology, chemicals, pharmaceuticals, space, metrology and measurement, optics, information processing, integrated circuit (chip) fabrication, synthetic chemistry, scanning probe microscopy, artificial proteins, self-assembling monolayers and many more. Several major scientific disciplines are aiming towards this accurate and precise manipulation of the matter at atomic scale to influence the properties of the various materials. Nanotechnology holds great promise to dramatically revolutionize the various processes, materials and manufacturing of products in various industries in future. Efforts are being made to construct devices that manufacture at little or no cost (not exceeding the costs of the required raw materials and energy), by treating atoms in a discrete manner. Nanotechnology will be heading to
significantly impact the fabrication technologies and processes for micro- and nano-scale structures that have come into existence and are currently under the research phase.

Today, nanotechnology is still in its infant phase, because only rudimentary nanostructures can be created with some control. Nonetheless, it has captured the imaginations of scientists, engineers and economists alike, not only because of the explosion of discoveries all over at the nanoscale, but also because of the potential applications in various fields. Controlling matter at the nanoscale has important implications for healthcare, the environment, sustainability and almost every industry. According to researchers at Rice University, Nanotechnology has been characterized into three different but interdependent areas:

1. “Wet” nanotechnology: This refers to the study of complex biological systems that primarily exist in a water environment.
2. “Dry” nanotechnology: This derives its name from surface science and physical chemistry and deals with fabrication of different materials and structures from elements such as carbon, silicon, and other inorganic materials.
3. Computational nanotechnology: This involves modeling and simulation of complex nanometer-scale structures.

The nanoscale is just not another step towards miniaturization, but a qualitatively new scale. There are many unique properties, phenomena and processes which occur only when nanoscale manipulation is possible. Quantum mechanics, material confinement in small structures, and large interfaces dominate the new behaviour. New materials that are developed through nanotechnology will allow the ultra-miniaturization of space systems and equipment, including the development of “smart”, compact sensors; minuscule probes; micro spacecrafts and other things.

Nanotechnology will fundamentally change the way materials and devices that will be produced in the future. The ability to synthesize nanoscale building blocks with precisely controlled size and composition and then to assemble them into larger structures with unique properties and functions will revolutionize materials and manufacturing. Researchers will be able develop material structures not previously observed in nature. Some of the benefits that nanostructuring can bring include lighter, stronger, and programmable materials; reductions in life-cycle costs through lower failure rates; innovative devices based on new principles and architectures; and use of molecular/cluster manufacturing, that takes advantage of assembly at the nanoscale level for a given purpose.

Conventional computing machines are limited by the manufacturing capability to create smaller and smaller chips and circuits, and to dissipate the heat that is generated as the device operates. Nanotechnology will make it possible to create computing devices called “quantum” computers, which will exceed the limits of speed and miniaturization of conventional computers through exploitation of the quantum nature of matter. Quantum computers will far exceed the normal speed and efficiency of the conventional computing devices. They could also trigger the development of other advanced nanoscale manufacturing and mechanical systems. In essence, nanotechnology is expected to bring about some major breakthroughs that could make possible fabrication of materials at the molecular or atomic scales, self-replicating structures, self-repairing structures, novel computing devices with totally new capabilities and accelerated emergence of intelligent systems and smart structures and objects.

4.3 The Impact of Nanotechnology on Rail Transportation

Given the diversity of possible applications, it is conceivable that nanotechnology will provide a number of new tools to build the transportation system for the 21st century. For example, experts claim that advances in nanotechnology may make possible carbon-based fibers which are 100 times stronger than steel, at only
one-sixth the weight. The breakthrough applications that might be forthcoming in transportation from nanotechnology are as follows (8):

- **Communications:** Nanotechnology has great potential to support advanced communications that can leverage the benefits of intelligent railroad systems and obviate the need for some travel altogether; sensors that have the capability to continually monitor the real-time condition and performance of roads, tracks, bridges, runways, pipelines, rail systems and other components of the transportation infrastructure; and develop vehicles that have the capacity to avoid crashes and improve operator performance. It will also enabling miniaturization of computing devices and leading to development of “smart” and “intelligent” subsystems that enhance the control and management of the railroad.

- **Structures and Components:** Nanotechnology will be able to yield advanced materials that will possess properties that in turn will allow for longer service life and lower failure rates. Nanomaterials and nanoelectronics will yield lighter, faster, and safer vehicles and more reliable, efficient, and cost-effective structures and systems. Some of the key applications include nano-coatings of metallic surfaces to achieve super-hardening, low friction, and enhanced corrosion protection; “tailored” materials for the infrastructure and vehicles; and “smart” nanocomposite materials to monitor and assess their own current status and repair any defects resulting from fatigue, excessive fatigue, fire, etc. It will enable structures and materials to have higher levels of performance, unique properties and functions that traditional sciences and technologies could not create.

- **Environment and Alternative Fuel:** Nanotechnology will provide the ability to create affordable products with dramatically improved performance. Nanotechnology also has the capacity to reduce transportation energy use and its impacts on the environment. The various applications include nanosensors to monitor vehicle emissions and trigger various means to trap the observed pollutants; nanoparticle-reinforced materials that replace metallic components in the vehicles, replacement of carbon black in various objects with nanoparticles of inorganic clays and polymers thus promoting environmental friendliness and also wear-resistance; and carbon-based nanostructures that have the ability to serve as “hydrogen super sponges” in the vehicle fuel cells.

Some of the potential changes from technological breakthroughs may not be direct in nature. For instance, nanotechnology can elevate safety levels through indirect means. Applying nanotechnology to address safety and security concerns may eventually lead to these solutions:

- **Safety and Security:** Nanotechnology has many applications in this area, including: (1) advanced information processing and sophisticated virtual reality systems for training using nanoelectronics (2) automation and robotics to reduce manpower and risks of human error (3) lower failure rates of life-critical components through new nanomaterials (4) improvements in terrosist monitoring and management through better sensors (5) combined nanomechanical and micromechanical devices for control of safety and security systems.

Of course, these are just some examples of the impacts that could potentially take place. With cutting-edge technologies like nanotechnology, where the technology forecast is not certain, in many cases the impact would outwit the most imaginative of all minds. Thus, it is useful to explore beyond the first-order applications and impacts as we have outlined in this section. We will discuss the second-order impacts in the next section.

### 4.4 The ‘S-Curve’ of Technology
It is clear from the above analysis that nanotechnologies will have wide-ranging impacts in every industry, not just in transportation. It is thus useful to look at nanotechnology from a broader perspective – how would it impact society? When, in what sequence, and in what way would the impacts occur? When the transistor replaced the vacuum tube in the revolution that came in the 1950's, it was not clear to anyone at the time that the integrated circuit revolution was just round the corner. Even today’s electronics research is still based on the basic idea of integrating circuit components onto silicon wafers – the ideas on which the first transistors were built. We can describe that process in terms of an S-curve of technology evolution.

**Figure 4:** The S-Curve of Technological Development (9)

Gingrich (American Enterprise Institute) suggests that newest, least understood and the most promising area of science is the nanoscale science and technology. As a general rule breakthroughs relatively start slow; they slowly build up momentum, they suddenly reach a period of catalytic change, they go up the curve of capability very, very rapidly and as they mature they tend to level out. The current S-curve that we have been experiencing is the revolution in computing and communications (also called the Information Age) that started back in 1965. This age is the product of two developments: one in computing and the other in communications.

Within a few years, combination of new technologies for compressing information and bigger transmission capacity, an entirely new approach may result in major changes to the S-curve for technology. Today, a second S-curve is beginning to develop, overlapping with the current S-curve. The best description of this second wave of change is the NASA Ames Laboratory version (See Figure 5) which uses a triangle with biology on one side, nanoscience or nanotechnology on the other, and information or supercomputing at the bottom. The interaction of these three will lead to an enormous wave of change that creates the second S-curve.

**Figure 5:** The Technology Triangle, according to NASA’s Ames Laboratory
The age of transitions will be an ever-evolving set of discoveries, with the information world increasingly interacting with the physical world. Some experts believe the application of nanoscience and nanotechnology into real marketable products will be much more rapid than what we saw with the internet or other revolutionary technologies (9).

There are negative aspects of nanotechnology, too. The technologies emerging from nanoscience may well prove disruptive too in some sense. “Disruptive technologies” are those which produce new products in new ways (10). Initially, they may cost more and be less effective than the more mature, “sustaining technologies”, but eventually, they become so much cheaper and better as to drive the older technologies out of the market. Particularly because of this, they may have societal implications that extend beyond their functional implications. Nanotechnology will turn out to have major impacts, just like any truly revolutionary advance in technology. Particularly in the fields of natural resources, human behavior and security, current trends will raise significant issues that drive significant technology change. Nanotechnology could potentially make a huge contribution in developing sustainable solutions.

4.5 Future Development Directions for Nanotechnology

It is clear from the above analyses that nanotechnology will have significant impacts in all industrial sectors, including transportation systems. It will have an influence on all the major modes of transportation, be it highways, airways or railroads or private automobiles. Overall, nanotechnology will offer substantial advantages, being smaller, faster, stronger, safer and more reliable. At the same time, it will also require additional investments in new production and manufacturing techniques.

Costs are likely to be relatively high in the beginning since it will take time to achieve economies of scale and for development of the most efficient fabrication methods. Thus, nanotechnology-based goods would be introduced first in markets where performance characteristics are of the utmost importance and price is of secondary concern. The experience gained here will help to reduce technical and production uncertainties and prepare these advanced technologies for deployment in the mass-market. Similarly, in the private sector, technology transfers are likely to take place from performance-oriented areas to price-oriented ones. As the given technology matures, its costs may decline, leading to greater penetration of the market even where major decisions are not taken based on performance. This will tend to accelerate the displacement of older technologies. However, this is also likely to stimulate innovations in the older technologies that may make them better able to compete – an ironic but potentially beneficial second-order effect (9).

The diffusion and impact of nanotechnology will partly be a function of the development of complementary technologies and of a network of users. Whole new industries may have to be developed and there may be many obstacles along this road that ordinary market processes cannot easily overcome. An important role for the government will be to invest in the long-term, high-risk, high-gain research needed to enable the potential developments of these technologies in various industries and also to ensure that they are consistent with the broader objectives.

4.6 Conclusions

It can also be concluded from the above potential applications that some of the applications of nanoscience and nanotechnology may bring about significant impacts and improvements on other transportation systems or railroad competitors as well. The lighter and stronger materials developed using nanosciences could enhance the airplane manufacturing techniques improve airline competitiveness vis-a-vis the railroad.

The current focus of the research being conducted in nanotechnologies is expected to revolve more around areas with immediate applications than long-term applications. Much research efforts are also being made
to make these technologies commercially available. The sector that leverages the immediate applications of this technology at the earliest and in the most organized and thoughtful way, is likely to benefit more than as compared to other sectors.

Given the apparently wide-ranging potential applications for nanotechnology, and the revolutionary nature of its impacts, we believe that it is imperative for the railroad industry to devote a small portion of its research resources to “watch” developments in the nanotechnology arena. The general nature of the technology means that it may be too soon to start investing in the technology heavily, but the fact that it can have potentially revolution implications would suggest that timing is critical. When indeed the technology does become mature, the mode or carrier ready to take advantage of it will have a definitely advantage over the others in the post-nano world. Thus, attempting to catch the inflexion point of the S-curve is of critical importance.

However, as investment experience in technologies and other sectors (such as railroad freight cars) have demonstrated, catching the inflexion point has proven to be very difficult, and the results of making a mistake can be disastrous. Investing too early result in large financial capital losses; investing too late result in competitiveness losses (which then translates to operating losses). While the freight car rates are determined entirely by supply and demand and are essentially random, technologies are less so. Although much analysis have suggested that the internet “revolution” has taken place in an explosive timeframe, and depended on many things coming together to reach a “critical mass” – in fact to those who have been following the technological developments, the revolution was much more of an evolution. Personal computers evolved to become client terminals to small scale local area networks, which were then connected to form a wide area network, and as each piece of “internet enabled” technologies and software protocols were brought on-line, more things became incrementally possible, to the point where the ability to accomplish business processes in novel ways began to look revolutionary to an outsider.

Nanotechnologies are likely to take a similar path. Whichever branch of nanotechnology matures first – whether that be coatings, materials, nanoelectronics, or sensors, would be utilized to the full extent, but the full effect of the revolution would not be felt until a number of areas are able to interact to enable a totally novel way of thinking and doing things. Companies that have been successful in the internet revolution were able to deploy technologies very quickly and make suitable adaptations to their business model when the critical mass was reached because they had been preparing for the moment by introducing computer and networking technologies incrementally on a consistent basis. Companies that did not develop the expertise as the technologies were developed were left behind when the revolution occurred. Of course, each piece of technological investment made should be justifiable on its merits (expected cost savings or revenue increases) alone, but at the strategic level it is important to ensure that the organizational culture keeps up with the technological developments. Again, we would emphasize the importance of scenario analysis in strategic planning. Companies (or indeed industries) that are able to deploy technologies quickly to their competitive advantage would be the ones where strategic planners have seriously thought about the consequences of the technology as a scenario before the technology reached a critical stage.

5. TECHNOLOGY VIGNETTES FOR RAILROADS

Based on the research group’s practical railroad operations experience, a number of ideas for potential applications of technology had been developed for future railroad research programmes. The approach taken in this section is generally thought of as “market-pull”, where the current operators and managers are attempting to persuade the technologists to come up with an invention to solve their problems. The technological ideas and application we discovered through brainstorming and interviewing operating personnel range from near-term, immediately applicable technologies that enhance day-to-day operations to
long-term concepts that may change the system as fundamentally as the steam to diesel and D.C. to A.C. transition. The following table is a summary of the technology ideas:

- Optical Coupler for Budd Cars
- Long Pantographs Stable at High Speeds
- Electroluminescent wire/surface
- Combined Intermodal Dispatching Systems
- Biological Breeding of Coach Designs
- Half Person Crew: Remote Operations
- Sensor Chair: For a More Comfortable Ride
- Application of Neural Technologies to Traction Control
- No More Gauge Corner Cracking – Track that Changes Colour
- Magnetically-guided High Speed Rail Systems

A brief review of the ideas are presented in this working paper, from the most immediately applicable to the most conceptual.

5.1 Optical Coupler for Budd Cars

Couplers are a maintenance headache, well known throughout the railroad and transit industries. The current technology is inadequate. AAR-derivative couplers require a manual connection of 27-pin MU jumper, brake pipe, and HEP line between two carriages by the conductor. Not only is this a potential hazard, it is also a time consuming process, with a known history of high failure rates. Various solutions have been developed to address this problem. On British Rail metals, as many as three different types of “intelligent” couplers are in use. With the advent of optical technology, it is conceivable that the electrical connexion between adjacent carriages may one day be replaced with a laser-based information transmittal link. The laser link would function in all weather (given a line-of-sight between the transmitter and the receiver), and would require minimal maintenance since there will be no moving parts and everything would be solid-state. If an information link cannot be made, the operator simply needs to clean the glass.

5.2 Long Pantographs Stable at High Speeds

Long pantograph have not generally been developed. This has meant that there are height restrictions for freight vehicles in electrified territory. The longest pantograph available are those on the Eurostar which has British dimensions but has to traverse under the wires in Europe which has a more generous loading gauge. The loading gauge in the Chunnel is also high but it will not support double stack operations. By developing pantographs and catenary supports which will support double-stack operations “under the wires”, greater economies of density can be reaped from an expensive piece of infrastructure by allowing double-stack and high-speed passenger trains to share the same track.

5.3 Electroluminescent wire/surface

Railroads used luminescent things for many reasons: signals, emergency lighting, permanent speed restriction warning signs, possession limits, etc. Over the past few years, traditional lamps with coloured lenses had been replaced with LED clusters. Electroluminescent Wire is a new technology which combines some of the properties of the existing lighting technologies. The basic design for the electroluminescent wire makes use of a transparent material (some kind of polymer) which is excited by the passage of A.C. current, and emits light of a specific color. It should be theoretically possible to build the device into a flat
panel. This can clearly be used as a substitute for a railroad signal whilst occupying less space than both the conventional bulb. It would also be possible to build active panels for speed restriction warning signs.

5.4 Combined Intermodal Dispatching Systems

The current state-of-practice in the trucking industry calls for dispatching decision-support models which use a combined demand model and optimization model to dispatch trucks for optimal utilization and also to assist in pricing. The concept has not been extended intermodally. Conceivably, if the railroad intermodal network is run in a scheduled departure fashion, the ‘slots’ available onboard an intermodal train could affect optimal utilization of truck trailers and tractors. Under a total logistics company framework, a model could be developed to assist the railroad carrier in winning a greater proportion of intermodal business if through its scheduled network, trucking companies are able to decrease their operating costs through more efficient use of drivers and tractors.

5.5 Biological Breeding of Coach Designs

There are many different coaching stock designs throughout the world, each with its own strengths and weaknesses. Each had been designed to different engineering standards. The efforts to standardize had been slow and the lessons learned by a particular group of design engineers are not necessarily applied to the designed produced for a different railroad by a different group of engineers. Genetic algorithms are already able to “cross-breed” different diesel engine designs to produce a more efficient diesel with characteristics such as lesser emissions and design features such as shape of cylinders etc “inherited” from its “parents”. Through an iterative process of introducing random perturbations and then selecting the most successful engines, development is cut down drastically. This process may be applied to the coaching stock design process.

5.6 Half Person Crew: Remote Operations

In general, in low density freight operations on single-track railroad, the train spends much of its time sitting in sidings waiting for passing maneuvers. This is not an effective use of traincrew time. With better and cheaper video transmission technologies, it is conceivable that a train could be operated with a remote crew, especially in rural areas this could lead to considerable savings. The view of the right-of-way and the instrument panel readings could all be transmitted back to an office using a wireless link. While the train is waiting for the signal, the train could be immobilized and the engineer could take over the control of a different train, effectively allowing less-than-one-man crews on average on a given set of trains. There are also economies associated with eliminating field operations – traincrew logistics would be simplified, with a central sign-on and sign-off location. Working environment for the traincrew could also be improved.

5.7 Sensor Chair: For a More Comfortable Ride

Train seats are uncomfortable. Current seats aren’t specifically designed for comfort. Aside from ergonomic designs adapted from office furniture, sensors also could be fitted to seats, along with active support fibres woven into the seat that will change stiffness and other physical properties with an electrical signal. The chair thus “adapts” to each rider depends on her posture and gives a more comfortable ride.

5.8 Application of Neural Technologies to Traction Control

This is a century-old problem which forms the core of the train engineer’s skill: the ability to start a train against a steep grade in the rain. This is the reason why engineers have to ‘learn a traction’, and a very important part of ‘learning a route’. More commonly this is done in a brotherly fashion; experience is
passed on from generation to generation, whether correct or not. Not running the train at the maximum coefficient of friction permitted by the rail conditions will lead to unnecessary loss of time and deviation from schedule; attempting to run the train at above the maximum coefficient of friction will result in signal overruns and mechanical damage when the wheel spins.

EMD has developed very sophisticated wheelspin control systems, giving the engineer much control even in the worst of rail conditions. Nonetheless in bad rail conditions it is still possible to spin the wheel. Defensive driving isn’t really a satisfactory solution. The performance of the rail system could be enhanced if the engineer didn’t have to worry about braking when the machine could operate at its maximum performance. Neural networks are already used in many areas to create illusion of artificial intelligence. Basically, neural networks are used to detect subtle correspondences between a set of inputs and a set of outputs which are perhaps to complex to be derived analytically. Neural networks also appears to give machines a way of ‘learning’ a skill.

5.9 No More Gauge Corner Cracking – Track that Changes Colour

Tracks are a high maintenance item, because when they break the consequences are disastrous. The inspection costs are too high. Current focus in technology is in developing technologies which will detect a rail break more efficiently and earlier, so that preventative maintenance can be carried out. However the current technology still depend on an active polling process – “the search for broken rail”, instead of a passive listening process, whereby the rail tells you if it is about to break. Development of either self-strengthening or “smart” materials may lead to a breakthrough in safety in this area. For example, a new type of track material or additive which turns hot pink when subjected to stress beyond design levels or when cracks are expected to appear could dramatically cut down the cost of inspections whilst improving safety. Although ultrasonic testing technologies are already available, this remains nevertheless a passive mode of track defect monitoring.

5.10 Magnetically-guided High Speed Rail Systems

High Speed Rail requires sweeping curves to minimize lateral acceleration while traversing a curve. However, sweeping curves are amongst the most expensive components of high speed rail systems. A breakthrough in level of passenger comfort whilst traversing restrictive curves was pioneered by Amtrak in the 1960s with the lightweight aerotrain. However, vehicle stability and rail wear issues had not been adquately addressed. Magnetic levitation (Maglev) technology for ground passenger transportation applications is already mature, although cost has precluded its deployment or planning except in Germany and China. The proposed solution combines Maglev technology with conventional rail. The magnetically-guided conventional train will only use superconducting magnet for one purpose: forming a guideway. On straight or slightly curved sections of right-of-way, conventional wheel flange guidance will be used. On severely curved right of way and a small transistion section on either end, electromagnets will be installed on one or both sides of the track.