PERFORMANCE-BASED TECHNOLOGY SCANNING: 
Overview and Application to Containerizable Freight Traffic

By

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Performance-Based Technology Scanning
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Abstract:

New technologies offer ways for transportation companies to reduce costs, increase capacity, improve service, and enhance safety. Determining the best opportunities requires understanding of the marketplace and a way to translate technological improvements into competitive advantage for a particular mode or company. Performance-based technology scanning is a methodology that can help a company or an industry formulate a broader yet better focused R&D program and improve its investment strategies, as well as identify new technological opportunities. Applying this methodology to containerizable freight helped identify promising innovations in equipment, track, and systems management. This application also highlighted gaps in the US rail industry’s research program, which is focused on heavy haul freight and safety with little attention devoted to other technologies that could improve service, asset utilization, or capacity. Three recommendations aim at closing this gap. First, the railroads should devote some R&D to reducing the costs of light density line operations. Second, the industry should seek international standards for modularized containers that would allow more efficient utilization of train space, more secure and more direct shipments to customers, and rail penetration into new intermodal markets. Third, railroads, rail customers, suppliers and government agencies should join in a cooperative research program aimed at improving the rail industry’s ability to handle intermodal freight.
1. Overview

The goal of technology scanning is to identify and evaluate new and emerging technologies that are potentially important to an industry, its competitors and its customers. Effective technology scanning can help an industry identify new technological approaches, formulate a broader yet better focused R&D program, and improve its investment strategies. A superficial technology scanning program will readily identify exciting technologies, but it can be distracted and diverted into finding high-tech solutions for minor problems rather than seeking technological assistance in dealing with fundamental problems. A balanced technology scanning program should consider how technology can help meet customer needs and overcome fundamental operating constraints.

This paper presents a new methodology for technology scanning and applies it in the context of the competitive market for inter-city movements of general merchandise (containerizable) freight. The paper begins with a description of the method, then reviews how various elements of this approach have been used in prior studies. The analysis of general merchandise traffic indicates what kinds of performance improvements will help railroads improve their market share and what types of technologies are needed to achieve these performance improvements. The paper concludes with recommendations for technological initiatives for improving the rail industry’s role in moving general merchandise freight.

2. Performance-Based Technology Scanning

Exhibit 1 shows the range of possible technology scanning activities for the transportation industry. At the broadest level, there is a “General search for technologies”. This search is of necessity somewhat unstructured, as it is not initially clear what new and emerging technologies will be available or what relevance they will have for the industry. This search should involve people with varied backgrounds and different working contexts, so that the search is truly broad. The three intermediate activities provide ways to narrow the technology scan from the "general search for
technologies" to the "analysis of specific technologies". “Technology mapping” is the most general of these activities, since it predicts the effects of hypothetical technological changes in order to find the most important technological constraints on system performance. This activity, for example, might consider the relative advantages and disadvantages of revising schedules, increasing vehicle weights, or reducing headways as alternative approaches to increasing capacity.

### Exhibit 1
Technology Scanning Activities for the Transportation Industry

<table>
<thead>
<tr>
<th>General Search for Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct a very broad review of new and emerging technologies that might be beneficial to the industry</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>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)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation Systems Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop and maintain a set of models that can be used to evaluate technological improvements as they affect specific aspects of transport systems performance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Requirements Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>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</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis of Specific Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examine specific technologies identified as having potential for improving system performance</td>
</tr>
</tbody>
</table>

Technology mapping begins with a base case that illustrates performance of a representative portion of the system. Next, high-level models predict performance for particular types of services as a function of technological capabilities, using inputs that capture the desired or anticipated results of
deploying new technologies on cost, service, or safety. Separate sets of models can be developed to predict the performance of typical routes and services at sufficient detail to provide realistic performance data and to capture the major competitive issues for different market segments.

For technology mapping, models should be less complex than planning models commonly used by carriers. For example, an investigation of railroad line operations need not model trains with a train performance calculator; what is necessary is to relate train speeds (or costs or safety) to parameters that reflect the technologies that are employed, e.g. the speed limit through turnouts or net-to-tare ratios for freight cars. Similar models can be developed for modal comparisons.

"Transportation systems modeling" is a more detailed activity. The objective here is to estimate the effects of particular technological improvements on modal capabilities and performance. This is where the train performance calculator would be useful. In the case of heavy axle loads, engineering models would be needed to predict track or highway deterioration rates.

"Customer requirements analysis" is another detailed activity that can be carried out at various levels of detail. There are several basic questions. How will a particular group of customers respond to potential changes in price, service, safety or capacity? What constraints, if any, limit the amount of services that will be purchased by these customers? How important are improvements in equipment design as opposed to improvements in trip times and reliability?

Finally, at the most detailed level of technology scanning, there is a need for "Analysis of specific technologies" to demonstrate that a particular technology is indeed suited for the industry. Care is required in selecting technologies for this expensive stage of technology scanning.

The overall process is called “Performance-Based Technology Scanning (PBTS)”. It includes consideration of the basic technologies, but also investigates how technologies translate first into better technological performance and then into better system performance in terms of the competitive market environment. The best technologies will relieve constraints that limit competitiveness with other
modes of transportation. Using PBTS, it is not only possible to find new technologies, but also to identify gaps in an existing research program and to rearrange investment priorities in order to achieve more rapid implementation of the most effective technologies.

3. Literature Review

This paper is based upon research conducted for the international railway industry (Martland, 2001) and builds upon the author’s participation in various technology mapping exercises, including studies of Advanced Train Control Systems (ATCS), Heavy Axle Loads (HAL), and service reliability. The paper focuses on containerizable freight, a market segment where there is considerable competition as well as technological opportunity for the rail industry.

3.1 Technological Research in the Rail Industry

The US rail industry has concentrated its limited research efforts on basic railroad technologies, while the Federal Railroad Administration has limited its rail research primarily to safety issues. The industry’s cooperative research program is coordinated by the Association of American Railroads and carried out by its wholly owned subsidiary, Transportation Technology Center, Inc. The major railroads meet several times each year to establish research priorities and to approve a research budget. The $9.6 million research budget for 2001 was dominated by projects concerning traditional railroad technologies related to equipment and facilities (Kalay, 2001):

- Heavy Axle Load Implementation ($2.45 million)
- Vehicle/Track Systems ($1.86 million)
- Engineering (Track Structure & Bridges) ($1.85 million)
- Mechanical (Freight cars and locomotives) ($1.05 million)
- Technology Scanning ($0.76 million)
- Network Reliability
  - Terminals ($0)
  - Signals, Communications & Train Control ($0.45 million)
  - New Technology Implementation ($0.35 million)
• Technical Support & Program Management ($0.84 million)

Earlier versions of the budget included modest funding for research on terminal capacity and asset utilization, but these initiatives were not funded in 2001. Most of the budget for “Technology Scanning” activities was devoted to a series of small, uncoordinated projects undertaken by the AAR affiliated laboratories at the University of Illinois, Texas A&M, and MIT. The “Technology Scanning Committee” met with each of the Affiliated Labs, reviewed research proposals, and selected projects for funding. This engineering committee did not use a structured approach to find the best opportunities, but instead depended upon the universities to identify technological opportunities related to the AAR’s research objectives cited above.

The industry’s research program has not always focused on hardware, as there have been extensive research programs addressing safety, service reliability, asset utilization and other systems issues. These programs, a few of which are discussed below, provide many examples of technology mapping, transportation systems modeling, and even customer service analysis, i.e. the key elements of technology scanning identified in Exhibit 1.

The technologies embodied in Advanced Train Control Systems (including what are now referred to as Positive Train Separation and Positive Train Control) enable enforcement of safe headways and thereby reduce the probability of certain categories of accidents. The analysis conducted by the industry and the Federal Railroad Administration in 1994 concerning ATCS mapped specific technological changes onto safety improvements, investment requirements, and operating costs [Office of Safety, 1994]. Martland, Zhu, Lahrech and Sussman [2001] demonstrated how to translate changes in train control systems into changes in risk for specific line segments.

The HAL economic analysis mapped the effects of reducing the axle load constraint onto investment and operating costs [Hargrove et al., 1996; Martland, 2000; Kalay and Martland, 2001].
Very detailed studies based upon engineering models and field tests estimated increases in track and bridge costs. Other models estimated the potential for savings in operations and equipment costs.

ARES was a version of ATCS designed by Burlington Northern and Rockwell International during the 1980s. The extensive benefits analysis carried out by BN to determine whether or not to invest in ARES was summarized in a Harvard Business School case study [Hertenstein and Kaplan, 1991]. Unlike the ATCS study cited above, which focused on safety improvements, the ARES benefits analysis addressed business benefits including better meet/pass planning [M.E. Smith, 1990] and improved control over line and terminal operations [Martland and Smith, 1990]. The ARES benefits analysis showed how better train control could lead to significant improvements in train performance and network control, which would in turn lead to modest improvements in terminal performance, trip times and reliability, and ultimately to small changes in mode share for merchandise traffic. An excellent example of technology mapping, this study incorporated rail systems analysis, knowledge of technology, and awareness of customer requirements.

Although the methods used in these examples are similar to the three intermediate steps in Exhibit 1, they were used more in assessing known technologies rather than in the broader task of technology scanning. The ATCS and ARES studies were driven by a desire to use emerging communications and control technologies to improve train operations and safety. Justifying the use of particular technologies is much different from a search for technologies that might improve cost, service, or safety. The HAL studies were driven by a desire to avoid the disruption to track and operations caused by increases in axle loads in the 1970s. The goal of the research was to develop track components better able to withstand the punishment of heavier cars, not to discover how best to use technology to increase line capacity or to move coal.

3.2 Technology Scanning for the Transportation Industry
Technology scanning activities have been sponsored by government agencies seeking productivity improvements within various industry sectors and by suppliers anxious to find markets for their technologies (Schofield, 2000). Schofield found several transportation applications, each of which included a general search for technologies that was guided by knowledge of existing systems and customer requirements. None of them used the full performance-based technology scanning methodology outlined in Exhibit 1. The National Commission on Intermodal Transportation (NCIT) conducted hearings, then produced a report documenting potential technological developments that would affect intermodal transportation. As part of their final report, they included a list of technologies that were likely to affect intermodal transportation, both passenger and freight [A&L Associates, 1994]. Industry Canada applied "technology roadmapping" to freight transportation as part of a large technology scanning effort [Moore, 1996]. Industry Canada's initial technology scan addressed four areas of Information Technology that they felt were of critical importance to the transportation sector: wireless communication systems, location systems, vehicle performance systems, and information systems. They also examined two other areas, advanced manufacturing & materials and environmental technologies (e.g. fuels and batteries). This study was driven by technological concerns, rather than by transportation concerns.

The Port Authority of New York and New Jersey conducted an in-depth review of "significant emerging technologies and their impacts on the Port Authority" [Business Analysis Division, 1994]. Recognizing that "technological change directly affects both the economic vitality of the metropolitan region and the agency's own performance", the goal of the study was to "craft a thoughtful, systematic and effective approach that the Port Authority can employ to make critical decisions concerning investments involving emerging technologies." The study identified "significant emerging technologies" that were grouped into 5 categories based upon their potential impact on the port, barriers to implementation, and the time frame within which the technologies would become available:
Major new products likely to be introduced by the agency's customers or suppliers

Environmental and safety technologies

Information and telecommunications-based technologies

New products that could be introduced to improve competitiveness or customer service

Substitutions for agency core business

These five categories are appropriate for use in any technology scanning program. In particular, technology scanning should not be limited to technologies that improve the ways that carriers handle traffic, but should also include technologies that can help their competitors, their customers, and their customers’ competitors. The "substitutions for core business" is an especially important category. For railroads, a shift in energy usage away from coal could have a dramatic effect on capacity needs.

4. Performance-Based Technology Scanning Applied to General Merchandise Traffic

This section shows how performance-based technology scanning was applied to a specific market segment, namely general merchandise that is able to move by rail, truck or intermodal services. This market segment is of great interest not only to carriers, but also to public officials interested in reducing highway congestion and providing transportation capacity to support economic growth. This section shows how simple models were used to find out a) which service characteristics were most important to customers and b) how changes in technical constraints affect service characteristics. These are examples of the “technology mapping” and the “customer requirements analysis” elements of technology scanning. The section also includes some results from more detailed modeling of track costs as a function of line density.

4.1 Overview of Rail, Truck, and Intermodal Competition

The competition between rail and truck transportation is most intense for the movement of general merchandise over distances longer than 500 km. The competition for this freight is based upon transport prices, associated logistics costs (which are driven in part by transit times, transit time reliability, loss & damage and other service parameters), and economic geography. Three modes offer
different combinations of cost and service quality for general merchandise transportation. Boxcar transportation over an existing network can be very cheap, but also very slow. Truck transportation over an existing highway system is more expensive, but also faster and much more reliable. Intermodal transportation is generally somewhere in between, faster and more reliable than boxcars and cheaper than truck. Technological innovation for equipment, terminals, and control systems has been a major factor in the emergence of intermodal systems (Muller, 1995).

4.2 Overview of Cost Trade-offs for Boxcar, Intermodal, and Truck

This sub-section compares the costs of transporting general merchandise by each mode assuming that the network structure, technology, shipment sizes, and overall traffic volumes are sufficient to allow efficient operations. The purpose of this sub-section is to provide a base case for technology mapping. Spreadsheet models for boxcar, truck and intermodal services were used to predict modal performance as a function of customer, commodity, network, vehicle, and operating characteristics (Martland, 2001). These models included unit costs and performance indices related to:

- Terminals (capital, operating, and maintenance cost)
- Rights-of-way (capital and maintenance cost)
- Vehicles (ownership and maintenance)
- Operations (energy and crew)
- Administration

It was possible to represent technological innovation by changing relevant parameters in the models. A logistics cost model was then used to estimate mode choice. The intermodal model was initially developed to assess the effects of highway access on competition between truck and various types of intermodal operations (Frazier, et al., 1996). The rail and truck models were initially developed for classroom use at MIT and for providing case studies for workshops on freight transportation conducted for the AAR, the World Bank, and individual railroads. It is beyond the scope of this paper to go into detail concerning the models, as the nature and structure of freight costs is clear and well known, both
for individual modes (e.g. Norris and Haines, 1996) and for transportation systems in general (e.g. Kresge & Roberts, 1971; Mannheim, 1979; Sussman, 2000). However, it will be useful to review some of the key cost and service tradeoffs.

In general, train operations are very efficient because one crew can handle many cars and because energy costs are minimized by using the steel wheel on the steel rail. However, assembling trains is time-consuming and expensive. For truckload shipments, there is no equivalent fixed terminal cost, but line costs are higher than for rail. Hence, to justify shipping by rail or intermodal, the shipment distance must be long enough for the line-haul savings from using rail to justify the added terminal costs.

Truck costs provide a benchmark for rail costs. In North America, for the distances that we are considering, truckload transportation costs remained on the order of $1 per mile ($0.60/km) for long haul truckload operations from 1981 until the late 1990s (e.g. Corsi and Grimm, 1989; Roth, 1994; TTS, annual). This estimate assumes that general merchandise is carried in standard trailers or containers over good roads, with effective utilization of capacity and balanced loads (i.e. a very low proportion of empty miles). Costs can be slightly lower for the most efficient truckload carriers, who can achieve some economies in purchasing vehicles, fuel, and insurance, which is sufficient to allow the development of large truckload operators in an industry that many economists thought had no economies of scale (Corsi & Grimm, 1989). Larger trucks and long-combination vehicles allow further reductions in truck cost and present a formidable competition to intermodal services (Nix & Boucher, 1989).

In regions with good transportation infrastructure, the question is whether intermodal or boxcar operations will be cheaper than the truck costs of about $1/mi. Let’s start with intermodal, where the cost savings are real, but small, and the shipment size and service levels are similar to those for truck (Norris and Haines, 1996; D.E. Smith, 1990). If trailers or containers are loaded onto flatcars, the
linehaul transportation cost is about 15% less than for truckload operations, for a savings of perhaps $0.15/mile ($0.10/km). To load or unload a trailer costs on the order of $50 each or $100 for the trip. The intermodal trip also requires a dray at each end, which could easily add an additional $200 to the total cost. With savings of only $0.15 per mile, it would take 2000 miles (3200 km) to cover the additional $300 for combined terminal and drayage. It is therefore difficult to justify TOFC or COFC except for very dense corridors, long trips, or trips with very efficient terminals and drayage.

The development of double stack container trains changed the economics of intermodal transportation considerably. By fitting nearly twice as many containers on a train, it is possible to take advantage of the carrying capacity of the locomotives and achieve more effective utilization of the crew and the rail cars. Because double stack rail cars are shorter and lighter, these cars are also cheaper per unit carrying capacity than the traditional, heavy flatcars previously used in intermodal service. With lower operating costs and cheaper equipment, the double stack train is able to transport containers at a cost of well under $0.50 per mile ($0.30/km) (Smith, 1990), which sharply increases the line-haul savings and lowers the competitive boundary between rail and truck. With linehaul savings of about $0.50 per mile per container, it would only take 600 miles (960 km) to offset added terminal and drayage costs that totaled $300. The much shorter break-even distance is a major reason for the success of double stack container trains.

Evaluating the boxcar requires a more complex assessment, as differences in logistics costs will be very important in mode choice. Larger shipment size, slower trips, and less reliable deliveries all tend to increase inventories and the risk of stockouts. Therefore, even very substantial cost savings may be insufficient to keep the traffic in the boxcar. Efforts to improve service seek to reduce the number of intermediate yards, create efficient pickup and delivery operations, and achieve good backhaul utilization and low cycle times for the equipment. Boxcar will be most costly and have the poorest service when the trip requires handling at many yards, when pickup and delivery take place on
long, light-density lines, when the back-haul opportunities are small, and when cycle times are long. Service considerations and logistics costs will decline relative to transport costs when the commodity is lower-valued or when annual shipment volumes increase.

Efforts to improve boxcar service have had little success, despite major advances in technology for track, locomotives, freight cars, communications, and signals over the last 30 years. A major study of freight service in the early 1990s concluded that service and equipment utilization were essentially unchanged since the early 1970s (Kwon et al., 1995). Service problems in the United States in the late 1990s were worse than in any prior period during peacetime, prompting articles not only in the transportation and business press, but also in the general press (e.g. Whitaker, 1999). Extensive capital investments helped the industry return to typical levels – not gridlocked, but not very fast or reliable either. Apparently management and control issues swamp whatever benefits improvements in traditional rail technology might have for service reliability.

In most other countries, railroads have long since lost most of their single-car traffic and now concentrate on unit train operations for coal, grain and other bulk commodities. Even in North America, where railroads still have substantial amounts of so-called “loose car” service, the future of the boxcar is uncertain (McClellan, 2001). Some feel that the future depends upon the development of a reservation system for “loose car traffic” that would provide more reliable service and offer some hope for more efficient operations (McCarren, 2000). A basic question, therefore, is whether there is any future role at all for the boxcar in moving general merchandise traffic. If so, what is it and what technologies can be most useful? If not, then rail investment and technological research for general merchandise traffic might as well focus on intermodal transportation.

4.3 Modal Cost and Service Comparisons

We established a base case for technology mapping using costs and service levels representative of efficient North American operations. We used then conducted sensitivity analyses to
identify the types of changes in performance and technology that would be most helpful to railroads in competing for general merchandise freight. Details concerning the models and the analysis are presented in the research report that served as the basis for this paper (Martland, 2001). Major results of the research are taken from the report and summarized below. Exhibit 2 shows typical costs for hypothetical trips for distances ranging from 650 km (400 miles) where truck is likely to be dominant to 2000 km (1250 miles) where rail is likely to be dominant. These results illustrate several key trends:

1. Costs/tonne-km are lowest for boxcar service.
2. Costs for rail or intermodal decline for longer distances, whereas costs for truckload operations are nearly constant.
3. Costs for truck are competitive with intermodal costs even for 2000-km hauls.
4. Costs for double-stack operations are much lower than traditional intermodal operations.

These costs should be interpreted carefully, as they are merely representative costs for each mode. Even for a system with the same unit costs for crews, fuel, and other resources, the actual costs for particular situations would depend upon the terminal and linehaul operations, as well as the utilization of the route and the equipment. Moreover, Exhibit 2 is intended to illustrate the general trends in costs for a set of hypothetical movements, not system averages for any particular rail system.

**Exhibit 2 Typical Costs for Boxcar, Intermodal, and Trucking in North America**

(1 metric tonne-km equals approximately 2/3 ton-miles)

<table>
<thead>
<tr>
<th>Mode</th>
<th>650 km</th>
<th>1300 km</th>
<th>2000 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail boxcar</td>
<td>$0.023/tonne-km</td>
<td>$0.016/tonne-km</td>
<td>$0.013/tonne-km</td>
</tr>
<tr>
<td>Intermodal (TOFC)</td>
<td>$0.045/tonne-km</td>
<td>$0.035/tonne-km</td>
<td>$0.031/tonne-km</td>
</tr>
<tr>
<td>Double Stack</td>
<td>$0.036/tonne-km</td>
<td>$0.025/tonne-km</td>
<td>$0.021/tonne-km</td>
</tr>
<tr>
<td>Truck</td>
<td>$0.034/tonne-km</td>
<td>$0.031/tonne-km</td>
<td>$0.029/tonne-km</td>
</tr>
</tbody>
</table>

For service, the key factor is yard & terminal operations. The number of times that a car is handled, the average time required per handling, and the reliability of train connections all affect trip times and reliability. The more yards or the longer and less reliable the yard processing, the longer and less reliable the trip. Unfortunately, competitive pressure from trucks has generally forced railroads to
try to cut costs by increasing train length, which leads to lower train frequency, longer yard times, and less reliable train connections (Kwon et al., 1995).

These are of course not new observations, but they still provide a solid base for performance-based technology scanning. Since our goal is to find technologies that improve competitiveness, our next step is to determine how changes in service attributes would affect rail performance and mode share for typical markets. Part of what we are attempting in performance-based technology scanning is to ground the search for new technologies within a commonsense framework that recognizes the general characteristics of the operating and marketing environments (as opposed to simply searching for applications for robotics or wireless communications or neural networks simply because these are “hot” technologies.)

4.4 Sensitivity of Mode Choice to Service and Technology

For any potential shipment, the mode share for each mode depends upon the relative total costs, including logistics cost. We used basic models to estimate inventory, safety stock, loading & unloading, and loss & damage costs as functions of customer and commodity characteristics. The transportation cost per tonne, the logistics cost per tonne, and the total cost per tonne were calculated for various combinations of distance, annual use rate, and commodity value. If the total costs of rail and truck are similar, they can be expected to share the traffic equally; if one mode has substantially lower costs, it will be expected to carry the dominant share of the traffic. Rail systems will have higher mode shares where shipment distances are longer, production is more concentrated, and commodity values are lower. The base case was a representative group of 24 general merchandise customers:

- Trip distances: 650, 1300, and 2000 km
- Value/kg: $1.80/kg, $0.90/kg, and $0.45/kg
- Annual use rate: 450 to 1800 tonnes/year
We assumed that the cost estimates produced by the various models represented average costs for each set of trip, customer, and mode characteristics. We further assumed that actual costs would be normally distributed around our estimates with a coefficient of variation of 0.5 (standard deviation equal to half the expected value). We then estimated the market share for each mode as the probability that that mode had the lowest total cost. The predicted mode split for the base case was 72% truck, 22% rail and 6% intermodal. We then looked at various ways for improving performance:

- Bigger cars
- 20% cheaper service
- Slower and cheaper service
- Slower & more reliable service (i.e. car scheduling with a buffer included to ensure more reliable trip times)
- More reliable service (i.e. better car scheduling with no need for a buffer)
- Use of double stack intermodal services
- Reducing trip times by 50%
- Reducing trip times by 50% and reducing costs by 20%

Exhibit 3 shows the results in terms of mode share for rail (boxcar) and intermodal. The results show a wide range of responses. The best option is “Faster & Cheaper”, in which the boxcar captures two thirds of the market - but it may be unreasonable to expect that boxcar service can be both 20% cheaper and twice as fast! Instead, it might be possible to provide faster or cheaper service. Faster turns out to be better than cheaper for this hypothetical group of shipments: “Faster” results in a 55% share for boxcar, while “Cheaper” results in only a 36% share. Reliable service is as good as cheaper service, with a 39% market share. Historically, however, rail service generally became slower and less reliable as railroads cut costs and lost traffic to trucks. In practice, as in this exercise, “Slower, Cheaper” service loses market share. If reasonable truck service is available, cutting costs at the expense of service is not a good idea for railroads.
Another approach is to change the equipment rather than the service. Bigger cars offer some help, gaining a 32% share for boxcars. The potential of larger cars is offset for general merchandise because larger cars lead to higher inventory costs; compared to trucks, boxcars are already too large for many commodities. “Double Stack” works better, as this option increases the payload of an intermodal train without increasing the size of the shipment. “Double Stack” increases the market share for intermodal from 6% to 27%, attracting traffic both from boxcars (whose share declines from 22 to 16%) and from trucks (whose share declines from 72% to 53%). This dramatic change is consistent with the actual effect of double stack service in major corridors in the United States.

The results of the sensitivity analysis showed that there is still a role for each of the three modes. Boxcar is favored for long-distance shipments of lower value commodities for customers with high annual use rates. Truck is favored for shorter-distance shipments of higher value commodities for customers with lower use rates. Intermodal is favored for longer-distance shipments for higher valued commodities or lower annual use rates. The analysis also indicated that cheaper or better service could
move the break-even point for any of the modes. For boxcars, mode share could be increased by technologies that help improve:

- Branch line operations (track costs, locomotive requirements, and train costs)
- Terminal operations (number of terminals, average time, connection reliability, and cost)
- Line haul performance (train length and line density)
- Equipment utilization (back-haul ratio, capacity utilization, and cycle time)
- System control (planning & control systems, forecasting, and capacity management)

Note that these are different from the factors that are most important for bulk operations, where traditional rail concerns with track and equipment dominate. For general merchandise traffic, terminals, service, and branch lines are much more critical than they are for bulk traffic. Improving terminals and service requires a broad systems approach and technologies that enable more effective control. The branch line problem is primarily a question of infrastructure costs, as train costs can be controlled to some extent by reducing the frequency of service and using cheaper or smaller locomotives. Track costs are a serious problem on branch lines, as routine track maintenance must continue whether or not there is any traffic at all. To document this point, we examined track cost further, as discussed in the next section.

4.5 Track Costs: An Example of Transportation Systems Modeling

More detailed models were used to explore the differences in track costs between general merchandise and bulk unit train operations. Using models that were originally developed as part of research sponsored by the Association of American Railroads, we estimated the steady-state, life-cycle track costs for freight lines carrying 2 million gross tons per year (3 million gross tonnes/year) and 50 MGT (75 million gross tonnes/year). These two cases represent boxcars operating on a general merchandise branch line and coal cars operating on a medium density coal line. In each case, we considered “good” and “poor” track components, where the “good” components are what is typically used today on North American main lines and the “poor” components are what was typically used 30-50 years ago (Chapman and Martland, 1998). The differences in track costs were striking. For the
branch line, spot replacement of ties and spot surfacing accounted for 80% of track costs. For the coal line, the major concerns were rail & turnouts and renewal programs for ties and ballast. Furthermore, on high-density lines, it is financially feasible to install the best track components; on low-density lines, it is often difficult to maintain, let alone to rehabilitate the track. Hence, the branch lines generally continue with older components and higher maintenance costs. The total costs for track maintenance and renewal were estimated to be less than $2/1000 net ton-miles ($1.30/1000 net tonne-km) on the coal line, whereas the costs for tie replacements alone were estimated to exceed $10/1000 net ton-miles ($6.60/1000 net tonne-km) on the light density line.

As axle loads increase, the quality of the rail becomes more important. Hence considerable research has been devoted to developing harder, cleaner rail steel and more durable turnouts for heavy haul operations. This research has paid off handsomely for the heavy haul railroads, as the axle load limits have been increased to 33-tonnes (36-tons, i.e. the 286,000 pound car) or even higher. Heavier axle loads have allowed heavier trains and substantial benefits in terms of line capacity, equipment utilization, and crew costs. These benefits do not carry through to branch line operations, where the cost of new rail is unimportant (since the existing rail can last for many years) and the disruption caused by heavy axle loads, especially on bridges, can be major.

4.6 Implications for New Technology

The results of these analyses suggest areas where new technologies might be useful for general merchandise freight. Better mainline track and larger cars – the main options for improving bulk rail operations - offer little help for general merchandise traffic. Technologies that would be helpful are those that would reduce branch line and terminal costs and improve car utilization: cheaper cars, but not bigger cars; cheaper more durable ties; automated switching and more efficient terminals; better control and communications; better ways of moving the freight (e.g. double stack trains or even more efficient intermodal systems).
General merchandise service is clearly a systems problem that requires systems solutions. Further, it is clear that different types of technologies will be useful depending upon the prevailing levels of service. For the best operations, 400-800 km trips will require 2-3 days and offer 95% reliability (i.e. 95% within 3 days). This is not bad, although it is twice as long and less reliable than good truck service. Sophisticated control, more reliable track and equipment, and closer cooperation with customers could help boost reliability close to 100%. More typically, the service will require 6-8 days and achieve only 85% reliability. As long as this service is cheap, it may attract some business, but it will not attract much. To upgrade this level of service to the 95% level, better planning and more efficient terminals are the key. At its worst, rail service is totally unpredictable, taking 10-25 days with no more than 20% of shipments delivered on time. These levels are totally unacceptable, and they represent a failure of management in matching supply & demand. Sophisticated control is not the answer to service that is this far out of control. Better planning and forecasting techniques, reservation systems, yield management systems, and capacity management systems could help avoid prolonged service problems in the future, while reducing the need for costly investments in infrastructure.

The greatest potential for improvement for general merchandise service thus comes from information technology, with different types of applications relevant to different levels of performance. Fortunately for the rail industry, this is an area where technology has made and continues to make great strides, so that it is possible that ways can be found to offer more reliable service at lower cost or at least without increasing costs. Such technology will help intermodal as well as boxcar service.

For boxcar service, minimizing branch line costs is also critical. Cheap, low maintenance track components for light density lines would be helpful. Automated operations might be useful in situations where crew costs are high enough to prevent frequent train service. Innovations in equipment should seek better design in order to reduce tare weight, reduce the cost per unit capacity, allow easier loading/unloading, and reduce maintenance costs.
For intermodal service, the success of the double stack concept shows that railroads can gain market share through equipment innovation. However, the double stack is not the ultimate in intermodal equipment. It not only requires high clearances and expensive lift equipment, it wastes approximately 20% of the available clearance by using containers limited by highway widths and another 10-20% through the various gaps that result when non-standardized containers are loaded onto the train. Different systems could be developed that take greater advantage of the available rail clearances, thereby substantially improving capacity utilization and operating performance relative to existing systems. Technologies like the RoadRailer and the Iron Highway (now operated by Canadian Pacific under the name “Expressway”) provide many of the benefits of double stack without requiring costly terminal operations (D.E. Smith, 1990). Other possibilities include:

- Wider, higher containers that maximize the use of rail clearances and that can only be used on a limited number of access roads (allow greater productivity for intermodal operations without having to raise rail clearances or increase size/weight constraints on all roads)
- Modular container systems (allow better use of train capacity, reduce wind resistance, offer a wider mix of container sizes, allow automated loading & unloading)
- Shuttle systems for major cities and environmentally sensitive areas (allow high utilization of ports and urban terminals; reduce truck travel in congested cities; reduce emissions from trucks)
- High volume intermodal terminals (use automation, stacking, coordination, and control to achieve better utilization of terminal resources, to provide quicker loading and unloading of trains, and to allow lower detention times for draymen)

Safety and environmental factors may also justify the use of innovative equipment. In specialized situations, governments and railroads have made large investments in order to keep trucks off the highways in environmentally sensitive areas. A notable example is the use of intermodal service in tunnels that help reduce truck traffic over the Alps. Railroads also have the potential for electrification, which, although expensive, does not depend upon oil.

**Conclusions and Recommendations:**
Technology scanning programs such as those conducted by the Association of American Railroads traditionally are driven by technological rather than performance concerns. The participants in the research are more interested in finding potential applications for new and emerging technologies than in using technology to address fundamental rail systems problems. These programs are a minor adjunct to, not a defining element for the industry’s research program. Rail industry research, whether conducted by the railroads themselves or by suppliers, is very heavily concentrated on the basic technologies that affect current operations, especially those that reduce the costs of heavy haul railroading. Neither the suppliers nor the researchers have much concern with systems performance.

Performance-based technology scanning represents a different philosophy. It begins not with the “hot” technologies, but with customer requirements and constraints to operating performance. Technology-based scanning can only identify new technologies; performance-based technology scanning can also help prioritize R&D and focus investment strategies. To do so, it is essential to consider how changes in service might affect existing and potential customers. And it is important to do this as part of the technology scanning process, not as an afterthought.

Application of performance-based technology scanning to general merchandise freight highlighted serious gaps in current rail research programs. While technological development has helped improve safety and increase heavy haul efficiency, little has been done to improve the performance of general merchandise freight. There is clearly a mismatch between the technologies that the rail industry examines in its R&D efforts and the technologies that are most likely to help railroads carry more general merchandise freight and provide some relief to highway congestion.

If technologies are to have any dramatic benefit in helping railroads compete more effectively with trucks, then research and development must address technologies that have some hope of improving service in a way that makes a difference. This is not the case today in the United States. In fact, the railroad industry has cut back on its cooperative research by 75% since deregulation, with
little or nothing directly relevant to the issues identified in this paper (TTCI, 2001). Positive train control, heavy axle loads, and improved track components are all desirable and well-funded technological initiatives – but they will have almost no effect on general merchandise service. Much more helpful would be initiatives in the area of capacity, asset utilization, and intermodal terminals.

This performance-based technology scan therefore supports recommendations for three specific technological initiatives that would help railroads capture more general merchandise freight traffic.

- First, the rail industry should initiate research aimed at reducing the costs of operating light density lines, addressing both track and equipment.
- Second, the industry should seek to establish international standards for modular containers that would reduce the minimum shipment size required to use rail, improve security of intermodal shipments, increase capacity utilization of trains, and enable more direct service to customers. To handle such containers, new technology will be needed for terminals, and new equipment designs will be needed for both railcars and trucks. Effective control systems will be needed to match supply and demand for containers, to maximize utilization of train capacity, and to provide efficient, reliable drayage services.
- Third, the industry, its customers, major rail suppliers, and government agencies should jointly undertake a serious cooperative research & development program that is aimed at improving the ability of railroads to move general merchandise freight. Such a program would undoubtedly include major technological initiatives concerning control, intermodal equipment design, and customer relations, as well as some consideration of traditional rail technologies.

These three programs would fill the obvious gap in the U.S. rail industry’s research program and allow the industry to play a greater role in addressing such things as urban congestion, highway capacity, energy consumption, and sustainable freight mobility.
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