Draft

AN EXAMINATION OF THE COSTS AND BUSINESS BENEFITS OF POSITIVE TRAIN CONTROL

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Executive Summary

The purpose of this study is to provide a preliminary estimate of the business benefits of Positive Train Control (PTC) - a system designed to prevent train collisions and provide a variety of business functions for railroads. An estimate of business benefits is one component of a comprehensive benefit-cost analysis accompanying a rulemaking to determine whether regulations are required for safety reasons to equip all or part of US railroads with PTC.

The estimates in this study will be later refined after comment from the PTC Working Group of the Railroad Safety Advisory Committee, combined with estimates of safety and environmental benefits from other studies, and incorporated in a comprehensive benefit-cost analysis as the rulemaking proceeds.

Five railroad corridors, representing a range of conditions were selected for study of the business benefits that would accrue if PTC were applied in each corridor. Benefits were quantified in the following areas:

- reduced yard and transit time from improved work order reporting
- reduced maintenance hours and en-route failures from locomotive diagnostics
- fuel savings
- reduced cost from improved equipment utilization
- higher revenue from improved customer service

Benefits due to improved equipment utilization and customer service accounted for approximately 45% of estimated benefits; benefits from fuel savings and locomotive diagnostics, another 47%; and the remaining 7% was due to work order reporting.

Benefits quantified in this study were enough to cover 40% to 90% of total capital and operating costs of PTC, depending on the corridor and on the assumption regarding the number of locomotives that must be equipped. It is likely that cost coverage would be considerably higher if longer corridors conforming more closely to major transportation markets were chosen for analysis and if other business benefits not quantified in this study were able to be quantified. This is true not only because of the additional benefits, but also because, as more PTC-equipped route miles are added, fewer additional locomotives need to be equipped per added mile.

Preface

In July, 1994, the Federal Railroad Administration (FRA) published a report entitled, *Railroad Communications and Train Control,* as required by the Rail Safety and Review Act, Public Law 102-365. In that report, the following statements were made regarding the business benefits of Positive Train Control (PTC):

> As reflected in this report, ATCS [advanced train control systems, an earlier name for PTC] offers significant potential business benefits to railroads with pertinent needs not otherwise addressed through alternative technology. These include fuel savings, better utilization of track and equipment (such as work order reporting, locomotive health monitoring, and traffic control), reduced wear on track and equipment, on-board hot bearing detection, car/trip scheduling, more precise scheduling of employee deployment, reduced job stress for dispatchers, and better service for customers (such as more reliable schedules and decreased transit time). All of these potential benefits offer possibilities for additional cost savings and managerial efficiency through increased network intelligence and enhanced information flows. p. 61
>
> In the long term, the development of an integrated and interoperable communications network such as ATCS, which will produce safety benefits, is likely. Commercial needs are growing; high quality service is essential to market growth in many sectors, as shippers increasing demand precision with respect to both pick up and delivery schedules. The rapid increase in intermodal service using containers, trailers, and other intermodal options places a premium on higher average train speeds, which requires better use of plant capacity and increasingly competent signal systems (as reflected by continuing investments in new traffic control systems on high density routes). As service requirements become more demanding on railroad plant, equipment, and personnel, the business benefits of flexible, interoperable, communication based PTC should become more evident and more readily quantifiable. p. 62
>
> Previous rail industry technological advances produced benefits that were also difficult to estimate; the benefits of dieselization far exceeded predictions. FRA believes that the benefits of a central communications system -- or flexible networks capable of functioning as a single system -- can be expected to exceed the modest expectations of those advocating individual subsystems. Investments in safety and efficiency can produce synergies that result in unexpectedly high returns. p. 63
>
> As indicated previously, the application of PTC to all rail lines has not been shown to be cost beneficial at present based on safety alone. Business advantages to the railroad industry from such universal implementation can be expected, but

> the specific extent and nature of such advantages will differ greatly, depending on the particular circumstances. p. 63
>
> Railroads recognize the need to move in the direction of positive train control, but, with limited exceptions, have not considered the necessary investments justified. For the near future at least, safety benefits will have to be accompanied by "business" benefits for PTC investments to make business sense for widespread application to freight lines. p. 76
>
> A central communication-based approach to PTC remains the most likely path to safer train operations. In addition, that approach has the greatest chance of returning business benefits that can help pay for a portion of the communication infrastructure needed to support safety applications. Although the application of PTC on all rail lines would not be cost beneficial at the present time based on accident avoidance, PTC is required for high speed rail service and may be warranted on heavily traveled freight lines as well. Implementation of PTC that is interoperable will facilitate more widespread realization of safety and other benefits. p. 76
>
> On some major freight corridors, downsized rail plants are now straining to handle increasing volumes of intermodal freight movements, as trucking companies and international brokers recognize the value of rail as part of the intermodal team. If freight capacity becomes a limiting factor, the ability of the railroad industry to relieve pressure on congested highways and to serve the Nation's environmental goals may be compromised. p. 77
>
> FRA will take the following actions: Determine the cost/benefit ratio for application of PTC to priority corridors. p. 78

On March 26, 1996, FRA Administrator Jolene Molitoris testified before a joint hearing of the House Committee on Transportation and Infrastructure, Subcommittee on Railroads, and the House Committee on Science, Subcommittee on Technology. In her testimony, Administrator Molitoris made the following comments regarding business benefits of Positive Train Control:

> In keeping with that commitment [to initiate a rulemaking on PTC in FY1997], FRA is preparing for a comprehensive review of PTC deployment in 1997. .... Specifically, FRA will: .... Update benefit-cost analysis: The cost of computers, communication equipment, and other PTC components has declined significantly in just the past two years, while freight and intermodal traffic has grown, causing congestion on some lines. FRA will take a new look at the benefits of PTC along with potentially lower or revised implementation costs. pp. 14, 15
>
> Within the Department of Transportation, every Modal Administration has projects underway to examine how new information technologies can be used to

> increase the safety, efficiency, and capacity of our Nation's transportation system. The Intelligent Transportation Systems program represents a multimodal approach aimed at improving the throughput and safety of highways and transit systems. p. 17

This study, *An Examination of the Costs and Business Benefits of Positive Train Control,* represents FRA's fulfillment of the commitments it made in 1994 and again in 1996 to reexamine and quantify both the costs and business benefits of PTC in preparation for a rulemaking on PTC. Still in preliminary form, this study is being distributed to form the basis of a discussion of the issues before the Railroad Safety Advisory Committee (RSAC).

FRA recognizes that PTC refers to a loosely defined group of train control system architectures, all of which have to ability to reduce the probability of collisions between trains, of collisions between trains and maintenance forces, and of overspeed accidents. However, FRA also recognizes that not all of those architectures have the ability to provide some or all of the business benefits examined herein. Consequently, for the purpose of this study PTC was defined as having a central communication-based approach and all the costs and business benefits were calculated accordingly.

When FRA's 1994 report was in preparation, the freight railroads' message was that business benefits cannot be estimated at the national industry level. They contended that different railroads will realize different levels of benefits (and costs) from PTC. They felt that a finding that railroads will benefit by a certain amount "on average" would mean very little to the individual companies because railroads differ significantly in their operating structure, facilities, business requirements, markets, and profitability.

In response to those concerns, this study examines the costs and benefits of PTC on five railroad corridors scattered around the United States. The relatively short corridors were selected so that they would be similar to the length of the corridors being examined in the Corridor Risk Assessment at the Volpe Center. Some railroads have said that they might install PTC only on shorter corridors, while others have stated they might install it only on longer corridors. It is recognized by FRA, however, that certain business benefits would accrue only if longer corridors were equipped with PTC.

At an early meeting of RSAC, the railroad industry had also expressed the view that improved scheduling of train crews could not be viewed as a benefit of PTC since crew scheduling is a matter of labor negotiations. Even though FRA believes that crew scheduling is a benefit that would accrue from PTC, that benefit was not calculated for the five subject corridors.

The study team concluded that, for the corridors selected and with the limitations of data availability, PTC business benefits could be calculated for the following five areas: real-time work order reporting, real-time locomotive diagnostics, improved equipment utilization, fuel savings, and improved customer service. Because of these and the aforementioned decisions in the structuring of the analysis, FRA believes that the benefits that have been calculated are conservative and do not overstate the business benefits of PTC.

The team working on the study had originally selected a group of corridors for which they felt that data might be readily available and which they felt would be representative of a variety of types of railroad operations on the major freight railroads. There was no scientific criteria used in the selection of the corridors, nor was there intent that the corridors be viewed as "average" or "normal" or covering the full range of operating characteristics. As it turned out, two of the major railroads declined to submit data for the study, and another railroad found that it was unable to provide data on a proposed corridor and therefore suggested that it provide data on yet another corridor. It was pragmatic choices then, both on the part of the study team and on the part of the responding railroads, which led to the selection of the particular corridors.

In the 1994 report, FRA presented PTC cost numbers provided by the Association of American Railroads (AAR). Their high-end estimates for installing communication based PTC on the Class I railroads in the US and Canada range from $1.137 billion to $1.490 billion. At the time of the 1996 hearing, FRA believed that, with the reduction in costs of electronics equipment that has occurred in the intervening years, the cost of PTC would be less than the 1994 estimate.

This study, *An Examination of the Costs and Business Benefits of Positive Train Control,* incorporates new PTC cost estimates that are higher than those provided by the AAR for the 1994 report. An extrapolation of these costs to the same railroads covered in the 1994 cost estimate would be on the order of $2.5 to $3 billion.

Consequently, FRA believes that, with the higher cost estimate and the conservative estimation of benefits, this study has generated benefit-cost ratios that are not overstated. FRA recognizes that various groups may take issue with the analysis, and hopes that various interest groups - railroads, unions, train control system suppliers, and others - will provide additional data to provide for a more thorough, comprehensive analysis.

1.0 Introduction

Study Objectives

The objectives of this study are to quantify the business benefits of implementing positive train control systems on selected railroad corridors and adjoining operating areas. A variety of service types and densities, potentially including freight (local and through), hazmat freight, expedited freight, and commuter and intercity passenger operations are included in the sample corridors. In addition to estimating the costs and business benefits of PTC, a benefit/cost ratio and funds flow for each of the sample corridors is computed. Recognizing that many of the benefits will not accrue if positive train control and the digital data communications link are installed in relatively small territories, the study also includes an analysis of the sensitivity of benefit and cost estimates to PTC operating area size.

Operational Definition of PTC

For this study, the following operational definition of PTC was adopted:

> *At a minimum, Positive Train Control (PTC) consists of a two-way digital radio communications link between the field and the central office, real-time positioning, on-board intelligence, and central office supervision. Full implementation of PTC has the capability to include train control functions, predictive enforcement of movement authorities, and a range of business functions.*

PTC is a concept, rather than a single technology or system. It can include many different capabilities, covering a range of railroad functions. PTC, through use of a digital data link and real-time train location information, can be a train control system. The same data link can be used to transmit work instructions to train crews, receive acknowledgment of completed work, or transmit locomotive diagnostic information in real time. The digital data link and the on-board computer can be used for positive safety enforcement, stopping trains before movement authorities are exceeded.

While PTC is most often thought of as a train control system, the platform provided also has the capability for delivering business benefits, such as real-time work order reporting, locomotive diagnostics, administrative functions (such as time keeping), and "pacing" of trains to arrive at meet points closer to schedule. These added features are in large measure beyond the capability of other current systems.

While some PTC functions, such as work order reporting and locomotive diagnostics, may be and in some cases already have been implemented separately, there could be synergy if all the elements of PTC are installed together. For example, the PTC digital data link has sufficient capacity for train control, work order reporting, real-time locomotive diagnostics, and other functions as well. Alternative platforms, such as cellular digital radio, may lack sufficient capacity and coverage for all these functions, and with large volumes of messages, the cost of such technologies rapidly becomes prohibitive.

It is helpful to think of the PTC platform as having two-levels. The first level consists of the digital data link and on-board computer, the heart of any PTC application. This data link can support a wide variety of functions, including:

- work order reporting (real-time transmission of car movement instructions to and from train crews)
- locomotive health monitoring (on-board diagnostic sensors, with transmission of locomotive performance data to a central location continuously or intermittently)
- track forces' terminals (portable personal computers for on-track MOW equipment and work gangs, allowing for text communication of authorities and administrative data such as work hours, payroll, and daily production)
- work equipment reporting (diagnostic and production reporting for on-track equipment such as grinders and detector cars)
- code line replacement (use of digital radio to replace pole lines)
- transmission of authorities to locomotives or track force vehicles (as is done today with analog radio in DTC territory, for example).
- locomotive engineers' assist tools to improve train handling
- car environment monitoring to reduce damage to lading.

These functions require a digital data link, but do *not* require real-time train location. None of the functions involve train control, and none of them affect safety. However, they all benefit from the ability to send text messages to and from locomotives and other on-track vehicles. A PTC application could include only functions from this level of PTC.

The second level of the PTC platform includes the functions which enable a central safety system. This level includes real-time location information, provided continuously from trains through use of the Global Positioning System (GPS) and other devices, and train control software. This is a significant additional capability, but it builds on the digital data link and the on-board computer.[1] Functions provided at this level may include:

- train separation and speed enforcement (through real-time position information and on-board authority enforcement)

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[1] It is this level of PTC that provides the *positive* separation feature. It could be argued that the lower level systems are communications-based train control systems, but not positive train control systems.

- tactical traffic planning (use of central office software to manage train movements on each line)
- strategic traffic planning (use of central office software to optimize network operations)
- train "pacing" to save fuel (optimization of train speeds, through central planning, so that trains do not rush to arrive at meet points ahead of schedule)
- track force protection (with real-time location capability, central office and on-board enforcement of MOW track occupancies)
- on-board energy management (optimization of train velocity profiles, subject to schedule constraints, to minimize fuel consumption)

The broad PTC definition discussed above is compatible with full implementation of all the features available through this technology on both levels, but does not require all of them. For instance, locomotive engineers' assist tools to improve train handling or car environment monitoring to reduce damage to lading are features available with full implementation of PTC, but no credit has been taken in the calculation of PTC business benefits for these potentially useful functions. The PTC system application estimated in this study assumes a high-level application including predictive enforcement of authorities.

2.0 Study Scope and Data Sources

Scope of the Analysis

The purpose of the analysis presented here is to determine the costs and business benefits of PTC applications on five United States rail corridors:

1. Chattahoochee, FL – Flomaton, AL (CSX)
2. Syracuse – Buffalo, NY (CR)
3. Lincoln, NE – North Kansas City, MO (BNSF)
4. Barstow - Los Angeles, CA (BNSF)
5. Seattle, WA – Portland, OR (BNSF)

These five corridors were selected to represent the range of traffic volumes, traffic mixes, and signal control systems found on U.S. railroads. Of the five, two (#1 and #3) are single track with passing sidings. The other three are all partially or entirely double track (#2 and #4 have some multiple-track stretches). Corridor #1 is "dark" (unsignaled). Corridor #5 is partially ABS and partially CTC, while the other three are entirely CTC. Annual traffic volume ranges from about 24 million gross tons (MGT) to more than 100 MGT.

Table 1 summarizes the characteristics of the five corridors.

Table 1: Corridor Characteristics[2]

Corridor	Type of Signal Control	Length (Route mi.)	Traffic Volume (MGT)	Track Miles per Route Mile
Chattahoochee – Flomaton	DTC (dark)	204.5	24.050	1.04
Syracuse – Buffalo	CTC	146.0	104.017	2.40
Lincoln – North Kansas City	CTC	206.2	74.335	1.17
Barstow – Los Angeles	CTC	146.0	117.399	2.19
Seattle – Portland	CTC/ABS	186.2	80.495	1.99

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[2] Corridor length, control type, and track miles per route mile from railroad sources; annual traffic volume estimated from a one-week sample of railroads' actual train movements; typical tare weights and net loads for different traffic types, consultants' estimate.

Data Sources

For each corridor, a week of train movement data was obtained from the owning railroads (Conrail, CSX, and BNSF). This data included:

- dispatcher sheets listing actual train arrival and departure times at intermediate points
- train consists, gross weights, and motive power assignments
- a record of train delays, their duration and causes
- operating timetables showing speed limits, locations of crossovers and passing sidings, and type of signal control
- minimum feasible running times for each train type operated (calculated by a train performance simulation model)

These data, plus some additional operating information such as locomotive out-of-service and mean time between failures (MTBF) numbers, were used in various analyses of the several benefit areas identified as generally applicable to all railroads.

Table 2 shows the number of cars (loaded and empty) moved during the sample week (which was not the same week of 1997 for each corridor). In Table 3, these data have been annualized by multiplying by 52 weeks.[3] In Table 4, an annual gross ton estimate has been generated as follows:

- Using an average weight of 30 tons for an empty car, 95.3 tons for a loaded car, except for bulk commodities (average load from 1996 AAR *Yearbook of Railroad Facts*), and 132 tons for bulk commodities (coal, grain, etc.), cars were converted to tons
- Amtrak cars were assumed to weigh 65 tons (an average for the fleet; Superliners weigh somewhat more, Horizon cars somewhat less)

The results of this process were compared to gross tons information calculated by the railroad and from the Federal Railroad Administration traffic flow model. There was reasonable agreement between the three sources.

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[3] A one-week sample may not always be fully indicative of annual traffic patterns. This annualization approach may explain why in some cases the number of empty cars exceeds the number of loaded cars in Table 3.

Table 2: Weekly Car Volume by Traffic Type, Study Corridors

Corridor	Number of Cars, One Week							
	Carload Freight		Bulk Commodities		Intermodal		Amtrak	Total Cars
	Loaded	Empty	Loaded	Empty	Loaded	Empty	Total	
Chattahoochee – Flomaton	2,061	1,596	901	698	628	487	60	6,430
Syracuse - Buffalo	12,168	6,608	1,106	616	4,715	119	386	25,718
Lincoln – North Kansas City	3,236	2,427	5,614	6,572	1,116	125	0	19,090
Barstow - Los Angeles	10,180	6,449	2,651	210	6,684	661	953	27,788
Seattle – Portland	8,981	6,976	2,418	2,326	495	529	474	22,199

Table 3: Annual Car Volume by Traffic Type, Study Corridors

Corridor	Number of Cars Per Year, Loaded and Empty							
	Carload Freight		Bulk Commodities		Intermodal		Amtrak	Total Cars
	Loaded	Empty	Loaded	Empty	Loaded	Empty	Total	
Chattahoochee – Flomaton	107,154	82,977	46,857	36,285	32,669	25,298	3,120	334,360
Syracuse - Buffalo	632,736	343,616	57,512	32,032	245,180	6,188	20,072	1,337,336
Lincoln – North Kansas City	168,272	126,204	291,928	341,744	58,032	6,500	0	992,680
Barstow - Los Angeles	529,360	335,348	137,852	10,920	347,568	34,372	49,556	1,444,976
Seattle – Portland	467,012	362,752	125,736	120,952	25,740	27,508	24,648	1,154,348

Table 4: Annual Gross Tons by Traffic Type

Corridor	Annual Gross Tons				
	Carload Freight	Bulk Commodities	Intermodal	Amtrak	Total Gross Tons
Chattahoochee – Flomaton	12,701,130	7,273,619	3,872,296	202,800	24,049,844
Syracuse - Buffalo	70,608,221	8,552,544	23,551,294	1,304,680	104,016,739
Lincoln – North Kansas City	19,822,442	48,786,816	5,725,450	0	74,334,707
Barstow - Los Angeles	60,508,448	18,524,064	34,154,390	4,212,260	117,399,162
Seattle – Portland	55,388,804	20,225,712	3,278,262	1,602,120	80,494,898

Benefits Evaluated

The on-board computer, location system, and digital radio data link of any PTC installation can support a variety of functions, given the right software and access to railroad databases. For example, the Burlington Northern ARES system of the 1980s, as designed, would have maintained a record of train crew hours. ARES also was planned to incorporate an Energy Management System that was to provide train handling instructions to the engineer with the aim of minimizing fuel consumption and intra-train forces, subject to an external schedule constraint.

ARES and the Canadian National Railways' Advanced Train Control System (ATCS) also incorporated real-time location reporting for track maintenance forces, as well as production reporting and equipment health monitoring for MOW gangs. Both systems also included computerized train dispatching aids, which would provide the dispatcher with a suggested "best" dispatching plan.

A significant benefit identified in the Burlington Northern analysis was an increase in line capacity, due to the capability of ARES to safely space trains more closely than allowed by conventional signal systems. For CNR, however, this benefit was of minimal value due to the generally low level of capacity utilization. Because line capacity is only of value if a railroad faces capacity constraints, line capacity was not included as a specific benefit in this analysis.

Many of the functions of PTC may also be provided by other systems. Most modern diesel locomotives, for example, are factory-equipped with diagnostic systems. Work order instructions to train crews can be transmitted by digital cellular technology, as can MOW gang production data. However, to the extent that multiple systems can be supported by a single set of computer and communications equipment, overall costs may be minimized.

After a careful review of a long list of potential business benefits of PTC, a number of the benefit areas analyzed by CNR and BN in their earlier analyses were found to be either railroad- and route-specific (e.g., line capacity enhancement) or of minimal value on the five study corridors (e.g., pole line replacement, which has already been accomplished on these five corridors).

The short list of PTC business benefits retained for evaluation in this study and analyzed herein are as follows:

1. Real-time transmission of "work orders" to crews and real-time reporting of work performed
2. Real-time reporting of locomotive diagnostic (LD) information
3. Improved equipment utilization (due to more efficient dispatching)
4. Fuel savings (due to "pacing" of trains)

5. More reliable customer service

Dollar benefits in each of these areas are quantified in the following sections.

3.0 Benefits of Real-Time Work Order Reporting

The purpose of the work order system is to plan and schedule the work of train crews. It is not possible to schedule all work in advance, since it is impossible to perfectly predict future occurrences. The addition of unplanned work may mean delays to cars or train crews, since without advance knowledge of work to be done, crews may run out of time before completing all scheduled work plus any additional unscheduled work. Outbound connections in yards may also be missed if large volumes of additional work delay completion of a switching shift.

Real-time or near real-time information will reduce additional, unplanned work, by reducing the volume of inaccurate or out-of-date information used in the generation of work orders. Since most additional work is performed by yard and industry switchers and local freights, the benefits resulting from a reduction in additional work will be realized mostly in these services. For this reason, the analysis presented here is confined to switchers and local freights. There do not appear to be large benefits to be realized from real-time reporting of train consist data and completed work by unit trains and through freight trains.

Table 5 shows the various potential sources of work order reporting benefit, and the reasons for these benefits.

Table 5: Potential Areas of Benefit, Real-Time Work Order Reporting

Benefit Area	Sources of Benefits
1. Reduced car cycle time	• Advice to crew in near real time of car release by customer, after issuance of work order, increases likelihood of car pickup by crew • Real-time reporting of scheduled and additional work increases car scheduling integrity, increases planning effectiveness • Car movement through terminal improved
2. Reduction in extra handling of cars	• Advice in near real time of car release or switch request, after issuance of work order, may eliminate rehandling • Real-time information on cars not handled as instructed
3. Reduction in clerical effort	• Reduction in clerical work associated with processing work orders
4. Reduced switching hours	• Real-time information on car release or switch request may eliminate rehandling • Real-time information on cars not handled as instructed, allowing for immediate correction • Cars reported as additional work in real time will prevent posting of these work instructions for a subsequent shift
5. More accurate and timely reporting	• Work is processed into car cycle database immediately upon conductor's report • Elimination of need for clerk to interpret what conductor was reporting, or failing to report
6. Enhanced planning by operating supervision	• Confirmation of work completed, or not performed, increases car scheduling reliability • Work not performed, reported in real time, is available for inquiry and corrective action
7. Customer satisfaction	• More timely car location information • Better customer response time
8. More accurate work orders for train crews	• Work not performed is released immediately for assignment to next shift

Figure 1 is a schematic car cycle diagram. It shows the eight stages that a car passes through as it completes a cycle (load to load or empty to empty). Real-time work order reporting offers the potential for savings in four of these areas. These are indicated by numbers in Figure 1, and the expected benefits are as follows:

1) **Inbound classification**: reduced yard time for inbound cars, due to advance notice of consists and reduced time for consist verification
2) **Customer release:** quicker response to customer releases of cars, through enhanced ability to service late customer releases the same day they are received
3) **Local trains:** reduced yard time for outbound cars from local trains, through advance notice of consist and car destinations and through preblocking of cars to reduce switching
4) **Outbound classification:** better chance of making outbound connections

In addition, the use of work order reporting systems could improve billing accuracy for demurrage and intra-plant switching. No dollar value has been assigned to this benefit area.

Benefits will be quantified in this analysis only for areas (1), reduced inbound yard time, and (3), local train preblocking of additional work cars. Quantification of the other benefit areas requires additional detailed data not obtainable for this study.

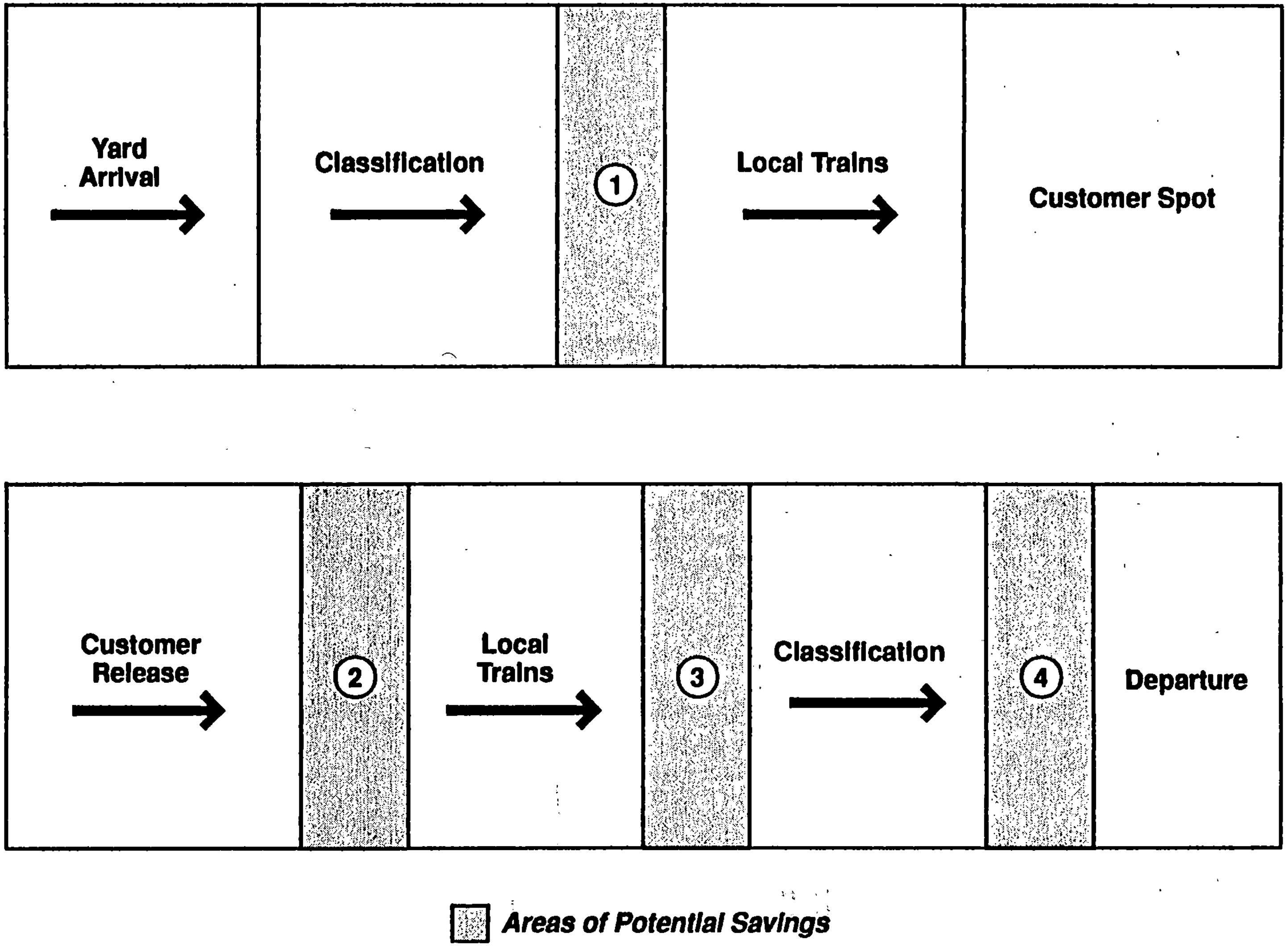
The benefits analysis presented here is based on a study performed for a major North American freight railroad. Data and statistics in the analysis are actual data on the performance of an implemented (although not a real-time) work order system. The following sections explain how real-time or near-real-time information will enable railroads to save car days and switch engine hours.

3.1 Methodology for Benefit Determination -- Yard Time Savings

Yard time savings can apply to both sides of the car cycle: loaded cars or empties inbound to customers, and outbound loads or empties for other destinations. The benefit does not appear to be symmetrical, however. Systems already in place on most North American railroads provide good information on inbound cars, so a savings of only one hour, on average, in yard processing time has been assumed. Many outbound cars, however, are picked up as additional (unscheduled) work or as "no-bill" cars at present – about 15% of cars in one typical case studied. More timely information should reduce this number, resulting in much faster yard processing time. The rationale for these savings is discussed below.

To quantify the savings from reduced yard delays (Areas 1 and 4 in Figure 1), a probability function from the railroad's blocking and scheduling model (the Service

Figure 1
Car Cycle Diagram



Planning Model) is used.[4] This function is a cumulative probability distribution calculated for each railroad yard from actual car movement data. This distribution can be used to determine the likelihood that a car will make the first scheduled connection, given that the scheduled yard time (number of hours between arrival and scheduled departure) is known.

Figure 2 shows a typical distribution of connection probability, with a 24-hour mean and an 8-hour standard deviation. On the Y axis, the percentage of cars making scheduled connections is shown, and on the X axis, available time for processing (yard switching). If more yard time becomes available (through earlier arrivals or more timely receipt of information), there is an increased probability that cars will make their scheduled connections. In application, the shape of the curve is calibrated to actual performance of each yard.

As an example, refer to Figure 2. With a mean yard time of 24 hours, cars spending this amount of time in the yard have a 50% probability of making their first onward connection. Now suppose that, due to some technological improvement, trains are able to arrive, on average, an hour earlier in the yard. This gives a mean yard time of 25 hours; from Figure 2, the percentage improvement in connect probability is determined by the slope of the cumulative probability curve. At the mean of 24 hours, the slope of the line is about 5. Thus, adding one hour to available yard processing time would increase the number of cars making connections by 5 percentage points. If there is one opportunity per day to connect, this percentage of cars would save 24 hours.

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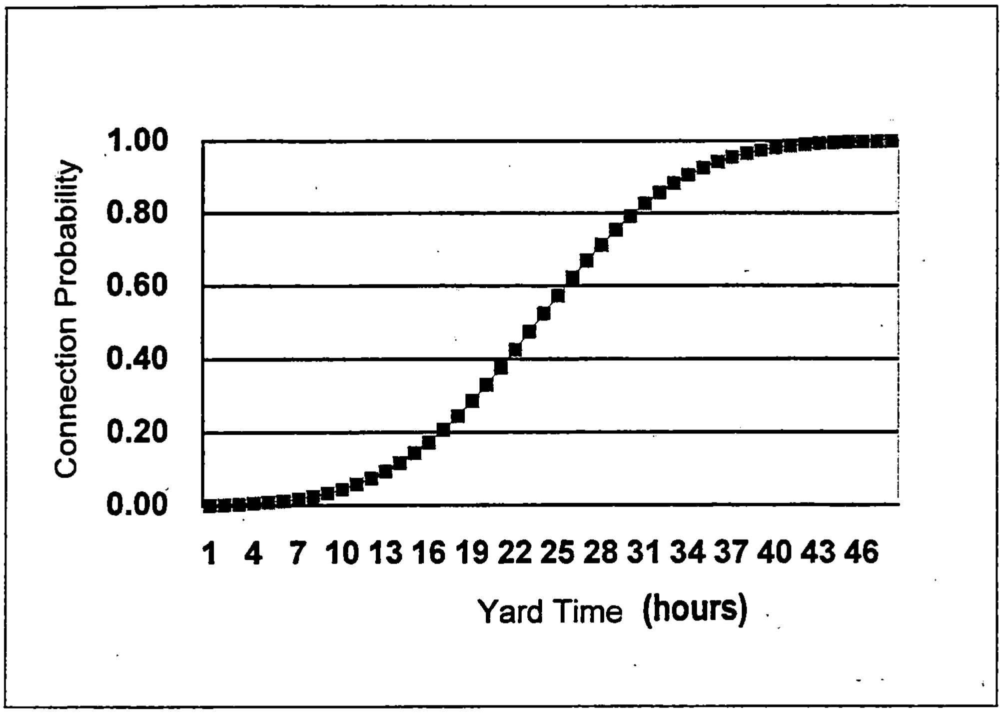
[4] The Service Planning Model was developed at the Massachusetts Institute of Technology as part of the Freight Car Utilization Project, funded by the Association of American Railroads and the Federal Railroad Administration during the 1970s. Sampling and observation of actual yard operations established that a statistical function could be developed that, calibrated to experience at each yard, could be used to predict the probability that a particular car would make a scheduled connection, based on the number of hours available between arrival and scheduled departure. See "Estimating the Impact of Advanced Dispatching Systems on Terminal Performance", by Carl Martland and Michael E. Smith, *Journal of the Transportation Research Forum*, Vol. XXX, No. 2, 1990.

Figure 2: Cumulative Connection Probability



The assumption behind the analysis is that actual performance of freight trains varies around their schedules. Sometimes trains are early, sometimes trains are late, due in part to random disturbances that occur in railroad operations. For each car moving on the railroad, there is a schedule that assumes certain train-to-train connections will be made. Sufficient time is allowed between scheduled arrival and scheduled departure in each yard so that, in theory, each car can make its schedule. In practice, a certain small percentage of cars never makes the schedule. For example, cars experience mechanical failures and are sent to the RIP (repairs in progress) track, are received as "no-bills" (no paperwork) and have to wait for the paperwork to catch up, or are held in the yard due to tonnage restrictions or lack of locomotive power.

Cars will therefore make their schedule some percentage of the time lower than 100%. However, holding all other factors constant, the longer the time a car is *scheduled* to be in a yard between trains, the greater the probability that it will make its scheduled connection. Sometimes, the apparently paradoxical result is that a longer scheduled time in a yard results in a shorter *average* yard time for cars making the scheduled connection. This is because most connections are once-a-day events. If a car misses a scheduled connection, the *minimum* yard time until the next opportunity is usually 24 hours.[5]

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[5] The reason for this once-a-day operation has to do with the nature of railroad operations. If enough traffic exists to warrant two trains, or two "blocks" of cars, per day between destinations, the railroad will usually refine the destination list further. For example, if enough traffic exists for two blocks from Los

Availability of detailed and accurate train consist information in real time or near real time will reduce time required to verify inbound consists. Information from a study of one North American railroad indicates that the *minimum* time to verify inbound consist information is 30 minutes (and this information may not be entirely accurate). On-board work order reporting should reduce time required to verify consists. The consensus of those involved in the study was that an average of one hour per inbound train might be saved, partially because cars will be available in en route inventory sooner. This one hour value is adopted in this study.

Using the composite "PMAKE" function shown in Figure 2, the percentage increase in cars making scheduled local connections may be calculated. As shown above, a one hour increase in yard time will permit an additional 5% of inbound cars handled to make their next available connection, saving 24 hours. This time saved applies to 5% of total inbound cars or 2.5% of total cars handled.

3.2 Methodology for Benefits Determination -- Preblocking

A recurring problem observed during field visits to a number of North American rail terminals was the need to handle many customer calls to release cars as additional unscheduled work. Most industry jobs work days, others afternoons, and a few work the midnight shift. But in all cases, some customer calls are received after the job has already gone to work. These calls do not, of course, show up on the crew's work order. If they are handled at all, it is as additional work. If they are not handled, the shippers must wait an additional 24 hours for service, and the railroad loses 24 hours' worth of demurrage payments, since demurrage stops as soon as a customer release of a car is received.

A major possible benefit of on-board reporting of information in real time or near real time is anticipated to be the ability of local switching jobs to "hold" blocks. At present, these jobs do not usually make blocks, since the number of cars to be handled, and the number of destinations for those cars, varies widely from day to day. With access to detail on intended destinations for all cars handled, it should be possible for the switch crew to make at least one block per day, and hold this block intact for delivery either to a yard or to a set-out location.

At present, locals and industry switchers do not put inbound cars in order before arriving in the yard, so all cars must be classified. With one or two pre-established blocks, yarding of some cars might be avoided altogether if the blocks could be set out for pickup by a through train.

Angeles to Kansas City's Argentine Yard daily, BNSF would most likely attempt to redirect one of the blocks, either moving it further east on the system, designating a block for direct interchange at Kansas City to an eastern connection, or some similar action. In this way, the number of yardings per car (as well as switching cost) is minimized.

In theory, if the crew has waybills for cars they already have the ability to engage in some preblocking under existing conditions. Therefore, the benefit of preblocking is being estimated here only for cars handled as additional, unscheduled work, for which crews do not know destinations. As stated above, these cars typically constitute about 15% of total cars handled.

The average number of cars handled by local freights, industry switchers, and yard switchers on one studied railroad is 39 per shift (inbound plus outbound). The inbound benefit has already been discussed (reduced yard time); this benefit applies to the other half of the cars, those outbound. If 20 cars, on average, are outbound, and 15% are now handled as additional, unscheduled work, three cars per shift that are not now preblocked could be preblocked if real-time information is made available to crews. Assuming these cars are pre-blocked will affect three of the 39 cars handled, or approximately 7.5% of cars handled from industries. It has been assumed that one car day can be saved for each of these cars.[6]

3.3 Additional Savings Areas

Although not quantified in this analysis, there are also expected to be clerical savings due to the use of on-board reporting and an anticipated reduction in additional work. In addition, more timely and accurate data will be available to clerks, supervision, and customers. Immediate confirmation of work completed, or not performed, will enhance the reliability of data used by a railroad's car scheduling system.

Benefits also will accrue to railroads in the form of additional demurrage and intra-plant switching revenue, since (unlike present practice) accurate data will be available on customer releases of cars and requests for intra-plant switches. Currently, it is suspected (but cannot be proven) by most North American railroads that customers are undercharged for both activities.

3.4 Summary of Calculated Benefits

Real-time transmission of train crew work instructions and reports of work completed may be expected to produce benefits in the four areas outlined above in Section 3.1. Benefits quantified in this study are as follows:

- A reduction in inbound yard time, based on an estimated 4.5% reduction in average yard time (based on analysis of one Class I railroad using calibrated PMAKE functions). If average yard time is reduced by 4.5%, it is as if cars arrived earlier, and 5% more cars make their first scheduled outbound connection.

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[6] In addition to the car day savings, preblocking will also reduce the number of cars switched by 7.5%, since yard handling could be avoided altogether for this group of cars. However, the benefit calculated here is based only on one car-day savings, without a credit for the reduction in required yard work.

- A reduction of one day's transit time for 7.5% of originating and terminating cars on each study lane (outbound to yard), due to ability to pre-block cars for onward connections

Additional benefits could be available from other mechanisms not quantified in this analysis, as follows:

- More timely response to customer "pull" requests (not quantified in this analysis due to a lack of specific data on each of the study lanes)

- A reduction in yard time in the outbound direction. This benefit has not been included in this analysis since yards have not been explicitly modeled.

- A reduction in yard switching activity. To the extent that blocks can be made for movement directly to outbound trains, these cars will not require yard classification.

The benefits of real-time work order reporting estimated above apply only to carload freight traffic originating or terminating on each study segment. These percentages have been calculated from the Surface Transportation Board's 1% Waybill Sample, and the calculated percentages have been applied to the annualized car volumes obtained from railroad dispatching records (since the 1% Waybill Sample includes only loaded car movements). Calculated volumes of originating/terminating traffic are shown in Table 6. Work order benefits only apply to carload freight, not to all cars, and this tabulation is included in Table 6.

As explained in the text above, an estimated 5% of originating/terminating cars will save one car-day due to improved connections outbound from yards, made possible by real-time work order reporting. In other words, 5% more cars will make the first scheduled outbound connection than at present. The savings is thus one car-day for each connection made (assuming that, in general, there is only one yard departure to any one destination in a 24-hour period). At a calculated $10.28 per car-day ($50,000 purchase price, 7% cost of capital, 40-year life), the annual savings are shown in Table 7.

A similar benefit applies to yard inbound cars. At present, about 15% of freight cars move without specific work orders (or even waybills, in some cases). It has been assumed that, on average, real-time information could enable switch crews to block half of these cars (7.5%) for onward movement if better information were available. Each car would save 24 hours. This benefit is also shown in Table 7.

Table 6: Number of Originating/Terminating Cars by Line Segment

Corridor	Total Cars		Carload Freight		Orig./Term Cars as %	# of Originating/Terminating Cars	
	Loaded	Empty	Loaded	Empty		Total	Carload
Chattahoochee - Flomaton	186,680	144,560	107,042	82,891	0.79%	2,633	1,500
Syracuse - Buffalo	955,500	381,836	632,736	343,616	1.07%	14,309	10,447
Lincoln – North Kansas City	518,232	474,448	168,272	126,204	8.81%	87,455	25,943
Barstow - Los Angeles	1,064,336	380,641	529,360	335,348	100.00%	1,444,976	864,708
Seattle - Portland	643,136	511,212	467,012	362,752	2.76%	31,860	22,901

Table 7: Real Time Work Order Reporting Benefits Calculation

		Inbound to Customer			Outbound to Yard			
Corridor	Total Cars	% Total Cars Affected	Cost/Car Day	Annual Benefit	% Total Cars Affected	Cost/Car Day	Annual Benefit	Total Annual Benefit
Chattahoochee - Flomaton	1,500	2.5	$10.28	$385	7.5	$10.28	$1,156	$1,541
Syracuse - Buffalo	10,447	2.5	$10.28	$2,685	7.5	$10.28	$8,055	$10,740
Lincoln – North Kansas City	25,943	2.5	$10.28	$6,667	7.5	$10.28	$20,002	$26,669
Barstow - Los Angeles	864,708	2.5	$10.28	$222,230	7.5	$10.28	$666,690	$888,920
Seattle - Portland	22,901	2.5	$10.28	$5,886	7.5	$10.28	$17,657	$23,543

4.0 Benefits of Locomotive Diagnostics (LD)

Locomotive diagnostics are a set of sensors that monitor critical locomotive components (air intakes, fuel injectors, electrical system) and provide warnings to train crews and/or mechanical maintenance employees when components are close to failure. Most modern diesel locomotives are equipped by manufacturers with diagnostic systems, of varying complexity and sophistication. Therefore, the central question in this part of the analysis is whether real-time transmission of this diagnostic information to a central location adds significant additional value. The analysis presented here assumes the existence of a digital data link (installed for train control purposes), and an on-board computer. As discussed later in this report, under these circumstances the incremental cost of locomotive monitoring with real-time reporting is small.

Other issues to be addressed include the expected benefits of locomotive health monitoring and the selection of systems to be monitored in order to maximize the return to a railroad. Much of what is presented here draws upon analyses performed for Burlington Northern's LARS (Locomotive Analysis and Reporting System) about ten years ago. After collection of detailed statistics on locomotive failures and delays to trains, repeated statistical simulations were undertaken (using probabilities derived from the failure statistics) to quantify the potential savings from LARS in five areas:

- Departure delays
- On-line delays (en route failures)
- Time off line (% out of service)
- Maintenance hours
- Reduced severity

Due to data limitations, this analysis addresses only reductions in en route failures (and resulting delays) and reductions in maintenance hours required (with a consequent reduction in time off line per locomotive). Data supplied were not sufficiently detailed to permit estimates of reductions in the severity of failures, and departure delays were not separately itemized from en route failures.

In addition to en route failures, the BN analysis also looked at four possible variants of the LARS system. LARS 1 made use of diagnostics simply as an aid in inbound and outbound inspections of locomotives already scheduled for shopping. This is the equivalent of the on-board diagnostics now available as standard features on new locomotives. LARS 2 used the digital data link to provide real-time component status when on-road failures occurred. The highest two levels of LARS evaluated also incorporated real-time telemetry: LARS 3 assumed that the shop would monitor alarms and diagnose the locomotive to schedule additional component replacements at a routine shopping, while LARS 4 used this information to bring units to the shop before failures could occur.

The BN analysis found LARS 1 to have little value, while LARS 4 caused additional costs due to excessive shoppings. LARS 3 was selected as the most reasonable approach. Therefore, this analysis will concentrate on a system similar to LARS 3, in which telemetry is used in real-time to reduce diagnostic time, en route failures, and their severity. It must be noted that any diagnostic or monitoring system does not affect component failure rates. Benefits come from the detection of likely failures before they occur, and from a reduction in labor hours required to trouble-shoot failed locomotives.

Two benefits of locomotive monitoring have been quantified in this analysis:

- a reduction in required labor hours (estimated through use of a probability model)
- a reduction in en route locomotive failures.

An annual savings can be generated in each of these areas by using available data such as annual expenditures for maintenance, the ownership cost of locomotives, and the ownership cost of train delay.

4.1 Reduction in Maintenance Hours

Burlington Northern found the largest benefits from the LARS system in two areas: reduction in locomotive and train delay times, with attendant cost savings; and reduction in repair times, severity of failures, and inspection times. In general, these savings will apply to other railroads as well, although there are differences between railroad locomotive fleets and maintenance practices.

The monitoring systems examined here, it must be emphasized, will not affect the failure rates of locomotive components. Therefore, there is no expected savings in material. However, it may be possible to avoid failures by early component replacement, and accurate diagnostic information should speed identification of the problem.

In the Burlington Northern's analysis of LARS, a simulation was undertaken to quantify the expected reduction in work hours required to diagnose locomotive problems. The simulation used two sources of data: locomotive failure reports and repair records, and train delay messages from the TNX (dispatching delay reporting) system. These two data sets were merged to produce a single list of train delays and repair activities. A model was constructed to flow locomotives (and their trains) across the BN network, with failures and delays occurring as reported. For each locomotive component failure, a correct diagnosis probability was developed. This probability varied with the type of LARS system being evaluated. Wrong diagnoses led either to additional shop time or to repeat failures.

The model was run repeatedly, and statistics were accumulated on delays leaving yards, en route failures, and total time to repair (including both scheduled and unscheduled work). For the purposes of the analysis presented here, the most important product of these simulations was an estimate that the labor hours required to diagnose locomotive problems would be reduced by 40.2%. This number (the variable KR in the Northrop model described below) was not obtainable directly from railroad data.

To quantify the benefits of LD in terms of reduced labor hours, the Northrop model was used to develop an estimate of labor savings. It calculates the savings in terms of the percentage of total labor hours, given that values can be obtained or estimated for each of the variables. The analysis presented here relies on fleet statistics for Canadian National Railways for the years 1989 and 1990.

The Northrop model postulates that:
$S = (FM/FA)(PS)(KR)(MT/MR)$, where:

$S =$ savings in percent, and
$FM =$ # of failures in systems monitored by LARS
$FA =$ # of total failures
$PS =$ probability that sensors work (assumed at 0.99%)
$KR =$ proportion of trouble-shooting and repair time reduced by LARS
$MT =$ trouble shooting time for a loco w/o LARS
$MR =$ total maintenance and inspection time (36.1 hours)

A second critical number in the Northrop model is the variable MT, trouble shooting time for a locomotive without LARS. Railroads contacted in this study estimated the proportion of trouble-shooting time to be about 20% to 30% of total maintenance hours. A value of 25% of total maintenance hours per locomotive has been used in this analysis.

For failures, data from Canadian National locomotive failure studies for two two-week periods in 1989 and 1990 were analyzed, and failures were divided into two categories: those occurring in monitored systems and those occurring in systems not monitored. As can be seen from Table 8, a total of 442 reported failures in 1990 out of a total of 507, and 435 out of 543 in 1989, occurred in systems assumed to be monitored by LD.

Table 8: Canadian National Locomotive Failure Statistics

Type of Failure	LD Status	1990		1989	
		Number	%	Number	%
Shutdown	Monitored	41	8.09%	31	5.71%
axle generator	Monitored	106	20.91%	105	19.34%
traction motors	Monitored	72	14.20%	60	11.05%
air brakes	Not monitored	21	4.14%	29	5.34%
other electrical	Monitored	135	26.63%	151	27.81%
Mechanical	Monitored	88	17.36%	88	16.21%
trucks, wheels	Not monitored	5	0.99%	17	3.13%
cab, safety	Not monitored	36	7.10%	38	7.00%
Bell	Not monitored	3	0.59%	24	4.42%
Total		507	100.00%	543	100.00%
LD monitored		442	87.18%	435	80.11%

The anticipated reduction in maintenance hours can be calculated from the data in Table 8 and the percentages mentioned earlier. The ratio of LD failures to total failures in 1990 is 442/507, or 87.2%, and for 1989 is 435/543 or 80.1%, and for both years is 84.5%. The anticipated reduction in troubleshooting labor hours is 40.2% (from the BN simulation) and the percentage of total labor expended on trouble-shooting is 25% (railroad estimate). Substituting these values into the Northrop model produces the following:

$$S = (877/1050)\ (0.99)\ (.402)\ ((0.25 \times 36.1)/36.1) = 0.0831,$$

or 8.3%, for an average of the two years. The anticipated reduction in total locomotive maintenance labor hours and labor dollars resulting from implementation of a LARS-type monitoring system is thus approximately 8.3%, based on the two years of available data.

This reduction is from a base case in which *no* locomotives have diagnostic equipment. In fact, since 1987 railroads have been purchasing new locomotives equipped with factory-installed diagnostics. The BN simulations indicate that LARS1 (the equivalent of on-board diagnostics with no real-time transmission capability) can achieve 44% of the reduction in hours estimated for LARS3 (on-board diagnostics with real-time transmission of diagnostic data to the repair shop.) Locomotive diagnostics became available in the mid-1980s, so the savings of 8.3% of labor hours must be reduced by 44% for those units already equipped with diagnostics.

Assume that diagnostics became standard on GE and EMD units in 1987, and further assume that all rebuilt locomotives were also equipped with diagnostics from

1987 on. A review of locomotive purchases by major North American railroads for the years 1987 - 1995 (from the 1996 AAR Yearbook of Railroad Facts) indicates that railroads purchased a total of 6,264 new and rebuilt units from 1987 through 1995, exactly 33.3% of the 1995 fleet of 18,812 units. For the 1/3 of the fleet assumed to be equipped with sensors and harnesses, the 8.3% savings in labor hours must be reduced by 44%, resulting in a net labor hour savings of 4.6%. For the fleet as a whole, then, the blended savings in labor hours is 7.07%.

The reduction in aggregate shop time results in improved availability and thus in a requirement to maintain a smaller locomotive fleet. This benefit can be monetized by calculating the hourly cost of locomotive ownership. Assume $1.5 million as the average purchase price of a new locomotive, a 30-year life and a 7% discount rate. Annual ownership cost is thus $120,880, or $13.80 per hour. Table 9 shows savings available to Conrail, BNSF, and CSX (using Conrail fleet performance) from a 7.07% reduction in shop hours, assuming an average shop duration of 36.1 hours at present, and an average number of out-of-service locomotives as shown in the table.

Table 9: Annual Savings from a Reduction in Average Shop Time[7]

Railroad	Loco Fleet Size	MTBF, days	Avg. Shop Time, hrs.	Savings with LD, %	Savings per Loco Hour	Annual Savings per Equipped Loco
BNSF	4,948	61.1	36.1	7.07%	$13.80	$210.41
Conrail	2,040	103.44	36.1	7.07%	$13.80	$124.28
CSX	2,604	103.44	36.1	7.07%	$13.80	$124.28

4.2 Reduction in Road Failures

In addition to savings in troubleshooting, a reduction in locomotive failures en route will also produce significant savings in train delay costs. This savings can be very substantial, since the cost per road failure includes operating costs (such as the cost of recrewing the train) as well as maintenance labor and materials costs. Table 10 shows the baseline reductions in total road failures achievable by LARS, based on expert judgment of Burlington Northern maintenance personnel, and confirmed by CN's Mechanical Department.

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[7] Savings reflect an assumed one-third of the fleet already equipped with diagnostic sensors, but no real-time telemetry.

Table 10: Reduction In Failures Due To Monitoring
(Estimates by BN and CN Mechanical Dept. Staff)

Type of Failure	1990	1989	Two-Year Total	Reduction in Failures	Failures With LD
shutdown	41	31	72	80.00%	14
axle generator	106	105	211	50.00%	106
traction motors	72	60	132	50.00%	66
air brakes	21	29	50	n.m.	50
other electrical	135	151	286	50.00%	143
mechanical	88	88	176	50.00%	88
trucks, wheels	5	17	22	n.m.	22
cab, safety	36	38	74	n.m.	74
bell	3	24	27	n.m.	27
Total	**507**	**543**	**1050**	**43.82%**	**590**

Note: n.m. = not monitored

The estimate of the reduction in failures expected with LD was made by mechanical maintenance experts based on experience and judgment. These judgments were reviewed by railroad mechanical department officers, and represent a consensus on the possible benefits of LD. After some consideration, it was decided that the ratio of repeat failures to first failures would remain unchanged (that is, repeat failures would be reduced in proportion to the reduction in initial failures). This was done partially because the data supplied did not contain detail on the types of repeat failures.

The anticipated reductions in road failures achieved by locomotive monitoring are estimates based on BN and CN experience, and were felt by both railroads' mechanical departments to be conservative. Some examples may be useful in understanding the reasons for expecting these reductions.

Take the failure cause "shutdown". In this case, an 80% reduction has been projected with LD. Shutdowns most often occur because of low crankcase pressure, low water or oil pressure, or an engine r.p.m. overspeed. All of these are progressive failures; they take time to reach the level that will cause the engine to trip out. Since the diagnostic systems being considered here monitor crankcase pressure, engine r.p.m., water and oil pressure, it is reasonable to suppose that upward or downward trends in these levels would provide an early warning to mechanics and could allow corrective action to be taken. In fact, Burlington Northern maintenance personnel believed that en route shutdowns would be virtually eliminated.

As another example, CN shows 151 failures for "other electrical" including engines not loading, ground relays dropping out, and miscellaneous electrical causes. A modern LD system would monitor a number of conditions, including: fuel pressure, horsepower, governor rack position, load regulator position, air filter pressure, traction motor current, transition, dynamic brake grid current, alternator volts and amps, horsepower, and load regulator volts. Any of these could result in a unit not loading, and again the problems that cause this condition are often progressive.

A third example is for locomotives running hot. There are multiple fans, and they rarely fail simultaneously. If one fails, the unit may perform adequately until it is required to produce full power output. LD will monitor the relays that activate cooling fans sequentially as engine temperature rises. If a fan relay is not picking up, this event will be monitored and recorded, and action could be taken to address the problem, possibly before the locomotive overheats.

Benefits of this monitoring are relatively simple to estimate. CN estimated a cost of $1,357 to CN (in 1990 Canadian $) for every road failure. This failure cost includes the cost of movement to the shop (dead in consist or dead in tow) and delay to trains, as well as the opportunity cost of the out-of-service time. Costs should be similar for US roads; adjusted to US dollars and 1997 price levels, the cost is $1,262 US per road failure.

Table 10 indicates a reduction of 43.8% in failures with LD. This number must be reduced by the percentage benefit already being obtained by locomotives equipped with on-board diagnostics. Simulations by Burlington Northern indicated that only 1.6% of failures could be avoided by on-board (as opposed to real-time, communicating) diagnostics. Reducing the 43.8% figure from Table 10 by 1.6% gives an estimate of a 43.1% reduction in failures. Assuming that LD could avoid an approximate 40% of en route failures, then Table 11 shows the savings potentially available to BNSF, Conrail, and CSX (estimated for CSX using CR values, since CSX data were not available) from avoided en route failures.

Table 11: Savings from Avoided En Route Failures

Railroad	Locomotive Fleet Size	Annual En Route Failures	Reduction due to LD	Failures Saved by LD	Cost Per Failure	Annual Savings	Annual Savings per Equipped Locomotive
BNSF	4,948	29,558	40%	11,823	$1,262	$14,920,878	$3,016
Conrail	2,040	4,752	40%	1,901	$1,262	$2,398,810	$1,176
CSX	2,604	6,066	40%	2,426	$1,262	$3,062,117	$1,176

As with the savings from troubleshooting labor, these savings are based on and sensitive to assumptions regarding the effectiveness of diagnostic and reporting systems. If the system prevents more than 40% of current failures on monitored systems, savings would be greater. Conversely, if LD prevents fewer failures, savings would be less.

These are only estimates, and probably represent an upper bound on the benefits obtainable through use of LD or a similar monitoring system. This is because locomotive monitoring does not prevent failure of components; it just allows early detection and quicker diagnosis. Consequent failures can be prevented, delays can be prevented, trouble-shooting time is reduced, and this produces savings. The savings depend upon the performance of rail workers monitoring the data and the response of other workers to suggested courses of actions. Component failure rates, however, are unaffected. Furthermore, LD-equipped locomotives may not always operate on PTC-equipped territory, which would reduce the benefit available.

4.3 Miscellaneous Benefits

A number of benefits potentially realizeable with LD, but which have not been included in this analysis, are briefly described in this section. These benefits are in the category of *de minimis* benefits from a return on investment standpoint.

Load Testing

A major benefit of locomotive monitoring is the ability to measure locomotive performance under load. In the United States, where a majority of locomotives are equipped with dynamic brakes, many are also equipped for self-load testing. Load cells are not required. While load testing is credited with improving fleet performance (BN reports a major increase in mean time between failures since the inception of load testing), it takes time. For BN, a benefit of LARS was the avoidance of time otherwise required for load testing, since LARS provided information on locomotive performance under load. For other railroads, the benefit will simply be the availability of information on locomotive performance under load, both before and after shop visits.

Material Cost Savings

Various filters (fuel, air, oil) are routinely changed out at 90-day intervals because there is no accurate way to gauge their condition. With diagnostic information on fuel, oil, and air pressure some of these routine changeouts may be stretched out to an as needed basis.

4.4 Summary of Benefits

Table 12 summarizes total benefits for the three railroads, per locomotive equipped with LD. The values per equipped locomotive are especially pertinent to this investigation of PTC application to relatively short corridors.

Table 12: Summary of LD Benefits[8]

Railroad	Labor Hour Savings per Equipped Locomotive	Avoided En Route Failure Savings per Equipped Locomotive	Total Annual Savings per Equipped Locomotive
BNSF	$210.41	$3,016	$3,226
Conrail	$124.28	$1,176	$1,300
CSX	$124.28	$1,176	$1,300

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[8] Table 12 reflects the assumption that one-third of the fleet (as of year-end 1995) is equipped with diagnostic sensors and harnesses. The estimate also assumes that equipped locomotives operate only in PTC-equipped territory, which may not always be the case, depending on the specific corridor application.

5.0 Benefits from Equipment Utilization

With a total of approximately $65 billion invested in locomotives and freight cars, equipment utilization is necessarily an important concern for railroads. However, while major improvements have been made in the productivity of employees, in safety, and in track maintenance productivity, equipment utilization remains relatively poor. For example, ordinary box cars still average less than 12 turns per year, and covered hoppers less than 20, despite many attempts to improve utilization by applying complex optimization algorithms or by taking a proactive approach to fleet management by tracking car movements carefully.

Improved equipment utilization is one of the largest benefits Positive Train Control can provide. By constantly monitoring train movements and providing real-time information to dispatchers, PTC can improve the effectiveness of train dispatching through improved over-the-road times and reduced delays.

The improvements in train dispatching possible with PTC stem in part from a reduction in what is defined here as "O/S (on station) interval." The O/S interval is the time between a dispatcher's receipt of train position information. The dispatcher must then decide on a proper course of action (either directly or with the assistance of a movement planner or other computer aided dispatching tool), and transmit instructions to locomotives, MOW personnel, and others.

5.1 Defining a Dispatching Model

In any controlled environment, the objective of a controller is to keep a system in the desired state. To accomplish this, the first task of the controller is to monitor the system's state and compare it to the desired state. If the comparison reveals no difference, nothing needs to be done. If a difference is detected, then the controller must apply a corrective force that attempts to move the system toward the desired state.

If the system performs inadequately in spite of the controller's best efforts, then the controller must be improved. There are three, and only three, ways to do this:

1. Increase the size of the corrective forces used
2. Increase the frequency with which corrective forces are applied
3. Increase the accuracy with which corrective forces are applied

Dispatchers cannot easily increase the size of control forces. In order to keep the cost of operation reasonably low, North American railroads generally run trains with low horsepower-to-trailing-ton ratios. Therefore, the size of the available corrective force is inherently small. If a train is beginning to run late, it is usually next to impossible to make up the time through faster running.

The frequency of corrective actions is usually determined by the spacing of sidings where trains can meet or pass. While decisions on when and where to meet trains can result in large differences in line-haul running times for individual trains, the time saved for one train is usually exceeded by the total delay to other trains on the railroad.

Finally, dispatchers might try to apply corrective forces more accurately by obtaining more accurate train position information. In theory, dispatchers could simply call each train on the radio at, say, five-minute intervals. In practice, dispatchers already spend about 80% of their time communicating, leaving little time for undivided attention to planning train movements, according to a published study for Burlington Northern Railroad.[9] Although the situation varies greatly with the territory in question, given the tools generally at their disposal, United States train dispatchers are somewhat constrained in their ability to develop and implement better dispatching plans.

PTC systems improve the frequency of dispatcher input by providing frequent real-time updates on train location and speed via the digital data link. When used in conjunction with sophisticated movement planning tools, more optimum meet-pass plans can be developed and implemented. As a result, when schedules are not being met, that information would be received and processed, and new commands sent out, in an estimated 3.5 minutes.[10] The comparable time interval with a conventional CTC system (the O/S interval) is typically about six minutes, but can be significantly lower, depending on the signaling and control infrastructure provided. O/S intervals for ABS territory with infrequent interlockings, and for dark territory can be much longer.

5.2 Measuring O/S Intervals in Railroad Control Systems

The most effective -- but also the most expensive -- way to increase line performance is to add track miles and/or associated control infrastructure. For a fixed volume of traffic, additional track will increase the performance effectiveness. Increases in traffic volume, absent any change in the type of control system, will also decrease performance effectiveness. However, the quality and timeliness of the information provided to dispatchers also has significance.

When one Western railroad was considering a type of PTC, they had intended to send position updates back to the control office every 90 seconds or every half mile, whichever came first. This analysis adopts the 90 second assumption. Still, the dispatch office must make up a new command and send it to the field for the communications loop to be completed. The amount of time required for that process was estimated in an earlier effort through regression analysis. This was done iteratively, each time adding one minute to the O/S interval, and the regression that showed the

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[9] "A Comparison of Voice and Data Link Communication: Railroad Dispatcher's Perspective," Burlington Northern Railroad, NTIS PB91 –130021, October 1990.

[10] It is assumed here that information is received every 1.5 minutes and new commands can be issued in about two minutes, as discussed further in the sections below.

highest r-squared was selected. By this technique, it was estimated that the amount of time required to formulate a new command is two minutes.

The reader should understand that this is only an estimate and, by the nature of how it was derived, must be an average. Certainly, routine situations can result in new commands being produced in less than a minute, especially in CTC territory. More complex situations could require more time, especially in DTC or TWC territory.

In this study, O/S interval was calculated as follows: On segments of railroad controlled by CTC, control points are typically five to ten miles apart. O/S information is sent to dispatchers when trains pass control points; thus, an O/S is received every four to twelve minutes, depending on the spacing of control points. For the CTC segments in this analysis, O/S interval has been determined by calculating the average running time between actual control points.

In ABS and dark territory, a somewhat different approach has been taken. The ABS and dark territory in this analysis has no manned interlocking towers or other points where a train position might be automatically reported. There is no "model board" or CRT screen to display occupied track circuits to the dispatcher. Therefore, the only time the dispatcher knows (or needs to know) train position is when he or she must issue a movement authority. A review of dispatchers' train sheets for the ABS and unsignaled segments was therefore made, indicating intervals of up to 180 minutes between issuance of authorities.

5.3 Analysis of Train Delays

PTC systems improve over-the-road times by reducing delays associated with the dispatch function, while not affecting assorted delays from other causes, which are largely random. If railroads were so prone to random delays that nothing about their operations could be predicted, then improving the control system would be of little value, since random and unpredictable delays would overwhelm every effort to operate on schedule.

In fact, there is some tendency among railroaders to believe that random events such as equipment failures, track failures, and bad weather are the chief cause of delays. This belief has fostered an attitude among some managers that little can be done to improve operations.

This belief cannot be dismissed lightly. However, examination of the causes of train delay suggests that it may not be entirely warranted. Delay reports were among the information received from the railroads cooperating with the Federal Railroad Administration in this study, and these delay reports were analyzed to determine the distribution of the causes of train delays. Results of the analysis were reduced to total delay minutes, since the critical value for railroads is not the total number of delays, but the total duration of delays, although this could not be verified from the data.

Because railroads differ widely in their characterization of delay causes, delays were grouped in four broad categories for analysis:

1. Track and signal delays (temporary slow orders due to track or signal work, signal problems, and similar causes)
2. Mechanical problems (locomotive failures, set-outs of defective equipment, detector alarms, etc.)
3. Dispatching delays (trains ahead, red signal, congestion, held out of terminal, blocked from departing by trains, meets with other trains, etc.)
4. Other (includes slow orders due to broken crossing gates, crews "dead on hours," unattributed "other line of road delays" on CSX, etc.)

None of these categories of delays can be completely eliminated by management efforts. Equipment will continue to fail randomly; track must be maintained; signals and track circuits will experience problems. However, the dispatching delays can be managed. There is ample evidence that, for a range of reasons, very seldom does a railroad achieve the best possible dispatch performance. Dispatchers may be especially cautious about delaying high priority trains, sometimes imposing excessive delays on low priority trains as a result. Yard operations and road train schedules are sometimes not as well coordinated as they might be, resulting in the simultaneous arrival of several trains at a single yard, temporarily overwhelming its capacity to process freight cars. The availability of better location information should enable railroad supervision to manage these operations more effectively.

A review of the causes of train delays, extracted from railroad train dispatching records, provides an insight into the relative distribution of delays. Table 13 shows the distribution of train delays for four of the study corridors: [11]

Table 13: Distribution of Delay Minutes by Cause

Corridor	**Delay Minutes by Cause, Percent** [12]			
	Track/MOW	Mechanical	Dispatching	Other
Chattahoochee – Flomaton	23.03%	2.26%	30.57%	44.15%
Syracuse – Buffalo	15.88%	3.49%	53.01%	27.63%
Lincoln – North Kansas City	21.71%	4.62%	73.67%	0.00%
Barstow - Los Angeles	41.28%	3.08%	47.20%	8.44%

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[11] Delay breakdowns were not available for the fifth corridor due to the phase-in of a new train recording system.

[12] Note discussion of the interpretation of "other" delays in text associated with this table.

While the pattern on each corridor is different, dispatching delays count for half or more of total delay minutes on three of the corridors. On the fourth, Chattahoochee - Flomaton, much of the "other" delay is accumulated automatically by the dispatching system. If no cause is supplied by the dispatcher, the delay is attributed either to "excess time in block" or "other en route delay". It appears likely that much of this delay is due to meets with other trains, waits to enter yards, and other categories of dispatching delays.

Track and other maintenance delays are consistent at around 20% of total delays except for Barstow - L.A. In the Barstow - L.A. corridor, a tie gang had one track out of service for the entire sample week. This accounted for the large track/MOW delay. Note, however, that mechanical and "other" delays are generally quite small in terms of total delay minutes. Conrail's delays were much more precisely tabulated than for the other railroads, and contained considerably more categories of "other" delays, often for such things a re-crewing. Delays to replace an "outlawed" crew were not specifically identified by the other roads.

5.4 Model Formulation

To build and test a model in which the effect of changing O/S intervals on performance could be investigated, data were needed that reflected the results of train dispatching under various methods of operation and physical plant configurations.[13] To accomplish this, actual train movement data on 33 railroad corridors was collected and analyzed, including data from the five study corridors and data for 28 corridors from the prior studies. For each segment, information on the number of trains, their motive power, tonnage and length, route topology, speed limits, and type of signal control was collected.

Train travel time was used as a measure of the effectiveness of line-haul operations (the lower the travel time, all other things being equal, the more efficient the operation of the railroad). Train travel time on each studied route depends on:

1. The physical limitations of train and route
2. Speed limits
3. Delays unrelated to traffic (mechanical, signal, etc.)
4. Volume, type, and timing of other traffic on the line

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[13] The model described here is in part the result of earlier work in which a number of different model forms were evaluated on a trial and error basis. While other model formulations may appear more direct and some could prove more meaningful, it is often difficult to obtain the data necessary to drive such models, and some proposed formulations although tried were not successful. For a description of other approaches investigated, see Resor, R.R., Smith, M.E., and Patel, P.K., "Train Dispatching Effectiveness with Respect to Advanced Train Control Systems: Quantification of the Relationship," *Transportation Research Record #1584,* Washington, D.C., 1997.

For each train, the minimum travel time over the route (absent constraints numbers three and four above) was calculated using a Train Performance Calculator or Train Energy Model. This was called the Unobstructed Travel Time (UTT). For each train, there is also an Actual Travel Time (ATT), defined as the actual observed running time for that train in the data collected for this analysis. The dependent variable, called "Performance Effectiveness" or η, is simply the sum of UTT divided by the sum of ATT, summed for each daily train on each corridor.

The independent variables proved more difficult to define. O/S interval, as measured from the raw data, is modified as a model variable to the amount of time required for a response to occur once a schedule deviation occurs. This has been defined as half the average time between receipt of position updates (half the O/S interval) plus two minutes, for the following reasons: 1) If a dispatcher requires position information at random intervals throughout his shift, he will have to wait, on average, half the time between O/S reports to receive a position update; 2) Having received the O/S information, two minutes is required to develop and transmit the revised plan.

It seemed reasonable that as the volume of traffic increased, train conflicts would increase, making the dispatcher's job more complex and reducing performance effectiveness.[14] Therefore a traffic density variable, train minutes per route mile, was included as an independent variable. Train minutes per route mile is a hybrid measure, measuring both volume and speed of traffic, so it would appear to directly include some effect of route topology (such as severe grades, or low speed limits on sharp curves) as well.

Finally, to measure the ability of the installed track infrastructure to handle traffic without saturating, a measure of capacity, track miles per route mile was included as an independent variable. This measure reflects the number and length of sidings on a single track line, or the mileage of double track or multiple track on more developed corridors.

The model described postulates that the effectiveness of operation on any specified corridor (basically, the closeness of total *actual* train operations hours to total *ideal* train operations hours) depends upon:

1. The type of train control system (measured through O/S interval)

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[14] Traffic volume affects performance effectiveness because, particularly on single track lines, trains get in each others' way, and also because the complexity of the dispatching problem increases with the number of trains. On a single-track railroad with very light traffic and no meets between trains, performance effectiveness could approach 100%. The busier the railroad, the more meets must occur, and therefore the more delays. Performance effectiveness will never reach 100%. However, railroad performance will depend not just upon the volume of traffic but on how fast trains move, how readily they can return to track speed after meet delays, and on whether overtakes as well as meets are routinely carried out.

2. The physical capacity of the route (track miles per route mile)
3. Train minutes per route mile (a measure of both operating speed and number of trains)

Upon preliminary evaluation, an exponential form was deemed most appropriate for the model. This is a standard treatment of the effect of increasing traffic volume on the performance of a transportation facility. The value of performance effectiveness is likely to be asymptotic with respect to the independent variables. For example, as traffic density increases, transit times will increase exponentially with an infinite value occurring at the ultimate capacity of the line. Therefore, a log-log form was chosen for the regression.

5.5 Regression Model Results

Regression analysis is a technique for testing a hypothesis. First, the independent variables that are presumed to be relevant must be defined. Second, the relationship between these independent variables and the dependent variable (in this case, performance effectiveness) must be specified. Finally, regression of the independent variables will produce results which indicate (by the signs of the coefficients and by T-tests of significance) whether the postulated model formulation is correct and whether any of the variables is a statistically significant predictor of the observed variance.

The final form of the equation quantifying the relationship between performance effectiveness, and the independent variables was as follows:

$$\eta = \frac{d^c}{y^a v^b}$$

where:

η = performance effectiveness
y = average dispatching update interval (1/2 O/S interval + 2 minutes)
v = traffic volume and flow (train-minutes per route mile)
d = capacity (track miles per route mile)

and a, b, and c are the exponents determined from analysis of train movement data.

The exponents a, b and c > 0.

It follows from this equation that η d, η 1/y and η 1/v. The overall effectiveness of train operations on any corridor can be determined, using simulated and observed data, by the following formula:

$$\eta = \Sigma t_{iTPC} / \Sigma t_{iCASE}$$

where:

η = performance effectiveness for the corridor
t_{iTPC} = theoretical running time for train i, the minimum feasible running time as determined by the Train Performance Calculator
t_{iCASE} = the actual running time for train i on the corridor from railroad dispatching records.

A cross-sectional logarithmic regression was used to determine values for the exponents a, b, and c. Using the data described in the previous sections, a log-log regression was carried out, initially for all trains on all 33 line segments for which data were available. Initial results were not satisfactory, due to a very poor performance effectiveness for the Barstow-Los Angeles segment. This was due to a very large number of train delay minutes, caused in part by track maintenance work during the sample period and in part by unique operating difficulties: a 3% descending grade which required trains to stop and perform lengthy safety checks, entailing several hours of delay for each train. After a number of attempts to rectify the problems with the Barstow - Los Angeles segment data, it was removed from the data set.[15]

Regression results for the remaining 32 corridors are shown in Table 14. All three variables test positive for significance. The R^2 term indicates a reasonable predictive relationship considering the relatively small number of data points in the analysis. The residuals show no bias in the results. The signs of the regression-derived coefficients are as expected; that is, effectiveness is inversely related to O/S interval and traffic volume (if the value of either variable increases, effectiveness decreases) and directly related to line capacity (the more track miles per route mile, the higher the performance effectiveness).

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[15] Several attempts were made to adjust the Barstow - L.A. data to produce more satisfactory results. First, on the advice of BNSF Operations Planning staff, 45 minutes was removed from each westbound train's travel time to account for the mandatory safety stop at Cajon summit. This produced little improvement in the regression results, since average delay per train was close to five hours. A second adjustment was made, removing all trains from the sample which incurred more than seven hours of delay (minimum unconstrained running time is about five hours, so trains with this much delay would have to be re-crewed, introducing an unpredictable delay dependent on crew availability, not dispatching). This was equally unsuccessful in improving the regression results.

Table 14: Results of the Regression Analysis

Constant:	0
Std. Error of Y Est.	0.07
R^2	0.34
No. of observations	32
Degrees of freedom	29

	Track Miles/ Route Mile	Train Minutes/ Route Mile	Dispatching Update Interval
X coefficients	c = 0.47	b = -0.10	a = -0.07
Std. Error of Coefficient	0.16	0.04	0.04
T. Statistics	2.96	-2.74	-2.04

Some general conclusions can be drawn from the data. First, a low O/S interval can produce high performance effectiveness even with heavy traffic. By contrast, infrequent train position reports will not degrade performance effectiveness where a line is partially or entirely double track. However, heavy traffic on single track with even a moderate O/S interval produces dramatically lower effectiveness. Here route topology may play a role as well, since some of the segments are located on extremely mountainous routes. The effect of terrain on operations may not be fully captured by the train minutes per route mile variable in these cases. Also, speed limits on sidings, length of sidings, and entrance speeds to sidings (time required to clear the main track) were not explicitly modeled here, and may be another source of the unexplained variance in the model. Finally, variations in the skill level and workload of dispatchers remain a source of unexplained variance as well.

Table 15 shows the 32 line segments used in the analysis, with corresponding values for the variables in the regression as well as a calculated performance effectiveness. The line segments for the study corridors are as follows:

Chattahoochee – Flomaton	Line Segment 30
Syracuse – Buffalo	Line Segment 1
Lincoln – North Kansas City	Line Segment 32
Seattle – Portland	Line Segment 18

Table 15: Data Used in the Regression Analysis (Sorted by Declining Performance Effectiveness)

Corridor	Track Miles/ Route Mile	Train Minutes/ Route Mile	Dispatching Update Interval	Performance Effectiveness
1	2.4	50.58	4.95	0.96
2	1.07	9.65	17.88	0.93
3	2	27.46	16.17	0.92
4	1.07	3.47	18.42	0.90
5	1.28	8.04	5.87	0.88
6	1.49	16.35	5.68	0.84
7	1.17	17.76	10.54	0.84
8	1.07	44.16	7.5	0.83
9	1.75	24.53	5.5	0.82
10	1.77	17.71	8.9	0.82
11	1.48	13.74	11.86	0.82
12	2	47.88	7	0.81
13	1.3	17.61	7.5	0.78
14	1.18	13.79	4.62	0.77
15	1.52	27.04	7.68	0.75
16	1.17	17.92	9.18	0.75
17	1.19	19.9	5.35	0.73
18	1.99	49.31	5.75	0.73
19	1.14	32.03	7.5	0.72
20	1.22	23.86	6.85	0.72
21	1.18	21.87	6	0.68
22	1.15	7.57	4.8	0.68
23	1.08	13.73	18.18	0.67
24	1.25	31.04	14	0.66
25	1.1	15.98	15	0.65
26	1.2	5.07	11.76	0.62
27	1.12	24.69	12.1	0.58
28	1.55	36.66	9.85	0.55
29	1.1	16.31	7.68	0.53
30	1.04	15.67	88.8	0.51
31	1.04	8.45	25.64	0.47
32	1.17	39.71	8.4	0.45

5.6 Equipment Utilization Benefits

The benefits of PTC in terms of equipment utilization are based on the improved running times over each lane, and the resulting savings in locomotive and freight car hours. These improved running times are the product of better information about train location and performance (decreased O/S interval).

The cost per train-hour used in this benefit calculation is based on the ownership costs of the equipment only, since PTC implementation would result in fewer locomotives and cars being required to provide the same transportation service. Table 16 provides a summary of cost calculations based on the following assumptions:

• Locomotive purchase price:	$1,500,000
• Economic life	30 years
• Discount rate	7%

• Freight car purchase price (typical)	$50,000
• Economic life	40 years
• Discount rate	7%

Table 16: Locomotive and Car Ownership Cost

	Ownership Cost		
	Annual	Daily	Hourly
Locomotive	$120,880	$331.18	$13.80
Car	$3,750	$10.28	$0.43
	Cost per Train Hour		
Avg. train size		locos	2.5
		cars	66.3
Train hr. cost		locos	$34.50
		cars	$28.51
		Total	$63.01

Table 17 shows calculated benefits from improved equipment utilization, reflected as reduced equipment ownership cost, due to implementation of PTC on the five study corridors. Equipment ownership cost per train hour is as shown in Table 16.

Table 17: Equipment Utilization Benefits Due to PTC

Corridor	Dispatching Update Interval, mins	Performance Effectiveness [16]			Train Hours			Running Time Reduction, hours [17]		Annual Benefit @ $63.01/train hour
		Actual	Predicted	PTC	Actual	Pre-dicted	PTC	Daily	Annual	
Chattahoochee - Flomaton	88.00	50.99%	58.93%	72.69%	120.2	111.0	84.3	26.7	9,745	$614,032
Syracuse - Buffalo	4.95	96.45%	95.13%	99.37%	118.8	127.0	116.1	10.9	3,978	$250,654
Lincoln – North Kansas City	9.39	45.02%	62.24%	73.37%	295.5	210.0	188.6	21.4	7,811	$492,171
Barstow - Los Angeles	8.36	43.72%	82.92%	98.65%	439.8	235.0	204.8	30.2	11,023	$694,559
Seattle - Portland	5.75	72.93%	85.19%	92.01%	210.1	187.0	177.2	9.8	3,577	$225,387

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[16] Actual effectiveness is the calculated performance effectiveness, the ratio between minimum possible train hours and actual train hours (including delays). Predicted effectiveness is the value produced by the regression equation for each corridor's variable values. PTC effectiveness is the effectiveness produced by the regression equation using the assumed 3.5 minute update rate achievable with PTC.

[17] Running time reductions are calculated as the difference between the predicted and PTC train hours for each corridor.

6.0 Benefits from Fuel Savings

Previous studies by Burlington Northern Railroad and Canadian National Railways examined in detail the potential for fuel savings through use of Positive Train Control. These savings had two sources:

- The use of an "energy management system" to minimize fuel consumption within the constraint of a defined schedule by optimizing each train's velocity profile
- The use of a "pacing" algorithm in the computer-aided dispatching system to supply target arrival times at meet points to trains, allowing them to operate at less than track speed where doing so would meet the arrival target, thereby saving fuel

The energy management system proved to be a very difficult programming task, and while fuel could indeed be saved, schedule targets could not be reliably met. As a result, the focus shifted to pacing of trains, which saved fuel and did not interfere with schedule maintenance.

Both CN and BN developed estimates of fuel savings in the range of 2.5% due to pacing and more efficient dispatching. A great deal of effort was expended in simulations of operations in order to develop these numbers, and they represent the best available estimates of savings from PTC implementation.

On a railroad-wide basis, even a 2.5% savings can be quite significant, although on the five short study corridors examined here, the savings are not large. Total fuel consumption has been estimated using an estimate of 7.62 gallons of fuel per train mile, derived by dividing the total fuel consumption for Class I railroads in 1995, as shown in the AAR *Yearbook of Railroad Facts 1996*, by total train miles operated in the same year. This number is multiplied by the estimated total annual train miles developed from the dispatching data supplied by the three railroads participating in the study. Results are shown in Table 18.

Table 18: Estimated Annual Fuel Savings
Five Study Corridors

	Corridor Length, miles	# of Trains/ Day	Daily Train Miles	Fuel per Trn Mi, Gal	Total Fuel/Day	Annual Fuel, Gal.	Fuel Cost per Gallon[18]	Annual Cost	Savings With PTC	Annual Savings
Chattahoochee - Flomaton	204.5	13	2,659	7.62	20,248	7,390,500	$0.63	$4,656,015	2.50%	$116,400
Syracuse - Buffalo	146	40	5,840	7.62	44,479	16,234,914	$0.63	$10,227,996	2.50%	$255,700
Lincoln – North Kansas City	206.2	45	9,279	7.62	70,672	25,795,165	$0.63	$16,250,954	2.50%	$406,274
Barstow - Los Angeles	146	86	12,556	7.62	95,630	34,905,064	$0.63	$21,990,191	2.50%	$549,755
Seattle – Portland	186.2	49	9,124	7.62	69,490	25,363,717	$0.63	$15,979,141	2.50%	$399,479

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[18] Association of American Railroads, *Railroad Facts – 1996 Edition,* Washington, D.C., 1996.

7.0 Benefits from Improved Customer Service

Improved service reliability has been identified in earlier studies as one of the largest potential benefits of PTC. [19] The ability to exercise more effective control over train movements should bring with it an ability to deliver more reliable service. This analysis, however, deals with five relatively short corridors rather than with entire railroad systems. While modest reductions in running times are achieved over each corridor with the use of improved train control systems, most movements over these corridors also move long distances over other rail lines which, in this analysis, are presumed not to have PTC installed. Therefore the effect of PTC on end-to-end performance, and therefore customer service, is limited in this analysis.

A second issue is that an improvement in performance effectiveness will not affect all traffic the same. The lowest-priority traffic on most rail lines is bulk commodity traffic. In previous analyses for Burlington Northern, improvements of as much as 35% in running time were achieved for this low-priority traffic, without delay to higher-priority trains, simply through better dispatching. However, for coal and grain, the benefit was calculated in terms of reduced equipment requirements (a benefit already addressed here) rather than in improved customer service.

Intermodal traffic is very service-sensitive. However, the intermodal business line already enjoys high priority, and almost certainly will not experience the same improvements in running times as bulk commodity traffic.

Carload freight, however, is still of importance to US railroads. This traffic suffers from relatively poor equipment utilization, due to a number of factors. Carload freight service is generally less reliable than competitive truck service, since most carload shipments have to pass through at least three yards between origin (shipper) and destination (consignee). An example will clarify this point: Let us assume that there are three yards involved in a shipment. In Yard 1, 90% of cars make their first scheduled outbound connections. The same is true in Yards 2 and 3. What is the maximum dock-to-dock probability of on-time performance? It is (.9)(.9)(.9), or 72.9%. More than one out of four shipments fails to meet schedule, a very poor performance, and this despite very good performance at each yard. To improve on this situation, an additional day is often added to published carload freight schedules, so the on-time reliability perceived by the customer appears higher. This scheduling treatment also illustrates that transit time *per se* is not as important to most rail freight shippers as is a

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[19] "Burlington Northern: The ARES Decision", Case Study No. 9-191-122, Harvard Business School, Boston, Massachusetts, 1991.

reasonable reliability of the arrival time. It is worthwhile to briefly examine some performance reliability mathematics.

7.1 Performance Reliability

Assume a typical rail movement of boxcar traffic involves movement through three yards, at origin and destination and at one intermediate classification point. The railroad quotes the customer a schedule that adds one day to the internally-scheduled time. This allows for one missed connection; that is, a shipment may miss no connections, or miss one connection, and still meet its quoted schedule.[20] In this formulation, early arrivals also count as "on time." Then the probability of the customer considering the shipment on time is the probability of its making all its connections plus the probability of missing one connection, which it can do three ways:

$$P_{\text{base}} = P_1P_2P_3 + (1-P_1)P_2P_3 + P_1(1-P_2)P_3 + P_1P_2(1-P_3),$$

where P_1, P_2, and P_3 are the probabilities of making scheduled connections at yards 1, 2, and 3, respectively. If the probability of making scheduled connection at each yard is 80%, then $P_{\text{base}} = 0.896$, or roughly 90% schedule reliabilty as seen by the customer. Without the one day slack time added to the schedule, the schedule reliability under the same assumptions would be only 51%.

Now assume that an improvement in connection probability is made at yard 2, in an amount ΔP_2. The new probability of on-time performance is:

$$P_{\text{new}} =$$
$$P_1(P_2+\Delta P_2)P_3 + (1-P_1)(P_2+\Delta P_2)P_3 + P_1(1-P_2-\Delta P_2)P_3 + P_1(P_2+\Delta P_2)(1-P_3);$$

and the improvement in the probability of on-time performance is:

$$\Delta P = \Delta P_2(P_1 + P_3 - 2P_1P_3).$$

If the probability of making scheduled connection at each yard is 80%, then the equation above reduces to:

$$\Delta P = 0.32(\Delta P_2).$$

This equation shows the relationship between improvement in yard connect probability at a single yard and end-to-end on-time performance for a case in which a car is yarded a total of three times.

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[20] This reflects the assumption that opportunities to make an onward connection generally occur only once each day.

It is assumed that carload freight trains will be yarded once at one end, or near one end, of each studied corridor. Because of the reduced delays and improved running times for carload freight resulting from PTC application on the study corridors, these trains will arrive earlier at this classification point and will therefore have a higher probability of making their scheduled connections. Assume that each train saves two hours on the road, and assume that train arrivals are randomly spread over the day, as is typical at large yards. Thus a steady flow rate of cars is classified to onward destinations, and at 24 hour cutoff intervals trains are assembled for departure. The effect of two hour earlier arrivals from the example corridor is to permit an additional two hours worth of flow rate onto each outbound train, on average, which is an improvement of 2 hr/24 hrs, or 8.3%. Alternatively, eight percent more cars from the study corridor make their "scheduled" daily connections. Assuming linearity between zero and two hour improvements in running times, there is an average improvement of 4.15% in connect probabilities per hour of running time saved.

These relationships may now be used to estimate probable dock-to-dock performance reliability improvement as a result of running time savings. It is assumed that each carload freight car is yarded at one end, or very close to one end, of each study corridor. Table 19 shows the running time savings on each studied corridor, the effect of the running time savings on connection probability at the associated yard, and the effect on the cumulative reliability on a dock-to-dock basis, assuming a three-yard scenario.

Table 19: Estimated Improvement in Connection Probability Due to Reduced Over-the-Road Running Time

Corridor	Reduction in Running Time, Hours/Train	Connection Probability Improvement	Dock-to-Dock Reliability Improvement
Chattahoochee- Flomaton	2.04	8.47%	2.71%
Syracuse-Buffalo	0.27	1.12%	0.36%
Lincoln- North Kansas City	0.47	1.95%	0.62%
Barstow-Los Angeles	0.35	1.45%	0.46%
Seattle-Portland	0.20	0.83%	0.27%

7.2 Revenue Impact of Performance Reliability

As mentioned earlier, the Harvard Business School case study of the BN ARES Project implementation decision noted that in the BN study the benefits attributable to improved customer service were at the same time the largest potential benefits and the least certain of the benefits.[19] In the BN studies, market research was performed to determine the price elasticity with respect to "consistency of transit time," or what we have been calling service reliability. A price elasticity for reliability of two, for example, would mean that shippers would be willing to pay 2% more for a 1% improvement in reliability.

The ARES market survey[21] found that certain carload freight shipments in certain industries might command significant price elasticities for reliability, while cautioning that these results applied only to the studied movements, and would differ for other classes of goods. The study also cautioned that reliability improvements must be delivered consistently over a long period of time for the market to first, perceive and acknowledge them and second, to accept them as real improvements. Specifically, the products evaluated and found to have significant price elasticities with respect to reliability were:

Product	Elasticity
• Pet Food	6.9
• Tires	6.2
• Paper, certain products	6.0
• Plastics	4.7
• Aluminum products & ingots	4.3

These particular commodities were chosen because they move in boxcars and are directly truck-competitive.. (Of the studied commodities, only small percentages of pet food (8%) and tires (6%) were shipped in intermodal service.)

As noted in the case study, railroad marketing department staff found these levels of price elasticity to be unreasonably high, and believed the proper figures were in the 0.0 to 0.3 range. Given the declining revenue yields per ton-mile within the rail industry in recent years, it is easy to understand the marketing staff's viewpoint. Many commodities hauled by rail are seeking the lowest possible freight rate. Further, traffic sensitive to delivery times and schedule reliability often moves by intermodal service (generally higher priced), whereas the commodities generally travelling by carload freight are less sensitive to delivery times and reliability -- this implies that the traffic routing decision may be based more on cost than on service considerations.

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[21] This was a stated preference survey of qualified shippers that defined reliability as "shipments arrive when I want them to."

Much additional market survey and research work is needed to refine the understanding of shipper decision making and the calibration of the relevant elasticities for different commodities, and in aggregations for the general traffic mix. Lacking results of such research, in this analysis we have examined a carload freight traffic commodity breakdown by two-digit commodity code. It can be seen that many of the traffic types highlighted above relate to consumer distribution channels. An estimate has been made of the percentage of each commodity class that might impart a high price elasticity with respect to reliability. (As an example, aluminum ingots may demonstrate this characteristic, as reported, while steel rolls and bars may not, and both are lumped into "primary metal products.") For the portion of each commodity group estimated to be reliability oriented, the elasticities shown above have been adopted. For the balance of the traffic within the group, the assumption is made that price is the most important determining characteristic, reliability is adequate, and the price elasticity with respect to reliability is set to zero. Table 20 displays the commodity groups and the estimated aggregate elasticities by group, along with the rationale for the assignment. The weighted average elasticity for all groups is 1.04. While this analysis is crude, it is believed to be more meaningful than an arithmetic average of opinions.

The estimated effect on revenue can now be determined. Revenue carload freight car-miles are available from tables presented earlier. Average carload and average revenue/ton mile figures have been adopted from AAR data.[22] The reliability improvement times the price elasticity with respect to reliability yields the potential percentage increase in revenue, and this multiplied by the imputed revenue for the carload traffic on the corridor yields the potential increase in revenues which could accrue to this traffic. The calculation of potential benefits from improved customer service are summarized in Table 21.

It should be noted that unlike a cost savings, this cashflow increment could only be achieved through an increase in freight rates. In addition, any cashflow increase from increased rates might be shared among all carriers handling the shipment. Only the portion representing the freight rate division would actually accrue to the carrier making the entire investment in PTC on the studied line segment. These effects are not included in this analysis.

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[22] AAR *Yearbook of Railroad Facts*, 1996. The revenue figure used here (3 cents/ton-mile) is higher than the overall average (2.41 cents/ton-mile in 1995, and 2.35 cents/ton-mile in 1996) to reflect the fact that carload freight receives a higher than average tariff, offset by bulk shipments at lower rates.

Table 20: Estimating an Elasticity for Carload (Mixed) Freight Trains

Commodity Description	Percent of Tons	Estimated Elasticity	Assumptions behind Elasticity Estimates
Forest Products	0.080	0.00	Assume not reliability-oriented traffic
Fresh fish & Produce	0.005	3.40	Assume 50% similar to Pet Food Elasticity of 6.9 or 3.4
Crude Petroleum	0.006	0.00	Assume not reliability-oriented traffic
Non-metallic Minerals	10.800	0.00	Assume not reliability-oriented traffic
Food Products	20.000	3.40	Assume 50% similar to Pet Food Elasticity of 6.9 or 3.4
Tobacco Products	0.020	3.40	Assume 50% similar to Pet Food Elasticity of 6.9 or 3.4
Textile Mill Products	0.070	0.00	Assume not reliability-oriented traffic
Apparel & Related Products	0.008	0.00	Assume not reliability-oriented traffic
Lumber or Wood Products	16.000	0.00	Assume not reliability-oriented traffic
Furniture or Fixtures	0.140	1.20	Assume 20% of Tire Elasticity of 6.2 or 1.2
Pulp and Paper Products	9.200	0.60	Assume 10% of Paper Elasticity of 6.0 or 0.6
Printed Matter	0.060	2.40	Assume 40% of Tire Elasticity of 6.2 or 2.4
Chemical and Allied Products	18.100	0.40	Assume 10% of Aluminum Elasticity of 4.3 or 0.4
Petroleum & Coke	5.700	0.40	Assume 10% of Aluminum Elasticity of 4.3 or 0.4
Rubber & Plastic Products	0.370	2.40	Assume 50% of Plastics Elasticity of 4.7 or 2.4
Leather / Leather Products	0.003	0.00	Assume not reliability-oriented traffic
Stone and Clay Products	8.500	0.00	Assume not reliability-oriented traffic
Primary Metal Products	4.000	1.70	Assume 40% of Aluminum Elasticity of 4.3 or 1.7
Fabricated Metal Prod	0.090	2.20	Assume 50% of Aluminum Elasticity of 4.3 or 2.2
Machinery	0.230	2.20	Assume 50% of Aluminum Elasticity of 4.3 or 2.2
Electrical Machinery & Equipment	0.230	2.20	Assume 50% of Aluminum Elasticity of 4.3 or 2.2
Transportation Equipment	2.800	2.70	Assume 60% of Aluminum Elasticity of 4.3 or 2.7
Instruments., Photo, Optical Goods	0.010	4.30	Assume equal to Aluminum Elasticity of 4.3
Misc. Prod. of Manufacture	0.030	0.00	Assume not reliability-oriented traffic
Waste and Scrap Material	3.400	0.00	Assume not reliability-oriented traffic
Misc. Mixed Shipments	0.140	2.50	Assume 40% of Tire Elasticity of 6.2 or 2.5
Average Elasticity		1.04	

Table 21: Estimated Revenue Impact of Improved Carload Freight Service Reliability

Corridor	Carload Freight Revenue Carmiles, millions	Revenue Ton Miles (RTM),[23] millions	Imputed Revenue @ $0.03 per RTM, millions	Reliability Improvement	Avg. Price Elasticity for Reliability	Potential Revenue Increase	Estimated Revenue Increase
Chattahoochee – Flomaton	21.890	1,429.4	$42.88	2.71%	1.04	2.82%	$1,209,216
Syracuse – Buffalo	92.379	6,032.3	$180.97	0.36%	1.04	0.37%	$669,589
Lincoln – North Kansas City	34.698	2,265.8	$67.97	0.62%	1.04	0.64%	$435,008
Barstow – Los Angeles	77.287	5,046.8	$151.04	0.46%	1.04	0.48%	$724,992
Seattle – Portland	86.958	5,678.4	$170.35	0.27%	1.04	0.28%	$476,980

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[23] Based on average car load of 65.3 tons (from AAR *Yearbook of Railroad Facts, 1996*); car miles calculated as number of carload freight cars (from Table 6) times length of corridor (from Table 1).

8.0 PTC System Capital Costs

The costs of implementing a PTC system on the study corridors have been estimated using assumptions concerning the capabilities of the system and unit costs based, to the greatest extent possible, on quotations from railroad communications and signal industry sources. It is important to recognize that there is no accepted industry-wide technical standard for a PTC system, or for the system architecture of a PTC system, and no large-scale systems have been implemented as of 1997. Significant efforts along these lines have been made in the ACTS and ARES projects, however, and the system considered here has similar functional capabilities. A system with lesser functionality, such as an "overlay" system that operates in parallel with an existing signal system, and depends on the continued existence of that signal system, could have a lower construction cost.

In the sections below, the assumptions and costs are discussed according to the major elements of the system: wayside, central, and vehicle-borne.

8.1 Wayside Costs

It is assumed that the backbone VHF communications system required for a communications-based train control system is already in place in each study corridor, and that radio coverage (signal propagation) is sufficient to permit contact between equipped locomotives and MOW vehicles and "central control" at all points in the territory. If enhancements to the radio system are required to reach this state of coverage, they are presumed to have been made without regard to the application of PTC. It is also assumed that the "refarming" operation (railroad radio frequency channel narrowing and reallocation) has taken place, but that in the absence of PTC the refarmed radio system installed remains an analog one. The PTC project converts the wayside radio base stations to digital radios at an estimated cost of $3,250 per station at an assumed 15-mile spacing, or $217/route mile. (Total cost savings would likely accrue if the digital conversion was made at the time of the refarming conversion.)

It is also assumed that a differential global positioning system (DGPS) is in place on the wayside to interface with DGPS units mounted on the vehicles. It is assumed that there is no railroad cost involved in the provision of the wayside DGPS, as FRA has proposed to underwrite the costs of universal DGPS coverage in the contiguous 48 states and Alaska. It is further assumed that DGPS in connection with switch position information will be sufficient to reliably determine train position among adjacent tracks.

Wayside interface units (WIUs) are provided at field locations where route changes can take place, i.e. interlockings, control points, and at many other points where turnouts and crossovers are present, whether hand-thrown or otherwise. In signaled territory, WIUs interface with existing switch circuit controllers and other existing signaling hardware. One WIU would be needed for each isolated route-change switch, or for a complete interlocking. These are estimated at a cost of $33,480 each installed, and the WIU count is based on an examination of the existing infrastructure. Each WIU includes a data link, safety-critical hardware and software, antenna, housing, foundation, and cable (power is assumed available at the location). No costs for signaling and/or interlocking changes are included in these estimates, nor for enhancements such as slide detectors or bridge motion detectors.

In addition, certain turnouts for access to sidings, spurs, industry tracks, yard leads, and the like must also be equipped with WIUs; these would include switches presently electrically-locked. These are estimated based on a count for the territory involved of switches not associated with crossovers, junctions, or route change points, with 70% of these access-function switches presumed to be equipped with WIUs.

In dark territory, WIUs can not rely on existing equipment to provide switch position information, so switch circuit controllers and associated wiring must be added. The switch circuit controllers are connected to spread-spectrum radio modules (SSRs) having a range of 10 miles. WIUs are installed every 20 miles, and these communicate with SSRs 10 miles on either side. The WIUs then communicate through the VHF backbone to central control. Component costs are as follows:

<u>SSRs</u>	
Case, piers, foundation	$3,690
Cable, antenna pole	1,535
Solar power, batteries	14,200
Circuit controller, switch rods	6,300
Relays	7,700
SSR module with antenna	<u>5,300</u>
	$38,725
<u>WIUs</u>	
Case, piers, foundation, antenna pole	$4,490
Solar power, batteries	14,200
Base WIU	<u>$30,000</u>
Subtotal	$48,690
Add for dark territory:	
SSR receiver module	$5,300
SSR Add-on modules (9 @ $3,100)	<u>27,900</u>
Total (for dark territory)	$81,890

The WIU location costs shown are for specific application to the dark territory in this study, Chattahoochee – Flomaton.

It is further assumed that broken rail protection will be provided as a feature of the PTC system, although it is not present in dark territory now and is not explicitly required under existing FRA regulations. A repeating cut-section coded DC track circuit application is proposed at a unit cost of $30,290 per section; a section provides about 4.2 miles of coverage. This approach is believed to achieve broken rail protection at the lowest possible cost with today's technology.

In dark territory, limited grade crossing warning device modifications are also presumed to be required in connection with the broken rail protection being provided. It is assumed that there is one grade crossing per route mile, on average, and that 25% of these have active protection requiring modifications. (Motion sensor and other overlay types of device controllers would not require these modifications.) The modifications are estimated to cost $17,570 per affected crossing, or an estimated $4,393/route mile in dark territory.

8.2 Central Control Costs

The PTC system envisioned in this analysis has a majority of its data storage and processing functions located at the control center. The center transmits data (including route data) to the trains and also issues appropriate authorities. The dispatching function, whether or not computer-aided, resides at central control. (Central control may in fact be distributed among several satellite centers responsible for portions of the territory if, for example, a PTC installation were applied to an entire railroad.) The central control facilities are assumed built to safety-critical standards.

A key element of central control is the operating system software containing the coding of the rail line territory. A significant amount of labor is involved in modeling the unique physical plant of each mile of railroad. In addition, there are development costs of the operating system which must be recovered through explicit or implicit licensing fees. As no full-scale system has been constructed to date, cost data are scarce. In this study, a $3 million budgetary allowance has been used for the safety-critical basic system software of each project, including the application to 200 miles of rail line. Additional miles of line are added (or subtracted) at $1000/mile.

In addition, $157,000 is estimated for provision of a control console for the corridor including data recorder, digital data link connection, antenna, server, cables, power connections, and modifications to existing central control. It is assumed that the control center will be housed within a larger existing control installation that has sufficient space for the facilities required without new construction or lease. For dark territory, a total of $315,000 is estimated for a safety-critical central control, including a larger stand-alone computer server.

8.3 Vehicle Costs

The major cost of a PTC project lies in equipping the fleet operating over the territory. Both locomotives and self-propelled MOW equipment (including hi-rail cars) must be equipped to ensure full coverage of operations. The components required to accomplish this are described in the cost build-ups shown below:

Locomotives	
DGPS Receiver and Antenna	$ 2,500
Digital Data Radio	2,500
Processor and Software	22,000
Applications software (WOR&LD)	4,000
Throttle/Brake Interface	5,000
Dual Cab Displays	8,500
LD Interface	500
Connecting cables, mounting hardware	2,000
Equipment Subtotal	$47,000
Installation Labor[24]	6,000
Total per Locomotive	$53,000

It is assumed that locomotives being equipped for PTC have LD sensors installed and harnessed to a central point on the locomotive, from which they will be interfaced into the PTC system.

MOW Vehicles	
DGPS Receiver and Antenna	$ 2,500
VHF Antenna	2,000
Digital Data Radio	2,500
Processor and Software	22,000
Cables, mounting hardware	1,000
Equipment Subtotal	$31,800
Installation Labor[24]	4,000
Total per MOW unit	$35,800

In estimating vehicle costs, the following assumptions are made. An average of 2.5 locomotives power each train, and each unit must be equipped. The number of trains that operate each day over the line segment must be equipped, with no reuse of equipment, i.e., all trains are implicitly assumed to be through trains. In the Case A, a 300% pool factor is applied, i.e., three times the minimum daily requirement of

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[24] Installation labor estimates furnished by FRA.

locomotives is assumed to be equipped to constitute the PTC-ready pool. An exception is made for the unique Barstow-Los Angeles link, on which 86 trains/day operate. On this corridor all trains are yarded at each end and are clearly not operating as through trains. An estimate of 500 locomotives to be equipped was used for this link (50 consists x 4 units x 250% pool/service factor). Other pool assumptions are tested in the sensitivity analysis of Chapter 10. In Case B, the pool coverage ratio is 200%; in Case C, it is 100%.

In estimating costs of equipping MOW units (here used to include all non-locomotive vehicles which may be on track), the intent is to equip every manned, self-propelled MOW unit, including hi-rail equipment, assigned to the territory being PTC equipped, and a prorated portion of the system gang equipment. Based on data from several Class I railroads, 0.2 MOW vehicles per route mile are equipped in single-track territory, and 0.3 MOW vehicles per route mile are equipped in double-track or greater territory. This allocation includes hi-rail equipment of all types and from all departments.

8.4 Operations and Maintenance Costs

Since PTC systems are not operating in the US at present, there is no data on O&M costs available. Much of the equipment required does not require adjustment and routine maintenance, but must be replaced when failure occurs, or preferably before. Vehicle-borne and field equipment, WIUs and data radios, will require testing routines with personnel dispatched to replace out-of-tolerance equipment. Changes to the physical plant, from slow orders to new track additions, will require frequent and detailed changes to the software programs running PTC, and this will be a recurring part of normal routine system maintenance. Lacking any true cost experience, an allowance of 5.0% of first cost per year for operations and maintenance has been assumed. This amount is believed to be toward the lower end of the range of O&M cost divided by first cost for complex systems. The costs estimated here relate to costs of the PTC system in excess of those costs encountered in any case, such as for dispatchers. These costs consist primarily of MofE, MofW, and transportation operations personnel and materials to repair and reconfigure all elements of the PTC system whether from failures, accidents, or the continuing requirement to encode bulletin order information in the database.

8.5 Cost Summary

The cost breakdowns for equipping each corridor with PTC are shown on Tables 23 A through E which follow. The total costs for the study corridors are summarized below in Table 22..

Table 22: Capital Costs for PTC on Study Corridors

Corridor	PTC System Capital Cost, $ millions		
	Case A	Case B	Case C
Chattahoochee – Flomaton	22.328	20.159	18.056
Syracuse – Buffalo	28.421	21.849	15.277
Lincoln – North Kansas City	32.456	25.030	17.669
Barstow - Los Angeles	44.471	37.899	24.755
Seattle – Portland	36.804	28.721	20.703

Table 23A: PTC Corridor Cost Estimate
Chatahoochie - Flomaton

Route Miles	204.5
Trains/day	13

Wayside Costs	Unit	Qty.	Unit Cost	Cost, $K
Wayside Interface Unit/SSRadio (dark)	Ea	11	$81,890	901
Switch location module	Ea	108	$38,725	4,182
Wayside Interface Unit, Base	Ea	0	$33,480	0
Radio, VHF, digital upgrade	RM	204.5	$217	44
Broken Rail Protection (dark territory)	Section	66	$30,290	1,999
Grade Crossing Treatment upgrade (dark territory)	RM	204.5	$4,393	898
Central Control Costs				
Central System Hardware/Software, vital, 200 mi	Ea	1	$3,315,000	3,315
Addl/Reduced miles	Ea	4.5	$1,000	5
Vehicles				
Locomotives (Case A)	Ea	98	$53,000	5,194
MOW Units	Ea	41	$35,800	1,468
Sub-Total Cost				18,006
Final Design @ 5%				900
Test/Commissioning @ 4%				720
Contingency @ 15%				2,701
Total Estimated Cost				**$22,328**

Assumptions

Avg. number of locomotives/train	2.5
Locomotive pool coverage ratio, Case A	300%

Locomotive Diagnostic Benefits/Sensitivity Cases

Pool Ratio	Benefit Per Locomotive	No. Locos Equipped	Total Est. Cost	Total Steady State Benefit
100%	$1,300	98	$22,328	127,400
200%	$1,300	65	$20,159	84,500
300%	$1,300	33	$18,056	42,900

Table 23B: PTC Corridor Cost Estimate
Syracuse - Buffalo

Route Miles	146
Trains/day	40

Wayside Costs	Unit	Qty.	Unit Cost	Cost, $K
Wayside Interface Unit/SSRadio (dark)	Ea	0	$81,890	0
Switch location module	Ea	0	$38,725	0
Wayside Interface Unit, Base	Ea	69	$33,480	2,310
Radio, VHF, digital upgrade	RM	146	$217	32
Broken Rail Protection (dark territory)	Section		$30,290	0
Grade Crossing Treatment upgrade (dark territory)	RM		$4,393	0
Central Control Costs				
Central System Hardware/Software, vital, 200 mi	Ea	1	$3,157,000	3,157
Addl/Reduced miles	Ea	-54	$1,000	-54
Vehicles				
Locomotives	Ea	300	$53,000	15,900
MOW Units	Ea	44	$35,800	1,575
Sub-Total Cost				22,920
Final Design @ 5%				1,146
Test/Commissioning @ 4%				917
Contingency @ 15%				3,438
Total Estimated Cost				**$28,421**

Assumptions

Avg. number of locomotives/train	2.5
Locomotive pool coverage ratio, Case A	300%

Locomotive Diagnostic Benefits/Sensitivity Cases

Pool Ratio	Benefit Per Locomotive	No. Locos Equipped	Total Est. Cost	Total Steady State Benefit
100%	$1,300	300	$28,421	390,000
200%	$1,300	200	$21,849	260,000
300%	$1,300	100	$15,277	130,000

Table 23C: PTC Corridor Cost Estimate
Lincoln - Kansas City

Route Miles	206.2
Trains/day	45

Wayside Costs	Unit	Qty.	Unit Cost	Cost, $K
Wayside Interface Unit/SSRadio (dark)	Ea	0	$81,890	0
Switch location module	Ea	0	$38,725	0
Wayside Interface Unit, Base	Ea	106	$33,480	3,549
Radio, VHF, digital upgrade	RM	206.2	$217	45
Broken Rail Protection (dark territory)	Section		$30,290	0
Grade Crossing Treatment upgrade (dark territory)	RM		$4,393	0
Central Control Costs				
Central System Hardware/Software, vital, 200 mi	Ea	1	$3,157,000	3,157
Addl/Reduced miles	Ea	6.2	$1,000	6
Vehicles				
Locomotives	Ea	338	$53,000	17,914
MOW Units	Ea	42	$35,800	1,504
Sub-Total Cost				26,174
Final Design @ 5%				1,309
Test/Commissioning @ 4%				1,047
Contingency @ 15%				3,926
Total Estimated Cost				**$32,456**

Assumptions

Avg. number of locomotives/train	2.5
Locomotive pool coverage ratio, Case A	300%

Locomotive Diagnostic Benefits/Sensitivity Cases

Pool Ratio	Benefit Per Locomotive	No. Locos Equipped	Total Est. Cost	Total Steady State Benefit
100%	$3,226	338	$32,456	1,090,388
200%	$3,226	225	$25,030	725,850
300%	$3,226	113	$17,669	364,538

Table 23D: PTC Corridor Cost Estimate
Barstow - Los Angeles

Route Miles	146
Trains/day	86

Wayside Costs	Unit	Qty.	Unit Cost	Cost, $K
Wayside Interface Unit/SSRario (dark)	Ea	0	$81,890	0
Switch location module	Ea	0	$38,725	0
Wayside Interface Unit, Base	Ea	139	$33,480	4,654
Radio, VHF, digital upgrade	RM	146	$217	32
Broken Rail Protection (dark territory)	Section		$30,290	0
Grade Crossing Treatment upgrade (dark territory)	RM		$4,393	0
Central Control Costs				
Central System Hardware/Software, vital, 200 mi	Ea	1	$3,157,000	3,157
Addl/Reduced miles	Ea	-54	$1,000	-54
Vehicles				
Locomotives	Ea	500	$53,000	26,500
MOW Units	Ea	44	$35,800	1,575
Sub-Total Cost				35,864
Final Design @ 5%				1,793
Test/Commissioning @ 4%				1,435
Contingency @ 15%				5,380
Total Estimated Cost				**$44,471**

Assumptions

Avg. number of locomotives/train	4 (50 consists base)
Locomotive pool coverage ratio, Case A	250%

Locomotive Diagnostic Benefits/Sensitivity Cases

Pool Ratio	Benefit Per Locomotive	No. Locos Equipped	Total Est. Cost	Total Steady State Benefit
100%	$3,226	500	$44,471	1,613,000
200%	$3,226	400	$37,899	1,290,400
300%	$3,226	200	$24,755	645,200

Table 23E: PTC Corridor Cost Estimate
Seattle - Portland

Route Miles	186.2
Trains/day	49

Wayside Costs	Unit	Qty.	Unit Cost	Cost, $K
Wayside Interface Unit/SSRadio (dark)	Ea	0	$81,890	0
Switch location module	Ea	0	$38,725	0
Wayside Interface Unit, Base	Ea	149	$33,480	4,989
Radio, VHF, digital upgrade	RM	186.2	$217	40
Broken Rail Protection (dark territory)	Section		$30,290	0
Grade Crossing Treatment upgrade (dark territory)	RM		$4,393	0
Central Control Costs				
Central System Hardware/Software, vital, 200 mi	Ea	1	$3,157,000	3,157
Addl/Reduced miles	Ea	-13.8	$1,000	-14
Vehicles				
Locomotives	Ea	368	$53,000	19,504
MOW Units	Ea	56	$35,800	2,005
Sub-Total Cost				29,681
Final Design @ 5%				1,484
Test/Commissioning @ 4%				1,187
Contingency @ 15%				4,452
Total Estimated Cost				**$36,804**

Assumptions

Avg. number of locomotives/train	2.5
Locomotive pool coverage ratio. Case A	300%

Locomotive Diagnostic Benefits/Sensitivity Cases

Pool Ratio	Benefit Per Locomotive	No. Locos Equipped	Total Est. Cost	Total Steady State Benefit
100%	$3,226	368	$36,804	1,187,168
200%	$3,226	245	$28,721	790,370
300%	$3,226	123	$20,703	396,798

9.0 Benefit/Cost Analysis

An analysis has been performed of the costs and business benefits of PTC as applied to the sample corridors, using the benefit and cost data developed in the prior chapters. A number of factors undergird this analysis and are important in understanding and interpreting the results correctly.

- This analysis is essentially an investment analysis, examining the costs and benefits as cash streams incurred by the investing party, in this case presumed to be the owning railroad appropriate to each corridor evaluated.
- The cashflow analysis is based on considerations appropriate to a private sector investor, and includes no consideration of public benefits or any benefits external to the business of operating a railroad.
- Safety benefits, a portion of which may have an impact on railroad cashflow, are not considered in this analysis, but it is FRA's intention to include them in a total benefit/cost analysis at a later date.
- The analysis is conducted in 1997 constant dollars (real dollars rather than current dollars) and the effects of future inflation are therefore nullified, assuming that costs and benefits would in actuality increase together at the same rate in years following 1997.
- The analysis is static in terms of traffic growth, traffic composition, etc., and attempts to examine the impact of PTC on today's railroads extended into the future period without detailed projections of future conditions.
- In keeping with Office of Management and Budget (OMB) guidelines for benefit/cost studies, the analysis incorporates a real discount rate of 7.0%. This level, when adjusted upward by the nominal inflation rate, is not too dissimilar from the general cost of capital in the railroad industry (11.7% in 1995 on a regulatory capital basis).[18]

9.1 Timing Effects

In order to evaluate properly the costs and benefits of PTC, it is important to place the costs and benefits incurred at the right point in time, so that the discounting mechanism implicit in a discounted cashflow analysis is effected correctly. Timing considerations affect both costs and benefits.

Cost Effects

Capital costs for PTC system development and installation are estimated to be incurred over a three-year period. In the first year planning and design will predominate, and the cash expense is estimated at 5% of total system cost. In the second and third years, procurement and installation, testing, and qualification of the various PTC components will take place, with cash outflows of 30% and 65%, respectively.

Benefit Effects

Benefits will begin to accrue in the fourth project evaluation year, following completion of construction, installation, and testing in year three. Because of the complex interaction of PTC-provided business data with the management and control systems of a railroad, the potential benefits identified in earlier chapters will not be available fully at the inception of operations. While it is not known precisely how long a period of training and development will be required to attain the "steady state" benefit levels estimated earlier, it is clear that such a process will be required. There will be "teething" and "burn-in" problems with hardware and software, management systems must be changed to accommodate and capitalize on the new information available from PTC, new operating rules and procedures must be written and promulgated, employees must be trained and qualified in new routines, and this entire process will involve a certain amount of trial, error, and revision. This is particularly the case inasmuch as a large-scale implementation of a full PTC system has yet to be undertaken by an American Class I railroad.

This training and development factor is reflected in the analysis by "ramping up" the benefits during the early years of operation of the PTC system. For all benefits other than customer service (improved reliability), it is estimated that 30% of steady state benefits will be available in the first operating year, 50% in the second year, 70% in the third year, 90% in the fourth year, and 100% in year five and following years.

The customer service benefits from improved reliability are subject to all of the factors discussed above. In addition, as emphasized by the BN market studies during the ARES project, customer service improvements must be routinely delivered (as opposed to now and then) in order for an improvement to be "believed" and considered real in the marketplace. Furthermore, it will take additional time for the fact of a routinely delivered improvement to be disseminated through the shipper community to the point where it has economic value, i.e., that shippers would be willing to pay for the improvement. This is particularly true for improvements in railroad segments s short as those covered in this analysis. Much quicker reaction from the shipper community can be expected from improvements on longer route segments having more noticeable effects.

As a result, customer service benefits lag other benefits in their timing. In this analysis, estimated availability of steady state customer service benefits is as shown below:

Operating Year 1	10%
Operating Year 2	25%
Operating Year 3	40%
Operating Year 4	55%
Operating Year 5	70%
Operating Year 6	85%
Operating Year 7	100%

9.2 Benefit/Cost Analysis Results

Table 24 summarizes the results of the benefit/cost analysis of PTC applications in the five study corridors. In Case A, the pool coverage ratio is assumed to be 300% (except between Barstow – Los Angeles). In Case B, it is assumed that the pool coverage ratio is 200% for each corridor, and in Case C it is assumed to be 100%. These cases can alternatively be thought of as reflecting more aggressive management of the equipped locomotive pool by the implementing carrier(s). While this task becomes easier with widespread application of PTC, it is by no means impossible to achieve reduced pool coverage requirements under even moderate implementations.

Benefit-cost ratios range from 0.34 to 0.90 for the five corridors. Two corridors have B/C ratios of roughly 0.6, indicating that there are significant benefits present, although too low to warrant investment on a corridor stand-alone basis. It must be remembered that corridors are being evaluated in isolation, and that this is the most costly method of implementation.

Clearly, the business benefits make up only a portion of the benefits that must be considered in any benefit/cost analysis. In a separate study, FRA is in the process of quantifying the expected safety benefits, including the reduction in deaths, injuries, and property damage in railroad-related incidents. Also to be considered are additional safety and environmental benefits resulting from possible diversion of truck traffic to the safer and less polluting rail mode. A more thorough treatment of all benefits along with costs, will be contained in a forthcoming FRA report.

Tables 25A through 25E present the cashflows for each corridor over a 30-year evaluation period, consisting of three years of design and construction, and 27 years of operation, beginning in 1998. These tables provide backup detail for the Case A information summarized in Table 24.

Table 24: Positive Train Control Benefit-Cost Evaluation*
Summary Results by Corridor

Corridor	Discounted Business Benefits ($ millions)	Discounted Costs ($ millions)	Ratio of Business Benefits to Costs
Chattahoochee – Flomaton			
Case A	*16.641*	*29.665*	*0.56*
Case B	*16.271*	*26.783*	*0.61*
Case C	*15.912*	*23.989*	*0.66*
Syracuse – Buffalo			
Case A	*12.937*	*37.760*	*0.34*
Case B	*11.815*	*29.028*	*0.41*
Case C	*10.693*	*20.297*	*0.53*
Lincoln – North Kansas City			
Case A	*20.716*	*43.121*	*0.48*
Case B	*17.569*	*33.255*	*0.53*
Case C	*14.450*	*23.475*	*0.62*
Barstow – Los Angeles			
Case A	*37.867*	*59.084*	*0.64*
Case B	*35.083*	*50.352*	*0.70*
Case C	*29.513*	*32.889*	*0.90*
Seattle – Portland			
Case A	*19.483*	*48.897*	*0.40*
Case B	*16.058*	*38.158*	*0.42*
Case C	*12.660*	*27.506*	*0.46*

** Assesses the effects of business benefits against PTC capital and O&M costs.*

Table 25A: PTC Benefit-Cost Evaluation — Chattahoochee-Flomaton

	Year	*Costs ($ × 1,000)*		*Benefits ($ × 1,000)*					*Discounted Present Valuations*		
		Capital	***O&M***	***Work Order Reporting***	***Locomotive Diagnostics***	***Fuel Savings***	***Equipment Utilization***	***Customer Service***	***Costs***	***Benefits***	***Annual Net Benefits***
1	1998	(1,116.4)	–	–	–	–	–	–	(1,043.4)	–	(1,043.4)
2	1999	(6,698.4)	–	–	–	–	–	–	(5,850.6)	–	(5,850.6)
3	2000	(14,513.2)	–	–	–	–	–	–	(11,847.1)	–	(11,847.1)
4	2001	–	(1,116.4)	0.5	38.2	34.9	184.2	120.9	(851.7)	288.9	(562.8)
5	2002	–	(1,116.4)	0.8	63.7	58.2	307.0	302.3	(796.0)	521.9	(274.1)
6	2003	–	(1,116.4)	1.1	89.2	81.5	429.8	483.7	(743.9)	723.1	(20.8)
7	2004	–	(1,116.4)	1.4	114.7	104.8	552.6	665.1	(695.2)	895.8	200.6
8	2005	–	(1,116.4)	1.5	127.4	116.4	614.0	846.5	(649.8)	992.8	343.1
9	2006	–	(1,116.4)	1.5	127.4	116.4	614.0	1,027.8	(607.2)	1,026.5	419.3
10	2007	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(567.5)	1,051.6	484.0
11	2008	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(530.4)	982.8	452.4
12	2009	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(495.7)	918.5	422.8
13	2010	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(463.3)	858.4	395.1
14	2011	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(433.0)	802.2	369.3
15	2012	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(404.6)	749.8	345.1
16	2013	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(378.2)	700.7	322.5
17	2014	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(353.4)	654.9	301.4
18	2015	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(330.3)	612.0	281.7
19	2016	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(308.7)	572.0	263.3
20	2017	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(288.5)	534.6	246.1
21	2018	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(269.6)	499.6	230.0
22	2019	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(252.0)	466.9	214.9
23	2020	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(235.5)	436.4	200.9
24	2021	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(220.1)	407.8	187.7
25	2022	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(205.7)	381.1	175.4
26	2023	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(192.2)	356.2	164.0
27	2024	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(179.7)	332.9	153.2
28	2025	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(167.9)	311.1	143.2
29	2026	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(156.9)	290.8	133.8
30	2027	–	(1,116.4)	1.5	127.4	116.4	614.0	1,209.2	(146.7)	271.7	125.1
Evaluation Period		(22,328.0)	(30,142.8)	39.1	3,236.0	2,956.6	15,596.4	28,839.8	(29,664.8)	16,641.0	(13,023.8)

Benefit-Cost Ratio	**0.56**	**Internal Rate of Return**	**-7.0%**

Table 25B: PTC Benefit-Cost Evaluation — Syracuse-Buffalo

Year		Costs ($ × 1,000)		Benefits ($ × 1,000)					Discounted Present Valuations		
		Capital	O&M	Work Order Reporting	Locomotive Diagnostics	Fuel Savings	Equipment Utilization	Customer Service	Costs	Benefits	Annual Net Benefits
1	1998	(1,421.1)	–	–	–	–	–	–	(1,328.1)	–	(1,328.1)
2	1999	(8,526.3)	–	–	–	–	–	–	(7,447.2)	–	(7,447.2)
3	2000	(18,473.7)	–	–	–	–	–	–	(15,080.0)	–	(15,080.0)
4	2001	–	(1,421.1)	3.2	117.0	76.7	75.2	67.0	(1,084.1)	258.7	(825.4)
5	2002	–	(1,421.1)	5.4	195.0	127.9	125.3	167.4	(1,013.2)	442.7	(570.5)
6	2003	–	(1,421.1)	7.5	273.0	179.0	175.5	267.8	(946.9)	601.6	(345.3)
7	2004	–	(1,421.1)	9.7	351.0	230.1	225.6	368.3	(885.0)	737.7	(147.2)
8	2005	–	(1,421.1)	10.7	390.0	255.7	250.7	468.7	(827.1)	800.7	(26.3)
9	2006	–	(1,421.1)	10.7	390.0	255.7	250.7	569.2	(773.0)	803.0	30.0
10	2007	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(722.4)	801.5	79.1
11	2008	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(675.1)	749.1	73.9
12	2009	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(631.0)	700.1	69.1
13	2010	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(589.7)	654.3	64.6
14	2011	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(551.1)	611.5	60.4
15	2012	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(515.1)	571.5	56.4
16	2013	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(481.4)	534.1	52.7
17	2014	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(449.8)	499.1	49.3
18	2015	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(420.4)	466.5	46.0
19	2016	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(392.9)	436.0	43.0
20	2017	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(367.2)	407.4	40.2
21	2018	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(343.2)	380.8	37.6
22	2019	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(320.7)	355.8	35.1
23	2020	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(299.8)	332.6	32.8
24	2021	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(280.2)	310.8	30.7
25	2022	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(261.8)	290.5	28.7
26	2023	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(244.7)	271.5	26.8
27	2024	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(228.7)	253.7	25.0
28	2025	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(213.7)	237.1	23.4
29	2026	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(199.7)	221.6	21.9
30	2027	–	(1,421.1)	10.7	390.0	255.7	250.7	669.6	(186.7)	207.1	20.4
Evaluation Period		(28,421.0)	(38,368.4)	272.8	9,906.0	6,494.8	6,366.6	15,969.7	(37,759.9)	12,937.1	(24,822.8)

Benefit-Cost Ratio 0.34 **Internal Rate of Return** -10.9%

Table 25C: PTC Benefit-Cost Evaluation — Lincoln-North Kansas City

Year		*Costs ($ × 1,000)*		*Benefits ($ × 1,000)*					*Discounted Present Valuations*		
		Capital	*O&M*	*Work Order Reporting*	*Locomotive Diagnostics*	*Fuel Savings*	*Equipment Utilization*	*Customer Service*	*Costs*	*Benefits*	*Annual Net Benefits*
1	1998	(1,622.8)	–	–	–	–	–	–	(1,516.6)	–	(1,516.6)
2	1999	(9,736.8)	–	–	–	–	–	–	(8,504.5)	–	(8,504.5)
3	2000	(21,096.4)	–	–	–	–	–	–	(17,220.9)	–	(17,220.9)
4	2001	–	(1,622.8)	8.0	327.1	121.9	147.7	43.5	(1,238.0)	494.5	(743.6)
5	2002	–	(1,622.8)	13.3	545.2	203.1	246.1	108.8	(1,157.0)	796.1	(361.0)
6	2003	–	(1,622.8)	18.7	763.3	284.4	344.5	174.0	(1,081.3)	1,056.1	(25.3)
7	2004	–	(1,622.8)	24.0	981.3	365.6	443.0	239.3	(1,010.6)	1,278.6	268.0
8	2005	–	(1,622.8)	26.7	1,090.4	406.3	492.2	304.5	(944.5)	1,350.3	405.8
9	2006	–	(1,622.8)	26.7	1,090.4	406.3	492.2	369.8	(882.7)	1,297.4	414.7
10	2007	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(824.9)	1,245.7	420.8
11	2008	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(771.0)	1,164.2	393.2
12	2009	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(720.5)	1,088.1	367.5
13	2010	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(673.4)	1,016.9	343.5
14	2011	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(629.3)	950.4	321.0
15	2012	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(588.2)	888.2	300.0
16	2013	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(549.7)	830.1	280.4
17	2014	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(513.7)	775.8	262.0
18	2015	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(480.1)	725.0	244.9
19	2016	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(448.7)	677.6	228.9
20	2017	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(419.4)	633.3	213.9
21	2018	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(391.9)	591.8	199.9
22	2019	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(366.3)	553.1	186.8
23	2020	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(342.3)	516.9	174.6
24	2021	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(319.9)	483.1	163.2
25	2022	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(299.0)	451.5	152.5
26	2023	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(279.4)	422.0	142.5
27	2024	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(261.2)	394.4	133.2
28	2025	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(244.1)	368.6	124.5
29	2026	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(228.1)	344.5	116.3
30	2027	–	(1,622.8)	26.7	1,090.4	406.3	492.2	435.0	(213.2)	321.9	108.7
Evaluation Period		(32,456.0)	(43,815.6)	677.4	27,695.9	10,319.4	12,501.1	10,374.9	(43,120.7)	20,715.7	(22,405.0)

Benefit-Cost Ratio	**0.48**	**Internal Rate of Return**	**-9.6%**

Table 25D: PTC Benefit-Cost Evaluation — Barstow-Los Angeles

Year		Costs ($ × 1,000)		Benefits ($ × 1,000)					Discounted Present Valuations		
		Capital	O&M	Work Order Reporting	Locomotive Diagnostics	Fuel Savings	Equipment Utilization	Customer Service	Costs	Benefits	Annual Net Benefits
1	1998	(2,223.6)	–	–	–	–	–	–	(2,078.1)	–	(2,078.1)
2	1999	(13,341.3)	–	–	–	–	–	–	(11,652.8)	–	(11,652.8)
3	2000	(28,906.2)	–	–	–	–	–	–	(23,596.0)	–	(23,596.0)
4	2001	–	(2,223.6)	266.7	483.9	164.9	208.4	72.5	(1,696.3)	912.7	(783.6)
5	2002	–	(2,223.6)	444.5	806.5	274.9	347.3	181.2	(1,585.4)	1,464.7	(120.6)
6	2003	–	(2,223.6)	622.2	1,129.1	384.8	486.2	290.0	(1,481.6)	1,940.6	459.0
7	2004	–	(2,223.6)	800.0	1,451.7	494.8	625.1	398.7	(1,384.7)	2,348.0	963.3
8	2005	–	(2,223.6)	888.9	1,613.0	549.8	694.6	507.5	(1,294.1)	2,475.7	1,181.6
9	2006	–	(2,223.6)	888.9	1,613.0	549.8	694.6	616.2	(1,209.5)	2,372.9	1,163.4
10	2007	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(1,130.3)	2,272.9	1,142.6
11	2008	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(1,056.4)	2,124.2	1,067.9
12	2009	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(987.3)	1,985.3	998.0
13	2010	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(922.7)	1,855.4	932.7
14	2011	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(862.3)	1,734.0	871.7
15	2012	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(805.9)	1,620.6	814.7
16	2013	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(753.2)	1,514.6	761.4
17	2014	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(703.9)	1,415.5	711.6
18	2015	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(657.9)	1,322.9	665.0
19	2016	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(614.8)	1,236.3	621.5
20	2017	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(574.6)	1,155.4	580.8
21	2018	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(537.0)	1,079.9	542.8
22	2019	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(501.9)	1,009.2	507.3
23	2020	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(469.1)	943.2	474.1
24	2021	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(438.4)	881.5	443.1
25	2022	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(409.7)	823.8	414.1
26	2023	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(382.9)	769.9	387.0
27	2024	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(357.8)	719.6	361.7
28	2025	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(334.4)	672.5	338.1
29	2026	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(312.5)	628.5	315.9
30	2027	–	(2,223.6)	888.9	1,613.0	549.8	694.6	725.0	(292.1)	587.4	295.3
Evaluation Period		(44,471.0)	(60,035.9)	22,578.6	40,970.2	13,963.8	17,641.8	17,291.1	(59,083.7)	37,867.2	(21,216.5)

Benefit-Cost Ratio	**0.64**	**Internal Rate of Return**	**-5.6%**

Table 25E: PTC Benefit-Cost Evaluation — Seattle-Portland

Year		Costs ($ × 1,000)		Benefits ($ × 1,000)					Discounted Present Valuations		
		Capital	O&M	Work Order Reporting	Locomotive Diagnostics	Fuel Savings	Equipment Utilization	Customer Service	Costs	Benefits	Annual Net Benefits
1	1998	(1,840.2)	–	–	–	–	–	–	(1,719.8)	–	(1,719.8)
2	1999	(11,041.2)	–	–	–	–	–	–	(9,643.8)	–	(9,643.8)
3	2000	(23,922.6)	–	–	–	–	–	–	(19,528.0)	–	(19,528.0)
4	2001	–	(1,840.2)	7.1	356.2	119.8	67.6	47.7	(1,403.9)	456.5	(947.4)
5	2002	–	(1,840.2)	11.8	593.6	199.7	112.7	119.2	(1,312.0)	739.4	(572.6)
6	2003	–	(1,840.2)	16.5	831.0	279.6	157.8	190.8	(1,226.2)	983.3	(242.9)
7	2004	–	(1,840.2)	21.2	1,068.5	359.5	202.8	262.3	(1,146.0)	1,192.2	46.2
8	2005	–	(1,840.2)	23.5	1,187.2	399.5	225.4	333.9	(1,071.0)	1,262.6	191.6
9	2006	–	(1,840.2)	23.5	1,187.2	399.5	225.4	405.4	(1,000.9)	1,219.0	218.0
10	2007	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(935.5)	1,175.6	240.1
11	2008	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(874.3)	1,098.7	224.4
12	2009	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(817.1)	1,026.8	209.7
13	2010	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(763.6)	959.6	196.0
14	2011	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(713.7)	896.8	183.2
15	2012	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(667.0)	838.2	171.2
16	2013	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(623.3)	783.3	160.0
17	2014	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(582.6)	732.1	149.5
18	2015	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(544.4)	684.2	139.8
19	2016	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(508.8)	639.4	130.6
20	2017	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(475.5)	597.6	122.1
21	2018	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(444.4)	558.5	114.1
22	2019	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(415.4)	522.0	106.6
23	2020	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(388.2)	487.8	99.6
24	2021	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(362.8)	455.9	93.1
25	2022	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(339.1)	426.1	87.0
26	2023	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(316.9)	398.2	81.3
27	2024	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(296.1)	372.2	76.0
28	2025	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(276.8)	347.8	71.0
29	2026	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(258.7)	325.1	66.4
30	2027	–	(1,840.2)	23.5	1,187.2	399.5	225.4	477.0	(241.7)	303.8	62.1
Evaluation Period		(36,804.0)	(49,685.4)	598.0	30,154.1	10,146.8	5,724.8	11,376.0	(48,897.4)	19,482.7	(29,414.7)

Benefit-Cost Ratio 0.40

Internal Rate of Return -13.1%

10.0 Scale Sensitivity Considerations

Since the corridors under analysis are all short (150-250 miles) with respect to the average freight car haul of some 840 miles, it is reasonable to examine what the effects of larger-scale implementation of PTC would be, from the standpoint of the benefit/cost analysis.

On the cost side of the equation, increased application of PTC would result in more miles equipped, more locomotives and MOW vehicles equipped, and expanded facilities at central control. On the benefit side, increased benefits would accrue as more traffic was handled under PTC. To the degree that these increases are linear and no economies of scale are present, the results would stay the same, or similar, to the results presented. We will therefore examine the areas in which the effect of increasing scale of implementation results in a change from linearity.

Vehicle Costs

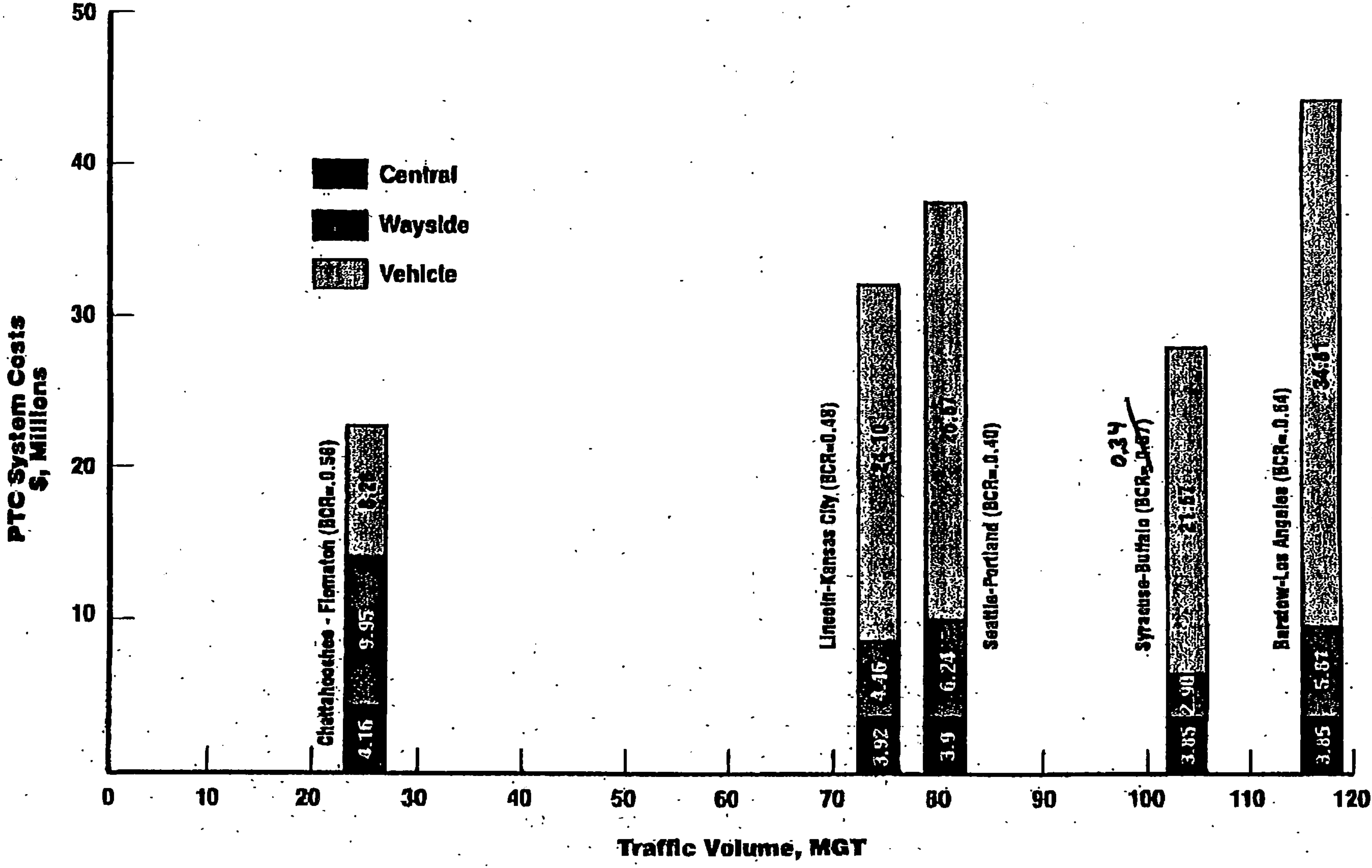
PTC costs are heavily dominated by vehicle costs (locomotives and MOW units). On the four signaled territories examined, vehicle costs varied between 72% and 78% of total PTC system capital costs. Because of the requirement to provide an adequate pool of equipped locomotives, the fleet is being equipped much faster than the infrastructure. For example, if all three of the BNSF corridors studied in this analysis were equipped, using a 300% pool coverage ratiothis would involve an estimated 538 miles of line and 1206 locomotives. This is 2.4% of BNSF miles operated, but 24% of BNSF locomotives owned, ten times the route mile coverage.[18]

A commitment to implement PTC on major BNSF lines could quickly equip the entire railroad's locomotive fleet, with the cost of equipping *additional* lines then falling to only around 10-12% of the costs estimated for corridor applications in this study. (These savings apply within a single railroad or within a single locomotive pool.) This would have a significant positive effect on the benefit/cost ratio.

Figure 3 shows the relative magnitude of the three major cost components of PTC for the studied corridors, plotted against a scale of traffic volume. This plot indicates not only the relative importance of vehicle costs, but also the effect of increasing traffic volumes on this cost component and total system cost.

The highest B/C ratio is associated with the highest traffic volume corridor. In this case, the cashflow tables reveal a significant amount of benefits from reduced evacuations, locomotive diagnostics, and work order reporting, relative to the other corridors. Reduced evacuations relate to the high proportion of hazmat traffic and resulting high predicted evacuations. Large relative LD benefits stem from intensive locomotive use on this mountain line and more efficient locomotive pool assumptions because of the captive nature of the service. Work order reporting benefits come from carload freight and because all traffic on this unique line segment is handled essentially as carload freight these benefits rise markedly.

Figure 3
Cost Components of PTC vs. Traffic Volume
Five Study Corridors - Case A



This example serves to indicate how the particular conditions on a study corridor influence the results, and the difficulty of making judgments without a detailed, site-specific study.

Central Control Costs

Central control costs as estimated account for between 11% and 14% of total costs on the signaled lines studied (11% and 18% of all lines). The roughly $3 million software cost must be borne only once by each carrier. Additional miles covered by PTC would involve additional expense for central control, but at a much lower rate than the average rate for a small corridor implementation.

Unit Costs

As more PTC lines are equipped, unit costs for the various elements of the system could be driven down by the increased size of the market for PTC equipment and competitive forces. This would probably require an interoperable standard to be adopted by the industry.

Service Reliability Benefits

On the benefit side, adding additional miles of PTC would improve benefits mostly on a linear basis. A major commitment by individual railroads to capture the advantage of improved reliability to customers on a system-wide basis, and by the industry acting as a body to improve reliability *across railroad company interfaces* could have a significant accretive effect on dock-to-dock reliability performance. This in turn has the potential to permit positive rate impacts and/or market share gains vis-a-vis truck competition for carload and other types of freight. The extent to which such benefits would accrue would depend on the extent of application of PTC within individual railroads and the degree of commitment of the industry as a whole.

10.1 Sensitivity Tests

From the discussion above it is clear that more widespread application of PTC would generally have a positive effect on the overall benefit/cost ratio of a PTC system. This is due in large part to the reduced significance of locomotive costs as more and more territory is equipped and pool coverage becomes less of a problem. Part of this scale effect can be shown in the present analysis of five corridors by the different results obtained by using different pool coverage ratios between the 100% and 300% level.

In Case A, the pool coverage ratio is assumed to be 300% (except between Barstow – Los Angeles). In Case B, it is assumed that the pool coverage ratio is 200% for each corridor, and in Sensitivity Case C it is assumed to be 100%. These cases can alternatively be thought of as reflecting more aggressive management of the equipped locomotive pool by the implementing carrier(s). While this task becomes easier with widespread application of PTC, it is by no means impossible to achieve reduced pool coverage requirements under even moderate implementations.

Table 26 summarizes the benefit-cost evaluation for three cases for the five study corridors. It is important to note that using a 100% pool ratio applied to the short corridors studied in this report does not account for all the scale effects in the locomotive fleet. As already noted, going from covering 2.4% of BNSF lines with a pool ratio of 300% would require equipping 24% of BNSF's locomotives. Therefore, a 100% ratio would still equip 8%, or nearly three times as many locomotives as miles of line. Estimating the benefits of application of PTC to particular routes or combinations of routes longer than the short segments considered in this report would require consideration of the detailed locomotive movements involved in a case by case basis.

Table 26: Positive Train Control Benefit-Cost Evaluation*
Summary Results by Corridor and Sensitivity Case

Corridor & Case	Benefit-Cost Ratio
Chattahoochee – Flomaton	
Case A	*0.56*
Case B	*0.61*
Case C	*0.66*
Syracuse – Buffalo	
Case A	*0.34*
Case B	*0.41*
Case C	*0.53*
Lincoln – North Kansas City	
Case A	*0.48*
Case B	*0.53*
Case C	*0.62*
Barstow – Los Angeles	
Case A	*0.64*
Case B	*0.70*
Case C	*0.90*
Seattle – Portland	
Case A	*0.40*
Case B	*0.42*
Case C	*0.46*

**Assesses the effects of business benefits against PTC capital and O&M costs.*

An Examination of the Costs and Business Benefits of Positive Train Control,1997, Parsons Brinckerhoff Quade & Douglas, Inc. - 06-Signals, Control & Communications