QUANTIFICATION OF THE BUSINESS BENEFITS OF POSITIVE TRAIN CONTROL

Prepared for the
Federal Railroad Administration

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by

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Executive Summary

Purpose of the Study

The purpose of this analysis is to quantify the "business benefits" of Positive Train Control (PTC for the Class I freight railroad industry[1]. Positive Train Control is a concept, rather than a single technology or system. It can include many different capabilities, covering a range of railroad functions. The three components of PTC are the on-board computer (OBC) with Differential Global Positioning System (DGPS) location capability, a dedicated wireless digital data link between locomotives and a control center, and the central office hardware and software at the control center. Through use of a digital data link and real-time train location information, PTC can be a train control system. The digital data link and the OBC can be used for positive safety enforcement, stopping trains if movement authorities are exceeded. The same data link may also be used to transmit work instructions to train crews, receive acknowledgment of completed work, or transmit locomotive diagnostic information in real time. This report does not address the safety benefits of PTC. These were previously quantified by the Rail Safety Advisory Committee (RSAC)[2], which identified nearly a thousand "PPAs" (PTC-preventable accidents) on U.S. railroads over a 12-year period, and determined the savings to be realized from each avoided accident. The RSAC finding was that avoidance of these PPAs was not, by itself, sufficient (from a strictly economic point of view) to justify an investment in PTC.

The Congress of the United States then directed FRA to conduct a separate evaluation of the business benefits of PTC. These are the savings railroads (and shippers) might expect to see if PTC is deployed on the U.S. railroad network. Examples of potential business benefits include:

- line capacity enhancement
- improved service reliability
- faster over-the-road running times
- more efficient use of cars and locomotives (made possible by real-time location information)
- reduction in locomotive failures (due to availability of real-time diagnostics)
- larger "windows" for track maintenance (made possible by real-time location information)
- fuel savings

Definition of Positive Train Control

Any PTC installation will consist of three distinct segments:

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[1] The Surface Transportation Board classifies railroads as "Class 1" if they exceed an annual revenue threshold -- $266.6 million in 2001. In that year, there were seven Class 1 railroads, 34 "regional" railroads (revenues of at least $40 million annually but less than the Class I threshold) and 529 "local" railroads with less than $40 million in annual revenues.

[2] RSAC is a working group composed of representatives from railroads, rail labor, rail industry suppliers, and FRA. Its purpose is to develop safety regulations for the rail industry by reaching a consensus among the various stakeholders.

- The vehicle segment: on-board computer (OBC), location system, digital data link
- The wayside segment: wayside interface units for defect detectors, signals, and track switches; radio towers
- The central office segment: central computers, dispatcher interface

Since PTC is a collection of technologies, rather than one specific system, it may incorporate a range of functions. For the purposes of this analysis, two types of PTC have been defined. "PTC A" is an "overlay" system that provides enforcement of movement authorities, but does not incorporate a "vital" central safety system. Existing train control methods (signals and/or voice radio) remain in use, with PTC A providing positive enforcement (e.g., trains are stopped before they exceed authority limits). PTC A can rely solely on DGPS for location. Since PTC A incorporates a digital radio link and OBC, it can also be used to issue "work orders" (instructions to train crews regarding the pick-up and delivery of freight cars), transmit locomotive diagnostics, and record crew on-duty and off-duty times and train delays. Provision of real-time train location and speed to train dispatchers via the digital data link has been presumed to improve dispatching effectiveness, reducing train delays and increasing line capacity.

"PTC B" is a stand-alone vital system. Just as does PTC A, PTC B incorporates an OBC on each locomotive and a digital data link between locomotives and a central office. PTC B also includes a vital central safety system. This function requires more precise location information than PTC A. The PTC B evaluated here is based on the North American Joint PTC project in Illinois. In this test installation, DGPS is supplemented with accelerometers and a gyroscope that give locomotives the ability to resolve location down to a particular track. This increases the cost of on-board equipment.

The increased location accuracy enables PTC B to support "moving block" operation, in which the distance between following trains is reduced to that required to stop the following train short of a rear-end collision.[3]

Quantification of Benefits

The benefits of PTC are realized in a number of ways. Line capacity and service reliability are improved, in PTC A, by the availability of accurate, real time data on train location and speed. This enables train dispatchers to respond more quickly to service disruptions, and to more quickly formulate alternative dispatching plans as circumstances change.

PTC B permits trains to follow more closely, increasing line capacity even further than PTC A. Faster over-the-road running times, again, result from better "meets"

[3] Conventional signal systems relay on geographic blocks of fixed length. The length of these blocks must always be sufficient to allow the longest and heaviest train to stop safely. Further, since the blocks are of fixed length, time separation between trains lengthens when trains travel at less than "track speed" (maximum allowed speed). Both of these factors reduce capacity, because both distance and time separation between trains can be longer than necessary to ensure safety.

between trains (since dispatchers know train position more accurately and, in PTC B, trains can follow more closely).

Again, the real-time location information provided by both PTC A and PTC B enables railroad managers to exercise more effective control of locomotives and freight cars, increasing asset productivity.

PTC A and PTC B both provide the capability to issue instructions ("work orders") to train crews in real time. These instructions direct crews to deliver or pick up freight cars; PTC also permits the crews to report the completion of this work in real time. Again, this permits more effective management of rail equipment.

The digital data link in both PTC A and PTC B can be used to report diagnostic data on locomotives in real time, allowing shop forces to diagnose malfunctions and order necessary parts before a locomotive arrives in the shop. Diagnostics also should provide warning of impending failures, possibly allowing train crews to take actions that avoid an en-route failure that delays trains.

Real-time data on train location and speed also will allow track maintenance forces (track inspectors and others) to more effectively utilize their time. Traffic density on the U.S. rail network has increased significantly since deregulation of the industry in 1981. This has made the scheduling of track time for inspection and maintenance more and more difficult. Real-time, accurate information on train location should permit an increase in the productivity of track forces.

Finally, real-time position information will allow train dispatchers to "pace" trains between scheduled meet points, permitting fuel savings. Current practice is to run trains at maximum authorized speeds, often arriving at meet points well ahead of schedule. With real-time information on the location of opposing trains, it may be possible to slow a train down to save fuel while still arriving on schedule at the meet point.

Note that some of these benefits might be obtained by other means. For example, work order reporting might be accomplished through use of digital cellular radio and hand-held reporting devices. Use of computer tools to develop more efficient operating plans might produce increases in equipment utilization similar to those achievable with PTC. Some improvements in locomotive performance have already been obtained by use of on-board diagnostics. One Class I railroad is experimenting with an on-board computer that attempts to minimize fuel consumption subject to various schedule constraints.

In this analysis, the benefits of PTC are quantified. Where appropriate, benefits have been reduced to reflect the existence of systems (such as on-board diagnostics) that might already produce some part of the expected PTC benefit.

Because of uncertainties over exactly how PTC will be implemented, most benefits have been expressed as ranges. As can be seen from Table A below, the largest benefit categories are:

- For both PTC A and PTC B, A reduction in equipment ownership cost, due to an estimated 5% to 10% increase in car velocity
- For PTC B, the avoidance of a large investment railroads would otherwise have to make to increase capacity on an estimated 8,300 route miles of railroad (about 8% of the network) that are currently operating at or above design capacity. Here, the cost of constructing the 8,300 miles of track has been annualized over a presumed 80 year life at a discount rate of 7%; to this cost has been added an annual cost to maintain 8,000 additional miles of mainline track.
- For both PTC A and PTC B, significant benefits to shippers from a presumed improvement in service quality

Other benefits are relatively much smaller.

Expected costs of PTC have also been quantified. Available information from railroads and suppliers has been used to estimate the costs of the three segments of PTC. Of these, the cost of the central dispatch office is the least certain. In earlier analyses for Canadian National Railways and Burlington Northern Railroad, the cost of the central office equipment was estimated to be about the same as that of the wayside and vehicle components of the system. However, in this analysis, central office cost is estimated to be a relatively smaller part of the total, for two reasons. First, in the past decade most of the Class I railroads have built consolidated dispatching centers, and will most likely put PTC equipment in these existing buildings (previous studies assumed the need to build new dispatching centers). Second, software for both PTC A and PTC B is now being developed at test installations on railroads. By the time any decision is made to install PTC nationwide, the necessary software should already have been developed. It will only require customization for each railroad installation.

But due to the uncertainty over central office cost, a very large range has been used. The same range has been used for PTC A and PTC B; while they will require different software, there are currently projects underway to develop software for both applications, so there seems no reason to suppose that software for a PTC B installation will necessarily be more costly than software for a PTC A installation. Benefits have been quantified separately for PTC A and PTC B. It should be understood that, while the hardware requirements for the two systems are similar, the software is quite different. There is no obvious "migration path" from PTC A to PTC B. They are simply different approaches to the same problem: management of a rail network and its assets. PTC A is less complex, less expensive, but also offers less in the way of line capacity benefits than PTC B.

The safety benefits of PTC (essentially the savings realized from elimination of most or all "human factors" rail accidents) have been quantified separately by the Federal Railroad Administration. This study quantifies the business benefits.

Table A offers a benefits quantification for the two systems. Benefits have been estimated for each of several areas. The line capacity benefits represent an avoided expense for capacity expansion, for the estimated 8,000 route miles of the U.S. network that is currently operating at or above design capacity.

"Precision dispatching" is the term given to train dispatching aided by real-time location information. In PTC A this enables dispatchers to make better decisions regarding how trains are to pass each other on single track. In PTC B, there is an additional benefit realized from "moving block" operation, in which trains can run on closer geographic spacing. The result in both cases is an increase in average car velocity across the rail network, enabling the railroads to offer the same service with fewer locomotives and cars. PTC B, of course, also offers increased line capacity.

The use of real-time work order issuance provides some benefit in the form of reduced car ownership expense (since cars are moving more expeditiously). Locomotive diagnostics allow some en-route locomotive failures to be prevented, and also reduce shop time by providing shop forces with the ability to diagnose problems prior to the arrival of locomotives in the shop.

Finally, a fuel savings estimated at 2.5% to 5% is realized through better control of operations: better timing of meets between trains, and pacing of trains rather than operation at maximum authorized speed where it is unnecessary.

A comparison of costs and benefits has been undertaken to determine the expected return on investment (ROI) from a deployment of PTC nationwide on the Class I railroad network.[4]

Although the potential benefits of "track forces terminals" in terms of increased productivity for track maintenance forces are acknowledged here, they have not been quantified because they will be route- and railroad-specific, and dependent upon traffic volume. However, it should be noted that the railroad industry spends more than $10 billion annually on maintenance and renewal (operating and capital costs) of its fixed plant (track and structures, communications, and signals). If the availability of real-time information on train location can improve track workforce productivity by 5%, this equates to an annual savings of $500 million for the industry.

Most of the benefits quantified in Table A are savings to the railroads from more efficient operation. In the case of line capacity, the annual amounts shown are an annualization of the capital cost of 8,300 miles of second main track, plus the annual cost of maintaining that track. Car and locomotive savings are similarly calculated. In each case, an annual ownership cost is calculated using a purchase price, an expected service life, and a cost of money.

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[4] The analysis presented here owes a great deal to prior studies by Burlington Northern Railroad, Canadian National Railways, the Association of American Railroads, CSX Transportation, vendors of hardware and software for PTC, and the Federal Railroad Administration

The only benefits that are not direct savings to railroads are the "shipper benefits", which are composed of savings shippers might realize in total logistics cost if railroad service improved and rates did not increase.

It is important to note that it is by no means certain that railroads will realize all of the savings in Table A. Railroads might choose to give some of the savings to their customers in the form of lower rail rates; historically, 80% of the savings railroads have realized since deregulation have been given to shippers. But whether the benefits flow to railroads or to their customers, in one way or another the entire U.S. economy benefits.

Table A: Summary of Estimated Annual PTC Benefits

PTC A		Low	High
Line Capacity	Avoided Investment	N/A	N/A
	Avoided Maintenance	N/A	N/A
Precision Dispatch	Equipment Ownership	$407,996,280	$1,040,021,170
Work Order Report	Car Ownership	$10,109,900	$10,109,900
Loco Diagnostics	Loco Maintenance	$28,567,603	$28,567,603
	Loco road failure	$34,603,875	$34,603,875
Fuel		$55,949,775	$130,549,475
Shipper Benefits		$400,000,000	$900,000,000
Total Estimated Annual Benefits		$937,227,433	$2,143,852,023

PTC B		Low	High
Line Capacity	Avoided Investment	$299,532,652	$422,005,064
	Avoided Maintenance	$507,967,244	$761,956,956
Precision Dispatch	Car Ownership	$322,065,928	$868,160,466
	Loco Ownership	$85,930,352	$171,860,704
Work Order Report	Car Ownership	$10,109,900	$10,109,900
Loco Diagnostics	Loco Maintenance	$28,567,603	$28,567,603
	Loco road failure	$34,603,875	$34,603,875
Fuel		$55,949,775	$130,549,475
Shipper Benefits		$900,000,000	$1,400,000,000
Total Estimated Annual Benefits		$2,244,727,329	$3,827,814,043

Costs, Cash Flows, and IRR Calculations

Table B estimates the cost of PTC. These are the total one-time costs of implementing the three segments of either PTC A or PTC B: wayside, on-board, central office. Again, because of uncertainties, a range is given.

Table B: Summary of PTC Costs

1. PTC A	System Cost	
	Low	High
Vehicles	$410,120,000	$717,710,000
Wayside	$794,000,000	$1,191,000,000
Central	$100,000,000	$500,000,000
Total	$1,304,120,000	$2,408,710,000
2. PTC B		
Vehicles	$615,180,000	$1,537,950,000
Wayside	$1,588,000,000	$2,382,000,000
Central	$100,000,000	$500,000,000
Total	$2,303,180,000	$4,419,950,000

Of course PTC cannot be deployed all at once, and there will be maintenance and training costs as well. Therefore, a cash flow analysis for an investment in both PTC A and PTC B has been carried out using the following assumptions:

- A five-year installation period for the wayside component of PTC, with 20% of Class I mileage equipped each year
- A five-year installation period for the vehicle component

- A five-year installation and testing period for the central office hardware and software
- A benefits phase-in over a five-year period lagging the installation by one year
- Beginning in Year 6, a charge of 15% of the total installation cost per year for training, maintenance, and obsolescence[5]
- A 7% cost of money
- A 20-year benefits period

A calculation of "internal rate of return" (IRR) and cash flow has been undertaken separately for PTC A and PTC B for four PTC scenarios:

- Low cost, high benefits
- High cost, high benefits
- Low cost, low benefits
- High cost, low benefits

Table C summarizes these calculations. To make the IRR calculations, a table of cash flows must be prepared, showing net cash flows per year, positive and negative, during the life of the proposed investment. Cash flows prepared from the costs and benefits of PTC vary among the four cases, and between PTC A (with relatively smaller costs and benefits) and PTC B (where both are larger). However, in all cases the period of negative cash flow is five years or less, and in some cases is less than two years. Cash flow then becomes positive, and stays positive, for the remaining life of the investment. This occurs despite the 15% annual charge for training, maintenance, and obsolescence.

Table C shows the calculated IRRs for PTC A and PTC B for each of the four cases.

Table C: Calculated Internal Rates of Return, PTC
Four Analysis Cases

PTC A

	Low Benefits	**High Benefits**
Low Costs	**68%**	**130%**
High Costs	**24%**	**73%**

PTC B

	Low Benefits	**High Benefits**
Low Costs	**95%**	**160%**
High Costs	**44%**	**79%**

[5] The 15% figure is used in the electronics industry. BN, in its business case for ARES, used a figure of 10% to cover training, maintenance, and replacement of parts. A typical number for less sophisticated equipment (such as rail/highway crossings) is 5%.

Conclusions

PTC is a large investment by any measure. A cost of $1.3 billion to $4.4 billion might seem daunting to an industry with gross revenues of only $35 billion. However, the projected annual savings of $2 billion to $3.6 billion provides a rapid payback period. It should be noted that the value of accident avoidance (the near elimination of human factors accidents) has not been included in either benefit calculation, but is being calculated separately by the Federal Railroad Administration.

Clearly, both PTC A and PTC B offer an opportunity to U.S. freight railroads. Implementation of such a system would:

- Improve service reliability for shippers, producing a large benefit for them
- Increase the capacity of about 8,000 route miles that are now at or above capacity, enabling railroads to avoid a very substantial near-term investment in track and signals
- Produce immediate savings in car and locomotive ownership cost through improved utilization

Either PTC A or PTC B provides significant business benefits to the freight railroads, as well as unquestioned safety benefits through positive enforcement of movement authorities. PTC B additionally provides a “moving block” capability that has the potential to greatly reduce future investments in additional railroad capacity. Beyond that, moving block is especially well suited for situations in which rail traffic operating at different speeds (i.e., freight and 110 MPH passenger trains) shares a common rail route. The central safety system, along with the moving block capability, may be essential where freight trains share track with high-speed passenger trains.

The results of this analysis suggest that the railroad industry should carefully consider the opportunity presented by PTC technology, especially in view of its ongoing shortage of line capacity and the need to increase the return on invested capital.

I. Scope of the Analysis and Definition of PTC

Definition of Positive Train Control

Positive Train Control (PTC) is a concept, rather than a single technology or system. It can include many different capabilities, covering a range of railroad functions. The three components of PTC are the on-board computer (OBC) with Differential Global Positioning System (DGPS) location capability, a dedicated wireless digital data link between locomotives and a control center, and the central office hardware and software at the control center. Through use of a digital data link and real-time train location information, PTC can be a train control system. The digital data link and the OBC can be used for positive safety enforcement, stopping trains if movement authorities are exceeded. The same data link may also be used to transmit work instructions to train crews, receive acknowledgment of completed work, or transmit locomotive diagnostic information in real time.

The Federal Railroad Administration (FRA) defines PTC as follows:

> Positive Train Control (PTC) systems are integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency. PTC systems are comprised of digital data link communications networks, continuous and accurate positioning systems such as NDGPS, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems may also interface with tactical and strategic traffic planners, work order reporting systems, and locomotive health reporting systems. PTC systems issue movement authorities to train and maintenance-of-way crews, track the location of the trains and maintenance-of-way vehicles, have the ability to automatically enforce movement authorities, and continually update operating data systems with information on the location of trains, locomotives, cars, and crews. The remote intervention capability of PTC will permit the control center to stop a train should the locomotive crew be incapacitated. In addition to providing a greater level of safety and security, PTC systems also enable a railroad to run scheduled operations and provide improved running time, greater running time reliability, higher asset utilization, and greater track capacity. They will assist railroads in measuring and managing costs and in improving energy efficiency. Pilot versions of PTC were successfully tested a decade ago, but the systems were never deployed on a wide scale. Other demonstration projects are currently in the planning and testing stages.[6]

PTC functions divide into two categories: safety functions and "business" functions. Safety is assured through the use of digitally transmitted authorities, real-time positioning via DGPS, and either remote or automatic authority enforcement. Business functions, such as work order reporting and locomotive diagnostics, may be implemented separately from the safety functions using other communications technologies, but there are obvious synergies if all the elements of PTC make use of the same OBC and data link. Alternative systems, such as cellular digital radio, may lack sufficient capacity and

[6] From Federal Railroad Administration Web site (http://www.fra.dot.gov/Content3.asp?P=784)

coverage for these functions, and with large volumes of messages, the cost of such technologies can become very high.

Positioning – A Central Functionality of PTC

Much of the analysis that has been performed regarding PTC in the past has shown that the majority of its potential benefit is most likely tied in some way to the core capability of PTC to provide accurate, real-time position information to railroad operating personnel on a continuous basis.

In its early days, PTC relied on the Global Positioning System (GPS) for determining the position of a train. This required that the locomotive have a GPS receiver on board. That receiver would listen for signals continuously from a constellation of GPS satellites in geosynchronous orbit over the Earth. By receiving signals simultaneously from at least four such satellites, it is possible to determine position within 100 meters. While that information can be combined with data on railroad track location to develop a more detailed and precision location, that level of position accuracy was not always sufficient for safety purposes.

More accurate positioning is now possible using Differential GPS (DPGS). By establishing known locations throughout the country and placing GPE receivers and transmitters at those locations, a "correction" signal can be broadcast over a local area, making it possible to use GPS for determining which track in multiple-track territory a train is operating on.

Two Types of PTC

Since PTC is a collection of technologies, rather than one specific system, it may incorporate a range of functions. For the purposes of this analysis, two types of PTC have been defined. "PTC A" is an "overlay" system that provides enforcement of movement authorities, but does not incorporate a "vital" central safety system. Existing train control methods (signals and/or voice radio) remain in use, with PTC A providing positive enforcement (e.g., trains are stopped before they exceed authority limits). PTC A can rely solely on DGPS for location. Since PTC A incorporates a digital radio link and OBC, it can also be used to issue "work orders" (instructions to train crews regarding the pick-up and delivery of freight cars), transmit locomotive diagnostics, and record crew on-duty and off-duty times and train delays. Provision of real-time train location and speed to train dispatchers via the digital data link has been presumed to improve dispatching effectiveness, reducing train delays and increasing line capacity.

"PTC B" is a stand-alone vital system. Just as does PTC A, PTC B incorporates an OBC on each locomotive and a digital data link between locomotives and a central office. PTC B also includes a vital central safety system. This function requires more precise location information than PTC A. The PTC B evaluated here is based on the North American Joint PTC project in Illinois. In this test installation, DGPS is supplemented with accelerometers and a gyroscope that give locomotives the ability to resolve location down to a particular track. This increases the cost of on-board equipment.

The increased location accuracy enables PTC B to support "moving block" operation, in which the distance between following trains is reduced to that required to stop the following train short of a rear-end collision.[7]

Scope of the Analysis

The purpose of this analysis is to quantify the "business benefits" of PTC for the Class I freight railroad industry[8]. Safety benefits were previously quantified by a Rail Safety Advisory Committee (RSAC) working group, which identified nearly a thousand "PPAs" (PTC-preventable accidents) on U.S. railroads over a 12-year period, and determined the savings to be realized from each avoided accident. The RSAC finding was that avoidance of these PPAs was not, by itself, sufficient to justify an investment in PTC.

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Note that some of these benefits might be obtained by other means. As has already been mentioned, work order reporting might by accomplished through use of digital cellular radio and hand-held reporting devices. Use of computer tools to develop more efficient operating plans might produce increases in equipment utilization similar to those achievable with PTC. Some improvements in locomotive performance have already been obtained by use of on-board diagnostics. One Class I railroad is experimenting with an on-board computer that attempts to minimize fuel consumption subject to various schedule constraints.

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[8] The Surface Transportation Board classifies railroads as "Class 1" if they exceed an annual revenue threshold -- $266.6 million in 2001. In that year, there were seven Class 1 railroads, 34 "regional" railroads (revenues of at least $40 million annually but less than the Class I threshold) and 529 "local" railroads with less than $40 million in annual revenues.

In later sections of this report, the benefits of PTC are quantified. Where appropriate, benefits have been discounted to reflect the existence of systems (such as on-board diagnostics) that might already produce some part of the expected PTC benefit.

Expected costs of PTC have also been quantified. Available information from railroads and suppliers has been used to estimate the costs of the three segments of PTC:

- The vehicle segment (OBC, location system, digital data link)
- The wayside segment (wayside interface units for defect detectors, signals, and switches; radio towers)
- The central office segment (central computers, dispatcher interface)

A comparison of costs and benefits has been undertaken to determine the expected return on investment (ROI) from a deployment of PTC nationwide on the Class I railroad network. This comparison owes a great deal to previous analyses undertaken by ZETA-TECH Associates and others for Burlington Northern Railroad, Canadian National Railways, CSX Transportation, and various suppliers of PTC hardware.

Two types of PTC have been examined here: an overlay system ("PTC A") which provides business benefits (work order reporting, locomotive diagnostics), as well as enforcement of movement authorities conveyed either by digital track warrants or by signal indication; and a full PTC installation ("PTC B") that permits dynamic block length as well as enforcement, and assumes no wayside signals.[9] It should be noted that both PTC A and PTC B offer the potential for increased line capacity. PTC A would provide a train dispatcher with real-time location and speed information for all trains in his territory. PTC B would, in addition, permit trains to follow more closely, thus providing an even greater increase in line capacity.

Definitions of these two systems are as follows:

<u>PTC Level A (Overlay)</u>

- Core Functions and Hardware / Software Assumed
  - Track circuits to be retained where they currently exist and if train speeds exceed 49/50 miles per hour
  - Ability to securely transmit text messages to provide movement authorities, with acknowledgement and completion through a Human Machine Interface (HMI)

[9] Wayside signals would be retained in PTC A, since they provide detection of broken rails (via an interruption of the signal circuit when a rail breaks). However, in a PTC B dynamic block installation, retention of wayside signals would constrain the benefit of moving blocks, therefore wayside signals would have to be removed. The issues involved are discussed later in this report.

- Ability to track train position and request release of authorities by train crews with positive acknowledgement. Location of rear of train will be determined by the system.

- Train (On-board segment)

  - Communications
    - Data Capable Radio (Low bandwidth radios like Spec 200) will probably work with PTC "A" systems; however encryption of messages will be necessary)
    - Locomotive Radio Gateway (LRG) if multiple radios are used, may be useful option
    - Simple locomotive local area network

  - Man Machine Interface
    - Keyboard or Touch Screen; optionally, display capable of providing location information, warning annunciation, and means to input train crew responses

  - On-board computer system to work with office or field based systems to control authority issuance and release process. Same computer could also be used as part of positioning solution.

  - Positioning System
    - DGPS with optional inertial navigation system (INS) integration.
    - If positioning system is required to determine which track train is on in multiple track territory in a "vital" manner, may require addition of accelerometers, tachometer interface, and/or gyroscopes to supplement any positioning solution that depends solely on DGPS.
    - Rear of train DGPS system that provides information that can be checked against information available in the locomotive. Consist information could also be tracked and used, in combination with EOT units, to determine length and train integrity as an option to DGPS.

- Wayside Segment

  - Existing track circuits
  - If new installations of electronic coded track and interlocking systems (WIUs) are to be installed, they are assumed to have data communications capability.
  - Communications network capable of handling the low volume, relatively high-latency-time data assumed for the "A" overlay configuration. Overlapping, redundant coverage of network is not an absolute

requirement for this application, making the network installation less expensive.
  - If authority is given by signal indication, interfaces to field signals may be useful, instead of getting the information from CTC systems via office communications. If operating in non-CTC territories, signal interfaces may be a useful option for providing information to conditionally modify authority.
  - Interfaces to switches in signaled or dark territory may be added to provide information about switch position and occupancy for purposes of conditionally modifying authority, or as part of positioning solution validation.

- Central Office

  - Software to support generation and release of non-CTC authorities.
  - Software to provide end-of-authority, work limits, and speed restriction location information to trains and other on-track equipment like work crews. This holds for both CTC and non-CTC operations. Alternately, CTC signal authority information may be provided by field interfaces and communication networks that bypass the office computer-aided dispatching (CAD) system. (Information related to bulletins and work limits would still have to come from the office in this case.)
  - Software to interpret and display accurate positioning information from the field. (This is both a safety function as well as one that provides improved tactical dispatching).

- Additional roadway worker protection provided:

  - Track forces terminal with location system to provide warnings to help prevent violation of authority limit, and to notify dispatcher of exceedences.
  - Similar units installed in all powered on-track equipment. They can be portable but each "lead" and "rear" unit traveling together should be tracked.
  - Implementation of warning system is highly reliable, but not "fail safe". System not relied upon to provide worker protection.

- Track Force Unit

  - Positioning system based on DGPS and/or INS integration an option.
  - Data communications radio compatible with system installed along wayside.
  - User interface (HMI) to allow user to receive and see, and release authority limits via data link.
  - Embedded computer with software to provide desired functionality for positive separation between track forces and trains.

PTC Level "B" – Stand Alone and Vital

- Core Functions and Hardware / Software Assumed

  - A stand-alone system that may be deployed incrementally
  - If advantageous economically, use existing signal logic and vital circuits in the field to support PTC functions. Vital circuits cannot be removed later.
  - Must have next-generation CAD system to generate authorities (a more distributed system is an option)
  - In addition to core functions of an "A" system, assume 98% improvement over past accidents. All mainline switches monitored by WIUs.
  - Positive train stops enforced for trains.
  - Flexible block capability, but only where capacity constraints exist (will require additional communications bandwidth).
  - No requirement to install additional hazard detectors
  - Adequate warning time for highway grade crossing still in place for high-speed operations (>79 mph.)
  - Track circuits or an alternative technology for broken rail protection
  - .
  - Alert "nearby" trains when emergency braking applied.

- Train (On board segment)

  - Communications
    - Locomotive Radio Gateway (LRG) to manage data from multiple radios.
    - Data network compatible with PTC "A" will probably work for first increments of "B" systems, depending on roll-out strategy; however, as vital functions are added, a more robust, high bandwidth, low-latency, highly reliable data network will have to be installed to support these functions. This is critical if vital functions are moved into an office PTC server.
    - Appropriate on-board data radio(s).
    - On-board local area network (LAN) (On-board computer integrated with communications for processing data from multiple sources).

  - Man-machine interface (HMI)
    - HMI must have capability to provide all information to train crew necessary for PTC "B" operations (a "super cab-signal display), including:

        - Authority Limits
        - Current "Aspect"
        - Track Integrity / Switch Position
        - Intended Route Information
        - Braking Profile Margins for preventing unnecessary interventions. (Knowledge of impending positive enforcement)
        - Location Information
        - Location of MOW work limits
        - Displaying relative position of other location-broadcasting track vehicles (for use in ensuring positive separation between track forces and trains)
    - HMI must provide straightforward capability for train crew inputs
    - Information displayed on HMI must be validated to be correct (vital closed loop operation)
    - HMI visible for all crew members, or separate MMIs for each.

- On-board Computer System
    - OBC must be vital (requires second CPU)
    - Depending on architecture (more central or distributed), OBC may be required to process a large amount of information necessary for allowing train to move in safe manner.
    - OBC must be responsible for performing or initiating all closed loop safety validation procedures necessary for assuring safety levels of locomotive subsystem as a whole. Individual subsystems to be validated include:
        - Location system accuracy, availability, and expected failure modes
        - Braking system availability
        - Communication system data validation
        - Self-tests for proper operation
        - Authority limits conform to expected limits
        - Positive communications with wayside elements occur at appropriate times, i.e. making sure a crossing warning system starts, or that all wayside inputs from all necessary sources are received and processed appropriately.
    - OBC is also responsible for non-vital functions related to traffic management, i.e., work order reporting, determining pacing speeds, etc.
    - OBC is assumed to be used to provide train-handling instructions to engineer.

- Positioning System
    - DGPS/INS with map-matching capability
    - Access to accurate territory maps – resolution to 3 meters, continually updated.
    - Wheel Tachometer Interface
    - Inertial navigation capability
    - Information from wayside equipment integrated into solution
    - Manual input capability from train crew
    - Capability to handle ambiguous situations by recognizing problem and reporting to train crew
    - DGPS equipped EOT units (for determining end of train position and train integrity).

- Other Locomotive Interfaces
    - Hardware to Interface to:
        -
        - Wheel Tachometer
        - Braking System
        - Throttle Controls
        - Selected Engine Performance Parameters

- Wayside Segment

    - Existing circuits (For many existing systems today, WIUs in the form of Harmon VHLCs or equivalent units from other vendors are already in place at powered switch locations and could possibly be used as part of the PTC solution.)
        - Track circuits are almost entirely coded track style circuits on today's railroads. Depending on specific PTC implementations, these units would have to be made compatible with the installed communications network so they could provide information directly to the system.

    - Additions of shorter block, multi-aspect signal systems in areas of high congestion; link signal indications to on-board PTC system. Do not try to design a full up PTC solution for a "5%" problem.
    - New data-capable WIUs.
    - New interfaces to existing equipment, i.e. monitoring actual signal aspects to provide information for generating authorities.
    - Maintenance of existing signals as backups or as "block indicators".
    - Interfaces to existing hazard warning systems.
    - Additional WIUs for non-powered switches, or all switches in dark territories.
    - New or modified highway crossing systems with data capability to operate with traffic in excess of 79mph.

- Communications System
    - The data communication system requirements for a stand-alone PTC "B" system as defined will not support the system envisioned once traffic densities are much above a fairly low nominal level. Data latency will be the primary issue with the limited bandwidth and channel error rates of Spec 200 radios.
    - The more highly distributed the system architecture can be, the less critical the data communications system becomes, in terms of overall performance capabilities. Specific solutions can be matched to particular areas.
    - Installation of appropriate data-communications systems in areas of more than nominal traffic density could be done with wide-band radio technology. Commercial sources vs. private networks could be considered. Both TDMA and CDMA networks are becoming ubiquitous. European railroads are currently installing GSM-R networks to support their ERTMS efforts. U.S. railroads testing PTC-type systems are equipping locomotives with multiple communications paths.

- Office CAD System

    - Next-generation CAD system update required
    - PTC Server
        - The PTC server must be:
            - Vital
            - Redundant (for reliability)
    - Highly capable of near real-time operation for generation of dynamic movement authorities and other time-sensitive data.
            - Capable of running stand-alone for short periods when existing office CTC systems are "down"; otherwise everything stops.
        - The PTC server could conceivably perform only non-vital functions if vitality is distributed to the field; however the processing power and real-time performance will still be necessary, i.e. traffic management vs. train control functions.
    - Interfaces between new next-generation CAD and PTC Server
    - New HMI designs to maximize performance of dispatchers in the new traffic management environment, keeping him in the traffic planning function effectively.
    - New interfaces to the railroads' IT systems for both management and customers.

- Additional roadway worker protection provided:
    - Similar to "A" system with the following differences:
        - Implementation of warning system is "fail-safe" and will be used to provide worker protection.
        - Authorities process is closed loop and "secure".
        - Track Forces Unit (Terminal)
            - Positioning system based on DGPS with or without INS integration as an option. Also an option is manually reported data regarding on or off track and track identification functions.
            - Data communications radio compatible with system installed along wayside. Simpler version of LRG if multiple radios are being used.
            - HMI allowing request, receipt, and release of authority limits. HMI could also show via a map or other means, proximity to authority limits and other vehicles, including trains, on track).
            - Embedded computer system must be "fail-safe" to the extent necessary to guarantee a level of performance within the system architecture for protection of track forces.
            - Unit could serve a positive separation function by broadcasting periodic position and status reports to the network and/or nearby on-track vehicles, including trains.

Benefits Evaluated

The on-board computer (OBC), location system (DGPS plus inertial), and digital radio data link that are the heart of any PTC installation can support a variety of functions, given the right software and access to railroad databases. For example, the Burlington Northern Advanced Railroad Electronics System (ARES) of the 1980s, as designed, would have maintained a record of train crew hours. ARES also was planned to incorporate an Energy Management System (EMS) 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 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 little value due to the generally low level of capacity utilization.

Specific PTC benefits analyzed here flow from several PTC functions (all benefits are achievable, in whole or in part, by both PTC A and PTC B):

1. Precision dispatching; improved service reliability for customers, enhanced line capacity
2. Real-time transmission of "work orders" to crews and real-time reporting of work performed
3. Real-time reporting of locomotive diagnostic information (LD)
4. Improved equipment utilization (due to more efficient dispatching)
5. Fuel savings (due to "pacing" of trains)
6. More reliable customer service

Table 1 summarizes the benefit areas and the functionality required for each.

Dollar benefits for some of these areas are quantified in the following sections. For others, particularly MOW gang productivity improvements, information was not available in sufficient detail for the entire Class I railroad network to estimate a benefit. Therefore, benefits have been quantified only for:

- Precision dispatching
- Equipment utilization
- Work order reporting
- Fuel
- Locomotive health monitoring

There would seem to be little question that availability of accurate, real-time information on train location would make the planning and scheduling of track inspection and maintenance more efficient. Certainly, as the track network shrinks and traffic grows, this has become a critical concern to the Class I railroads. However, neither Burlington Northern's ARES benefits analysis nor the business case prepared by Canadian National Railways for ATCS were able to assign a dollar value to this benefit.

Table 1: System Requirements and Methodologies Used For Quantification of PTC Benefits

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
WOR (Work Order Reporting)	WOR requires: Locomotive equipped with MCP (Mobile Communication Package), OBT (On-Board Terminal or OBC (On-Board Computer)), display, keyboard, wire harness, power supply – data radio base stations – FEP/CC (Front End Processor/ Communications Controller) – WOR central system – communication between the data radio base stations and FEP/CC.	– improved equipment utilization, carload freight – reduction in misroutes/misconnects – improved customer service – reduction in switching through pre-blocking – a reduction in clerical labor	1. Determine percentage of traffic moving in carload freight service 2. Use time reductions developed in prior studies for BN, CN, and CSX to quantify % savings in cycle time due to real-time WORS 3. Determine reduction in annual car-hours resulting from WORS. Quantify benefit by calculation of an ownership annuity per car-hour 4. Divide benefits between railroad and private fleets in proportion to the % of carloads moved by each equipment category

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
LD (Locomotive Diagnostics)	Hardware required for LD: - locomotive sensors - locomotive equipped with MCP (Mobile Communication Package), OBT (On-Board Terminal or OBC (On-Board Computer)), display, keyboard, wire harness, power supply - data radio base stations - FEP/CC (Front End Processor / Communications Controller) - LD central system - communication between the data radio base stations and FEP/CC.	- reduced road failures and a resulting reduction in train delays - reduced time to diagnose and repair locomotives - increased loco fleet availability - reduction in shop space required - possible additional fuel savings	1. Results of CN analysis by ZETA-TECH (in which BN participated as subcontractor) were used, updated with current loco failure data 2. Benefits quantified in terms of reduction in out-of-service time, reduction in "no defect found", reduction in road failures, totaling to an increased percent availability 3. Dollar value of benefits based on annuity for locomotive ownership, reduction in annual locomotive hours required due to improved performance

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
Customer Service	- locomotives equipped with MCP, OBC (and OBT), display, keyboard, wire harness, power supply, interrogator antenna, speed and direction indicators. - data radio base stations - FEP / CC - central system and dispatch work stations - communications between the data radio base stations and the FEP / CC WIUs for existing power switches (included here because remote controlled switches must be integrated with the local tactical planner to achieve the run time and reliability benefits included in this section) - central safety system - data radio - full train control (train location, transmission of authorities, automatic release of authorities, speed and limit enforcement, other authority information, automatic alert on emergency stop) - local tactical planner	- improved customer service is the largest single source of benefit in both the CN and BN business cases. Potential this benefit include: More reliable service (due to use of CAD software and real-time location) Better yard performance (leading to improved reliability) Improved equipment utilization due to better information Possible reduction in loss and damage due to an improvement in train handling An increase in revenues and/or traffic volumes as a result of improved service quality	1. Calculate current dispatching effectiveness 2. Incorporate data in regression model. Run regression 3. Use regression to predict reduction in running time made possible by PTC 4. Calculate reduction in total cycle time (% of total trip time spent in road trains, * % reduction in running time due to better dispatching) 5. Calculate expected improvement in reliability 6. Examine CN and BN studies of the price elasticity of service, along with other published references, to estimate the possible revenue impacts of the increase in service made possible by PTC

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
Work Equipment Reporting	Same equipment as for LD	- more accurate diagnosis of work equipment problems or failures - reduced time to repair	Not explicitly quantified
Line Capacity	- locomotives equipped with MCP, OBC (and OBT), display, keyboard, wire harness, power supply, interrogator antenna, speed and direction indicators. - data radio base stations - FEP / CC - central system and dispatch work stations - communications between the data radio base stations and the FEP / CC - engineering vehicles equipped with data radio and TFDTs - WIUs for existing power switches (included here because remote controlled switches must be integrated with the local tactical planner to achieve the run time and reliability benefits included in this section) - central safety system - data radio - train handling assist - full train control	- benefits accrue primarily through better meet/pass planning, resulting in the benefits stated under Customer Service. - ability to handle increased levels of traffic with the same trackage - deferral of capital expenditure on sections of track operating at full capacity - potential relief from increased delays and degraded service due to capacity constraints.	1. Determine improvement in "dispatching effectiveness" measured by ZT model 2. Whether railroad will take the benefit on any particular segment in terms of increased capacity (more traffic and therefore more revenue) or improved service (lower ratio of traffic volume to capacity), the benefit is best measured as an improvement in customer service

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
Direct Transmission of Movement Authorities to Loco	- locomotive equipped with MCP (Mobile Communication Package), OBT (On-Board Terminal or OBC (On-Board Computer)), display, keyboard, wire harness, power supply - data radio base stations - FEP/CC (Front End Processor / Communications Controller) - links with the appropriate central systems - communication between the data radio base stations and FEP/CC.	- reduction in dispatcher workload - reduction in clerical workload	Not calculated, or included as a separate benefit
Train Dispatch Productivity	- locomotives equipped with MCP, OBC (and OBT), display, keyboard, wire harness, power supply, interrogator antenna, speed and direction indicators. - data radio base stations - FEP / CC - central system and dispatch work stations - communications between the data radio base stations and the FEP / CC - engineering vehicles equipped with data radio and TFDTs	- reduced dispatcher stress and workload - reduction in the number of dispatchers needed - A reduction in communications load, since train locations, times, and other information would be continuously available, and the issuance of authorities would be automated. - An increase in communications efficiency	Not calculated or included as a separate benefit. Benefits improve dispatcher's job quality. Service improvements are reflected in reliability and better customer service.

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
Equipment Utilization	- locomotives equipped with MCP, OBC (and OBT), display, keyboard, wire harness, power supply, interrogator antenna, speed and direction indicators. - data radio base stations - FEP / CC - central system and dispatch work stations - communications between the data radio base stations and the FEP / CC - - engineering vehicles equipped with data radio and TFDTs - WIUs for existing power switches - central safety system - data radio - train handling assist - full train control (train location, transmission of authorities, automatic release of authorities, speed and limit enforcement, other authority information, a automatic alert on emergency stop)	- reduction in car fleet size - reduction in time-based car maintenance expense - reduction in locomotive fleet size	1. Quantify reduction in road train running time (from performance analysis) 2. calculate reduction in cycle time resulting (separately for cars and locomotives, and for each service) 3. determine fleet size impact (reduction in locos and cars needed, by service) 4. using unit costs, calculate reduction in required investment 5. calculate an annuity value based on avoided investment and a cost of capital 6. calculate reduction in *time-based* maintenance due to fleet size reduction Use BN, CN analyses to check validity of results

Benefit Area	System Requirements	Potential Benefits	Methodology for Quantification
Fuel Savings	- An on-board computer (OBC) - Real-Time train location - Digital data link - Local tactical planner - EMS	- savings through "pacing" of trains - additional savings through use of an Energy Management System (not directly related to PTC)	BN/CN estimated savings used (2.2% - 2.5%)
Crew Utilization/ Scheduling	- locomotives equipped with MCP, OBC (and OBT), display, keyboard, wire harness, power supply, interrogator antenna, speed and direction indicators. - data radio base stations - FEP / CC - central system and dispatch work stations - communications between the data radio base stations and the FEP / CC - engineering vehicles equipped with data radio and TFDTs - central safety system - data radio - train handling assist	- reduced arbitrary payments - reduction in required size of "extra board" - reduction in deadheads due to improved scheduling - possible lengthening of crew districts - improved quality of life for crews through better scheduling	Not calculated or included as a separate benefit

II. Benefits Assessment, PTC

While PTC is usually considered to be a train control system, it also has the capability for handling real-time work order reporting, locomotive diagnostics, administrative functions such as time keeping, and train control functions (such as remote enforcement of movement authorities and the "pacing" of trains to arrive at meet points exactly on schedule) that are beyond the capability of current systems.

It is possible to "unbundle" the PTC package. A railroad considering the implementation of PTC would not necessarily have to equip all locomotives, or all routes, with all of the hardware and software comprising the most sophisticated PTC installation.

Much of the benefit of PTC in earlier benefits analyses was associated with the train control functions. Train control requires real-time train location data, and implies the existence of safety software for enforcing train separation and preventing conflicts. However, it does not necessarily imply an equivalence to Centralized Traffic Control, with all track switches remotely controlled.

It is helpful to think of PTC as a two-story house. The first story (Figure 1) consists of a digital radio data link, which is really the heart of any PTC application. This data link can support a wide variety of functions. They include:

- 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)
- train handling assist (prompts to train crew that might reduce fuel consumption or intra-train forces)
- 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 or WIUs to replace vital relays for switches)
- transmission of authorities to locomotives or track force vehicles

These functions require a digital data link, but do not necessarily 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 might include only these elements.

The second floor of the PTC house (Figure 2) includes the functions, which require a central safety system. These functions will also require real-time location information, provided continuously from trains through use of digital radio, DGPS, inertial navigation capability, and odometers. This is a significant additional capability, but it builds on the digital data link and the on-board computer. These functions may include:

- train separation and speed enforcement (through real-time position information and on-board authority enforcement)
- 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 arrive at meet points exactly as scheduled)
- 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)

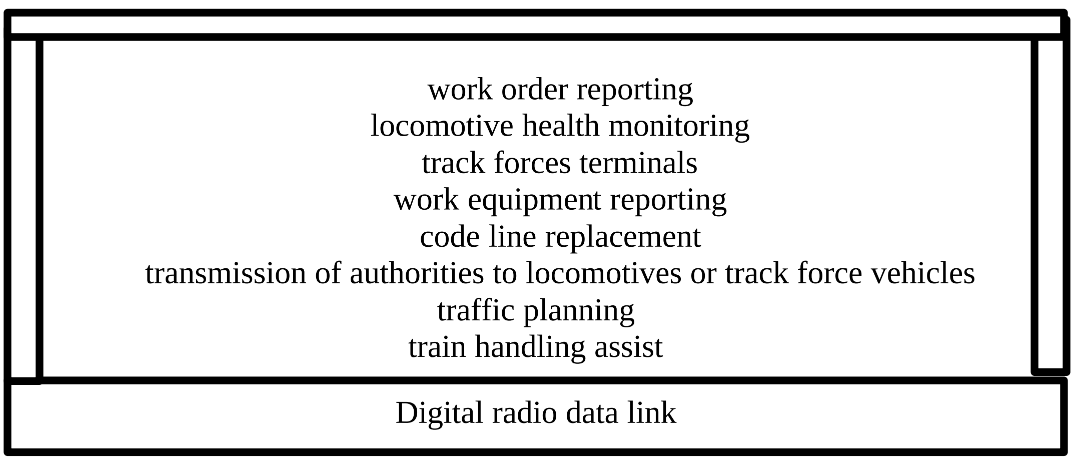


Figure 1: PTC A, The Foundation and First Floor of PTC

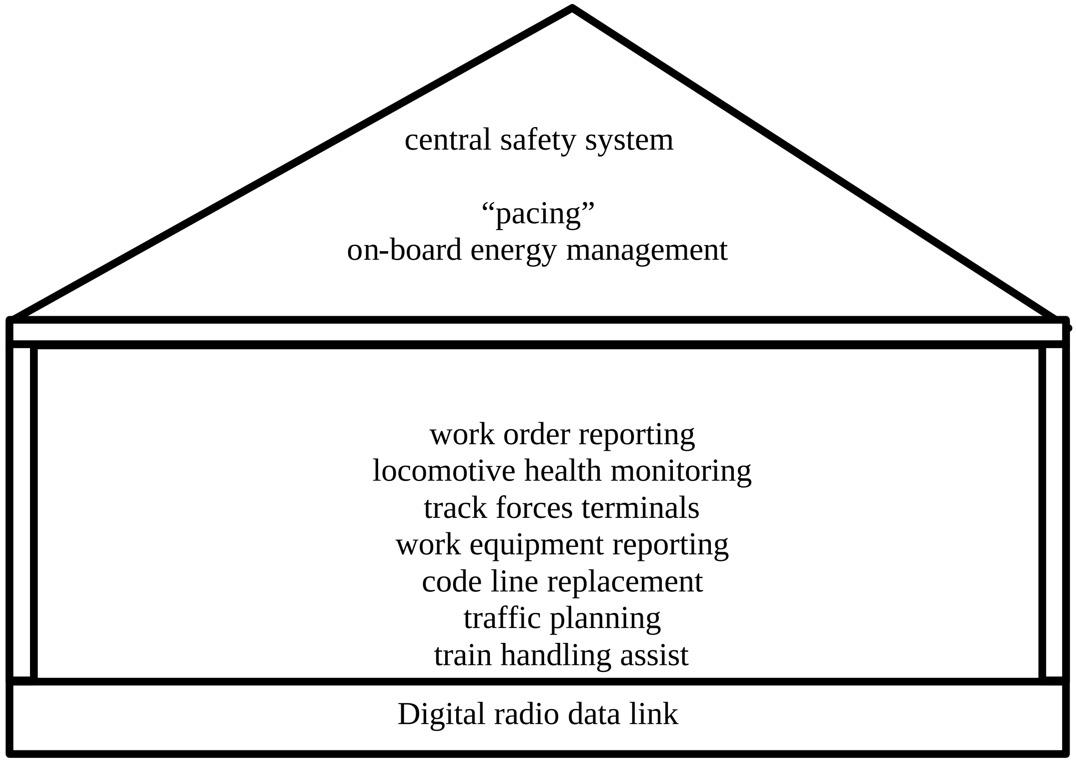


Figure 2: PTC B, The Two-Story House

III. PTC A Benefits

Work Order Reporting

The purpose of the work order system is to plan and schedule the work of train crews. However, it is not possible to schedule all work in advance, since it is impossible to perfectly predict future occurrences. However, 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 before completing all scheduled work and any additional work[10]. 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 yard and industry switchers and local freights perform most additional work, 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. Unit trains, intermodal trains, and mixed freight trains that do not perform work at points between terminals will not benefit from real-time work order reporting. However, the combination of accurate train consist information with

[10] The working time of railroad train crews is limited by Federal law to 12 hours. Once a crew has worked 12 continuous on-duty hours, they must stop work.

real-time train location data will provide other benefits for railroads, such as improved equipment utilization.

Table 2 shows the various potential sources of benefit, and the reasons for these benefits.

Table 2: 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 • 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 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 • Better schedule adherence
8. More accurate work orders for train crews	• Work not performed is released immediately for assignment to next shift

Figure 3 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. The expected areas of benefit 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

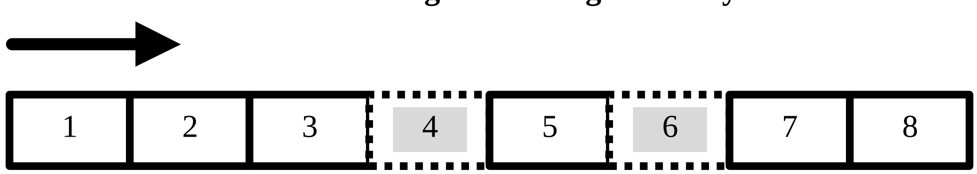
In addition, the use of work order systems will improve billing accuracy for demurrage and intra-plant switching.

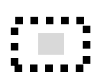
Unfortunately, quantification of customer release response requires data on the distribution of customer calls for releases in specific geographic areas. Information at this level of detail was simply unavailable for a nationwide study.

Quantification of the improvement in the probability of making outbound connections requires calculation of connection probabilities for specific yards. Again, this sort of detail was unavailable.

Therefore, only two of the four areas of benefit were quantified in this report. These affect the outbound and inbound classification of cars, and reflect a reduction in additional, unscheduled work due to more timely information and a reduction in classification work due to the ability of the switch crew to "preblock" an inbound train using this information. Figure 3 shows the car cycle and the two areas affected.

Figure 3: Freight Car Cycle



Areas of benefit quantified in this report: 

1. Customer release
2. Pull from customer
3. Local train
4. Outbound classification
5. Road haul

6. Inbound classification
7. Local train
8. Customer placement

In a small percentage of cases, cars incur extra handling in terminals due to incomplete or inaccurate information. In these cases, not only will car detention in yards be reduced, but the workload of switching crews will also be reduced. This will save both switching locomotives and crews. Preblocking of cars (made possible by more timely and accurate information) may also reduce the switching workload.

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.

Methodology for Benefit Determination – Yard Time Savings

Yard timesavings 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 the case studied. More timely information should reduce this number, resulting in much faster yard processing time. The rationale for these savings is discussed below.

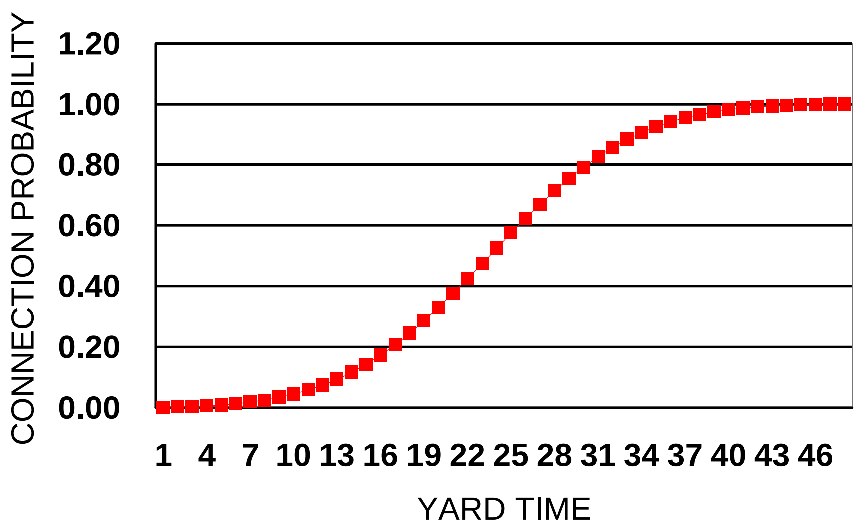
To quantify the savings from reduced yard delays (Areas 4 and 6 in Figure 3), a probability function from the railroad's blocking and scheduling model (the Service Planning Model or SPM) was used.[11] This function is a cumulative probability distribution calculated for each railroad yard from actual car movement data. This distribution can be used to determine the likelihood that a car will make the first scheduled outbound connection, given that the scheduled yard time (number of hours between arrival and <u>scheduled</u> departure) is known. The distribution is calculated from actual arrival, departure, and connection information for each yard. The function is termed "PMAKE", short for "probability a car will make its scheduled connection".

[11] The Service Planning Model (SPM) 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 4 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. (The same methodology is used to quantify customer service benefits in Section 5).

As an example, refer to Figure 4. The mean yard time is 24 hours, and these cars 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 will increase the number of cars making connections by 5%. If there is one opportunity per day to connect, this percentage of cars will save 24 hours.

Figure 4: 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 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 make 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.

Most cars make schedule some percentage of the time. 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. (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 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.

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 one North American railroad indicates that the minimum time to verify inbound consist information is 30 minutes (and the 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 analysis presented here was that one hour per train might be saved (partially because cars will be available in enroute inventory sooner). The effect is as if a train arrived an hour earlier – additional time is available for classification. Using a composite PMAKE similar to the one in Figure 2, the percentage increase in cars making scheduled local connections may be quantified. Each of these cars saves 24 hours.

On the outbound side, real-time reporting of "pulls" by industry switchers may enable yardmasters to plan and schedule classifications and departures more efficiently. It may also be possible to schedule tighter connections (again, it is as if cars arrived earlier at the yard). Since the impact of near-real-time information on outbound yard processing appears larger than that for inbound yard processing (there are three possible areas of benefit rather than one) a larger benefit appears plausible. However, the outbound benefit has been taken only for cars, which are now handled as additional, unscheduled work by train crews. These constitute about 15% of total cars handled, or six out of the average of 39 cars handled by a typical local switcher during a shift.

The benefits of reduced yard time for cars have been expressed in terms of car-days saved. If (for example) five percent more cars are assumed to make outbound connections as a result of better information, then the savings is 5% of total outbound cars times 24 hours per car (the additional time each car would have spent waiting for the next available outbound connection).

A.1 Yard Time Reduction

Benefit areas, in terms of the car cycle, are shown in Figure 3. The first benefit area (#4 on Figure 3) is the expected timesavings for inbound cars moving from road trains to local delivery. As described previously, a PMAKE curve was used to estimate the effect on connection probability of a one-hour increase in inbound yard time. This reduction worked out to be about 4.5% of average yard time across the entire railroad, using calibrated PMAKE functions for each major yard.

B. Improved Customer Response

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 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).

With the capability to transmit work orders directly to crews, and for crews to report work as it is completed, clerks can amend outstanding work orders by adding late releases as the calls are received. Of course, there is a chance that an enroute crew may have passed the customer who has just released a car, but with frequent updates by crews, clerks can judge where the train is and decide whether or not to transit a revised work order.

This benefit almost certainly exists, but to quantify it would require detailed statistics on local freight operations, information that has not been made available for this study. Therefore, this benefit has not been explicitly quantified. However, its order of magnitude may be estimated by noting that it will apply to the 85% of cars for which work instructions are now issued. Some percentage of these cars may save one day's transit time. The 15% of cars handled as additional work have been excluded, since it has been assumed that some late calls are handled as additional, unscheduled work at present.

C. Methodology for Benefits Determination – Preblocking

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 cars, 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 setout 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.

In theory, if the crew has waybills for cars they should be able to engage in some preblocking at present. Therefore, this benefit has been calculated only for cars handled as additional, unscheduled work (for which crews do not know destinations). Additional work 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 (advance consist notification); therefore, this benefit also 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 can be preblocked if more information is available to crews. It has been assumed one car day can be saved for each of these cars. In addition to the car day savings (one day for 7.5% of cars handled), preblocking will also reduce the number of cars switched by 7.5%, since yard handling can be avoided altogether for this group of cars. However, the benefit calculated here is based only on one car-day of savings. No credit has been taken for the reduction in necessary yard work.

B.1. Reduction in outbound yard time

Again, as in benefit area #1 and #2, it has been assumed that real-time or near-real-time information will reduce the time required in the yard to process outbound cars, through advance consist information. A composite probability curve has been used again to determine the expected reduction in average yard time. A savings of three hours has been projected, based on this data.

D. 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.

E. Summary of Calculated Benefits

Real-time transmission of train crew work instructions and reports of work completed may be expected to produce the following benefits:

1. A 5% improvement in inbound schedule adherence for all carload freight, 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.

2. More timely response to customer "pull" requests (not quantified in this analysis due to a lack of specific data)
3. A reduction of one day's transit time for 7.5% of carload freight outbound to yard, due to ability to pre-block cars for onward connections.
4. A reduction of the same percentage (7.5%) in cars handled in yards. This benefit has not been quantified in this analysis since yards have not been explicitly modeled.

The benefits of real-time work order reporting apply only to carload freight traffic. These percentages have been calculated from the STB 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).

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 $13.16 per car-day (calculated from a $61,000 weighted average car purchase price, 7% cost of capital, 40-year life), the annual savings are estimated as shown in Table 3.

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. Again, benefits for the rail industry are shown in Table 3. Note that benefits for shipper-owned cars (more than two-thirds of the car fleet in 2003) are shown separately.

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 will assume the existence of a digital data link (installed for train control purposes), and an on-board computer. In this case, the incremental cost of locomotive monitoring with real-time reporting is small.

It should be noted that the locomotive diagnostic computer is not, by itself, adequate to fill the role of the OBC in a PTC system. Rather, the diagnostic computer will be connected to the digital data link via the OBC, which will allow it to transmit real-time information on "exceedences" to the central office.

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 an analysis of Burlington Northern's LARS (Locomotive Analysis and Reporting System) performed a few 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 (enroute failures)
- Time off line (% out of service)
- Maintenance hours
- Reduced severity

Due to data limitations, this analysis will address 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 from General Electric and General Motors as standard features on new locomotives. LARS 2 used the digital data link to provide real-time component status when on-road failures occurred. LARS 3 assumed that the shop would diagnose the locomotive to schedule additional component replacements when a locomotive undergoes a routine shopping, and 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 will not affect component failure rates. Benefits come from the detection of likely failures before they occur, and from a reduction in time required to trouble-shoot failed locomotives. This reduction of time provides benefits in two ways: (1) reducing the out-of-service time of locomotives and (2) reducing the number of labor hours for locomotive maintenance.

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

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

Specifically excluded from the analysis is the benefit due to reducing amount of out-of-service time that would result from more effective diagnostics. 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 (a level annuity based on purchase price), and a cost per train delay (based on the ownership cost of cars and locomotives on a typical train).

Reduction in Maintenance Hours

A.1 Methodology

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 from the MMC system; 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, vital to the use of the Northrop model presented below, was not readily obtainable from railroad data.

This is the percent reduction in diagnostic labor time as a result of both an on-board diagnostic system and real-time reporting. Many of today’s locomotives are equipped with on-board diagnostic systems, making a portion of the 40.2% benefit available with no further addition of hardware. The portion of the benefit that is due to the presence of an on-board system is discussed later. Benefits of adding real-time data communication capability to locomotives already equipped with on-board diagnostic systems are based on the fraction of benefits that are available from real-time communications alone.

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 the variables. The analysis presented here relies on fleet statistics for Canadian National Railways for the years 1989 and 1990.

$$S = \left(FM/FA\right)(PS)(KR)\left(MT/MR\right)$$

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.

The anticipated reduction in maintenance hours can be calculated from the data in Table 4 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%. 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*36.1)/36.1)

S = 0.083102014, or 8.3%, for an average of the two years. The anticipated reduction in total locomotive maintenance labor hours (and therefore 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.

A review of locomotive purchases by major North American railroads for the years 1987 – 2001 (from the 2003 AAR *Yearbook of Railroad Facts*) indicates that 9,730 of the 2001 fleet of 19,745 units have been purchased since 1985. Therefore the 8.3% savings in labor hours applies only to the 50.7% of locomotives in service that were built prior to 1985. For the remaining 49.3%, the benefit is reduced by 44% * 8.3%, to a savings of 4.6%.

Table 3: Annual Savings from a Reduction in Average Shop Time

Loco Fleet	Diagnostics	No Diagnostics	Total Annual Labor Cost, Loco Maintenance	Savings, Locos Without Diagnostics	Savings, Locos With Diagnostics	Total Savings
	49.3%	50.7%		8.3%	3.8%	
20,506	10,109	10,397	$469,746,000	$19,767,381.43	$8,800,221.56	$28,567,603

B. Reduction in Road Failures

B.1 Methodology

In addition to savings in troubleshooting, a reduction in locomotive en-route failures will also produce significant savings in train delay costs. This savings can be very substantial, since the cost per road failure can include operating costs (such as the cost of recrewing the train) as well as maintenance labor and materials. Table 4 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.

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 4, 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 4: 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%

Although this data is more than a decade old, the critical value here is the percentage of failures in systems monitored by LD. It is not expected that this percentage has changed over the intervening years.

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.

TABLE 5: REDUCTION IN FAILURES DUE TO MONITORING
(Estimates by BN and CN Mechanical Dept. Staff)

Type of Failure	# of Failures		LARS Status
	1990	1989	
shutdown	41	31	80% reduction
axle generator	106	105	50% reduction
traction motors	72	60	50% reduction
air brakes	21	29	not monitored
other electrical	135	151	50% reduction
mechanical	88	88	50% reduction
trucks, wheels	5	17	not monitored
cab, safety	36	38	not monitored
bell	3	24	not monitored
Total	507	543	
LD monitored	442	435	
Reduction due to LD	233	227	

Take the failure cause “shutdown”. In this case, an 80% reduction has been projected. Shutdowns most often occur because of low crankcase pressure, low water or oil pressure, or an 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 allow corrective action to be taken. In fact, Burlington Northern maintenance personnel believed that en-route shutdowns could 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. LARS and other diagnostic systems monitor a host of values, 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. Again, if a fan relay is not picking up, this event will be monitored and recorded, probably before the locomotive overheats.

Benefits of this monitoring are relatively simple to estimate. CN estimated a cost of $1,357 (in 1990 Canadian $) to CN for every road failure. This failure cost included 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 2003 price levels, the cost becomes $1,350 US. If LD can avoid 50% of en-route failures (Table 5 indicates a reduction of 52.5% in failures), then Table 6 shows the savings potentially available to the U.S. Class 1 railroads, based on an in-service failure rate of 2.5 failures per loco unit per year (based on data from two Class I railroads).

Table 6: Savings From Avoided En-Route Failures

Loco Fleet	Avoided Failures	Failures per loco	Failures per year	Avoided	Cost/Failure	Avoided Cost
20,506	50.00%	2.5	51,265	25,633	$1,350	$34,603,875

As with the savings from troubleshooting labor, these savings are sensitive to assumptions regarding the effectiveness of diagnostic and reporting systems. If the system prevents more than 50% of current failures on monitored systems, savings will be greater. Conversely, if LD prevents fewer failures, savings will 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 are prevented, delays are prevented, trouble-shooting time is reduced, and this produces savings. Component failure rates, however, are unaffected.

C. Miscellaneous Benefits

C.1. Reduction in Fleet Size

Reduction in fleet size will permit a reduction in the size of the workforce, over and above the savings in troubleshooting labor, since there will be fewer locomotives to maintain. While the mileage-based component of maintenance cost will not be reduced, the time-based component (e.g. 92-day inspections) will. This should result in both a reduction in total shop forces and a reduction in shop facilities.

The value of this reduction in fleet size can be calculated by amortizing the purchase price of a locomotive over its assumed life, using an appropriate discount rate. Assume an average of $2 million as a purchase price for a new locomotive, a 30-year life and a 7.0% discount rate. Annual ownership cost is thus $161,173, or $18.40 per hour.

C.2. 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 eliminated.

D. Summary of Benefits

Table 7 shows total benefits for the three railroads, based on current fleet size and locomotive performance, and also shows total available savings per locomotive. All numbers take into account the fact that nearly half the locomotive fleet is already equipped with diagnostics by the manufacturer.

Table 7: Summary of LD Benefits

Loco Fleet	Avoided Failures	Failures per loco	Failures per year	Avoided Failures	Cost/Failure	Avoided Cost
20,506	50.00%	2.5	51,265	25,633	$1,350	$34,603,875

Loco Fleet	Diag-nostics	No Diagnostics	Total Annual Labor Cost, Loco Maintenance	Savings, Locos Without Diagnostics	Savings, Locos With Diagnostics	Total Savings
	49.3%	50.7%		8.3%	3.8%	
20,506	10,109	10,397	$469,746,000	$19,767,381.43	$8,800,221.56	$28,567,603

Train Handling Assist

The OBC in either a PTC A or PTC B installation will contain consist data. This, combined with DGPS location, will allow the computer to position the train accurately on the track. Since both plan (curvature) and profile (grade) of the track must be known in order to compute a train braking solution (for enforcement of authorities), the OBC can also compute throttle and brake settings as well as intra-train forces. This information can be used to display “best” control settings to the engineer.

Assistance can be provided either to minimize fuel consumption (subject to schedule constraints), to minimize slack run-in and run-out (avoiding equipment and lading damage), or both. Fuel savings have been quantified in this analysis; the potential reduction in lading and equipment damage has not.

Track Forces Terminals, Work Equipment Reporting, Code Line Replacement

These benefits have not been explicitly quantified. Track forces terminals offer the promise of more time on track for MOW forces, through better knowledge of train movements. This benefit will be highly line-specific, and will be of most value on the highest-density segments of the network. This makes it very difficult to quantify for the entire U.S. railroad network.

However, an order of magnitude estimate can be made. Total Class I railroad spending on track and structures capital and maintenance items (include track, bridges and buildings, communications, and signals) for 2001 was $10.123 billion. This is a very substantial number. If track forces terminals can produce even a 5% to 15% improvement in the efficiency of MOW work, this could potentially be worth between $0.5 billion and $1.5 billion annually to Class I Railroads. Anecdotal evidence alone would appear to support at least a 5% savings in maintenance costs due to improved productivity.

Work equipment reporting can also simplify daily production reporting, payroll, and other activities.

Code lines have largely been replaced by radio frequency communications, in many cases based on ATCS or ARES specifications (which mean that data radios are already in place on a substantial part of the rail network). PTC-compatible radios currently cover about 15% of the Class I network, and may be adequate for a PTC A installation. PTC B will probably require a more robust radio system.

Fuel Savings

Fuel savings are achieved through use of real-time location, combined with train consist and route profile data maintained in the OBC. Benefits of the same magnitude are realized for both PTC A and PTC B.

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” (EMS) 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 EMS proved to be a very difficult programming task. While fuel could be saved, schedule targets could not be reliably met. Therefore, the focus shifted to pacing of trains, which was computationally easier to do.

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 significant. For the entire U.S. railroad industry, fuel represented an annual expense of some $3.191 billion in 2001 (source: AAR “Railroad Facts”). Thus a 2.5% savings produces an annual savings of $79,775,000 in fuel costs.

Train Control

PTC A is an “overlay” system, which can provide enforcement of movement authorities provided by signals or track warrants. The expected safety benefits from this feature of PTC A are not addressed in this study, as the FRA has already prepared its analysis of the safety benefits. An argument could be made that the benefits of Precision

Dispatching and Improved Customer Service (discussed under PTC B benefits) would not be available in an implementation of PTC A. This, however, is likely not the case.

According to Smith, Resor, and Patel, significant reductions in travel time are available when there is a greater availability of real-time or near real-time information for railroad dispatchers.[12] In fact, their study showed that a travel time reduction of 2.3% could be available as a result of dispatchers receiving train position information every 3.5 minutes, as can be expected under PTC A, rather than every 17 minutes, as would be expected under a classic CTC system. For this reason, the benefits of Precision Dispatching are included in the discussion of PTC A benefits.

With effective meet/pass planning achievable with accurate position information and possibly supplemented with sophisticated computer analysis, system velocity and reliability can increase.

Similarly, a 20% reduction in run time will provide a (less than 20%) improvement in equipment availability. If trains spend one-third of the time on the mainline, this would provide only a 6.666% improvement in equipment availability (one third of 20%

However, it must be noted that the 20% improvement in run time cannot provide both a 20% increase in line capacity <u>and</u> a 7% improvement in equipment availability. It can provide either:

1) a 20% increase in line capacity or
2) a 7% increase in equipment availability or
3) part of each benefit (say 10% improvement in line capacity and a 3.5% improvement in equipment availability).

Here, the benefits of precision dispatching will be quantified in terms of reductions in running time. In the next section, the annual cost of avoided investments in capacity enhancements is quantified.

Railroad business case analyses conducted in the early 1990s identified very significant line capacity increases available from implementation of PTC. These capacity increases were achieved by use of sophisticated meet/pass planning algorithms, combined with the dynamic headways made possible by the PTC train control technology.

In Burlington Northern's analysis, a meet/pass planning model developed at the University of Pennsylvania was applied to actual train movement data on sixteen BN line segments. In all cases, use of the dispatching model produced substantial improvements in running time. Improvements ranged from less than 10% for high-priority (intermodal) trains to as much as 35% for low-priority coal and grain trains on some lanes. Most

[12] Train Dispatching Effectiveness With Respect to Advanced Train Control Systems: Quantification of the Relationship", Randolph R. Resor, Michael E. Smith, and Pradeep Patel. **Transportation Research Record** no. 1584 (Washington, DC: 1997).

interestingly, when running times of intermodal trains were held fixed and running times for bulk commodity trains were reduced as much as possible, total reductions approached 40%.

In the present analysis, more modest improvements have been assumed. For intermodal trains (which already enjoy preferential dispatching treatment) a reduction of only 2.5% to 5% in running times has been estimated. For carload freight service, where cars must pass through multiple yards, some of the reduction in over-the-road running time will be lost during yard visits, producing only a modest 2.5% to 8.5% reduction in dock-to-dock average time.

For bulk commodity movements (coal and grain) the potential benefit appears much larger, since these trains are not generally yarded between origin and destination. A reduction of between 6% and 15% in terminal-to-terminal time has been estimated, based on the BN analysis and some more recent work.

Table 8 quantifies the benefits of precision dispatching in terms of equipment ownership savings. In each case, the running time improvement identified in the analysis has been discounted by the percentage of time a car is actually moving (which varies between 52% and 59% depending on type of traffic).

As can be seen from Table 8, with about 1.4 million freight cars in the fleet, substantial savings are possible even with relatively minor reductions in dock-to-dock time. For railroad cars, these savings run from less than $200 million per year to almost $500 million. For all cars in the fleet (including shipper-owned cars, for which the savings will of course accrue to the shippers), savings are on the order of $300 million to almost $900 million annually.

Equivalent savings will be realized for locomotives as well. Assume they are moving 52% of the time (a figure developed from examination of event recorder logs). Using an annual ownership cost based on a purchase price of $2,000,000, a life of 30 years, and a cost of money of 7%, the annual ownership cost of a Class I locomotive is $161,173. Assuming the same improvement in utilization for locomotives as for intermodal freight, a total savings in ownership cost for locomotives may be calculated. When locomotive savings are added, total ownership cost savings range from $400 million to $1 billion annually.

Could these benefits be achieved simply by providing today's train dispatchers with meet/pass planning software? This question was asked in both the BN and CN analyses. The answer appears to be no. Where dispatch planning software has been provided to dispatchers, they do not appear to make use of it. The problem is apparently with the "latency" of information. The best dispatching plan requires accurate and timely train location data. Existing control systems provide neither the accuracy nor the frequency of position information required to keep a "best" dispatching plan current. Inevitably, as trains move across the railroad, their speeds and locations begin to differ from those projected by the dispatch planning software, and the plan becomes infeasible.

With the addition of accurate, real-time train location, dispatch planning becomes feasible. However, analysis carried out by BN indicates that most of the benefits of dispatch planning can be realized simply by providing the location data directly to a dispatcher. With accurate, real-time location data, the value of computerized optimization is small. The dispatcher has all the information needed to figure out a "best" solution without computer assistance.

Some administrative benefits might be realized, in terms of improved and simplified timekeeping and recording of such items as initial and final terminal delay, but these benefits have not been quantified here since they will be location-specific and cannot easily be estimated for the entire Class I railroad network.

Table 8: Equipment Ownership Savings From Precision Dispatching

Traffic Category	% Time In transit	Running Time Improvement		Equipment Ownership Cost/Year	Railroad-Owned Equipment, Ownership Savings		Private Equipment, Ownership Savings		Total, All Cars	
		Min	Max		Min	Max	Min	Max	Min	Max
Intermodal	52.00%	5.00%	10.00%	$4,713			$14,780,534	$29,561,067	$14,780,534	$29,561,067
Bulk	59.00%	10.00%	25.00%	$4,713	$132,924,924	$332,312,310	$96,153,900	$240,384,750	$229,078,824	$572,697,061
Carload Freight	52.00%	5.00%	17.00%	$4,713	$44,224,822	$150,364,395	$33,981,748	$115,537,943	$78,206,570	$265,902,338
Locos	52.00%	5.00%	10.00%	$161,173	$85,930,352	$171,860,704			$85,930,352	$171,860,704
Totals					$263,080,098	$654,537,409	$144,916,182	$385,483,761	$407,996,280	$1,040,021,170

IV. PTC B Benefits

PTC B adds a central safety system and the capability to implement "dynamic headways" (moving block train separation). The safety benefits also apply to track forces.

Safety benefits are not part of the benefits quantification presented here.

The benefits of PTC B are in addition to those quantified for PTC A, since PTC B also includes the necessary hardware and software for work order reporting, locomotive diagnostics, and fuel savings, while adding the capability for dynamic headways (which substantially increase line capacity).

To realize the full benefit of dynamic headways, wayside signals may need to be removed. The implications of this for detection of broken rails and avoidance of broken-rail derailments are discussed later in this section.

A. Line Capacity

Real-time location information allows railroads to operate with dynamic, rather than fixed-length, blocks between trains. Functionally, dynamic headways in PTC B work as follows:

- The OBC on each train continuously calculates a minimum safe stopping distance
- Using this distance, the central safety system can calculate a minimum safe distance between opposing and following trains
- This minimum distance is constantly recalculated by the OBC and the central dispatching software

Dynamic headways can increase line capacity by permitting shorter and lighter trains to operate on closer headways, rather than constraining all trains to the separation required by the longest and heaviest trains. The potential savings due to avoided investment in additional track and ROW has been quantified here. Dynamic headways can also, in conjunction with a local tactical planner, reduce average running times. For instance, a 20% reduction in run time means that a train which used to take five hours for a trip will now take four hours. This provides an extra hour when the track is free to run another train. Any reduction in run time produces an equal increase in track availability.

While Canadian National Railways found little economic benefit to line capacity improvement in its 1990 ATCS business case, much has changed in the intervening years. Traffic growth, line sales, and abandonments have largely eliminated the excess line capacity that existed prior to deregulation of the industry in 1980. Virtually all Class I railroads have made major investments in additional capacity in the last decade. For example, Union Pacific and Burlington Northern Santa Fe have constructed many miles of second and even third main track. Norfolk Southern and CSX Transportation have invested in track and yard capacity to enhance the value of the portions of Conrail that each railroad purchased in 1998. Most railroads have reconstructed existing yards and built new yards to accommodate changing traffic mixes and service patterns.

The amount of capacity expansion which might be needed, and hence the total cost of capacity expansion, depend on a number of factors which are difficult to estimate. Line capacity is determined by a number of location- and route-specific factors, including grades and curvature, operating speeds, type of signal control, and traffic mix. The specific actions which must be taken to resolve capacity bottlenecks will also differ from location to location.

In this analysis, an attempt has been made to determine the route mileage of the Class I railroad network that is now operating at or above capacity. This mileage has in turn been used to estimate the cost of capacity additions, a cost that may be avoided by PTC installation.

The Volpe Rail Network (VRN), which contains data on volume of traffic (in both MGT and number of trains per day), operating speeds, and type of signal control, has been used to estimate the percentage of the Class I route network where existing traffic exceeds current capacity. The cost of upgrading capacity on these segments to accommodate current levels of traffic provides a lower bound on the costs of required future capacity expansion.

1. Lines Currently at Capacity

The VRN contains data on traffic volume in MGT, type of signal control, number of trains per day, and number of main tracks for each line segment. In order to determine the capacity of a given segment, the network was divided into four categories, by current type of signal control:

<u>“Dark” (unsignaled)</u>

Dark territory is dispatched by voice radio, with switches at passing tracks thrown manually by train crews. Meets are thus time-consuming, and even on dark double track (of which there is very little) the lack of signal protection means that trains cannot follow each other closely.

<u>Automatic block signals (ABS)</u>

ABS provides signal protection, but is relatively inflexible. On ABS double track, trains are restricted to movement in only one direction on signal indication (“current of traffic”). Today, train movements are usually controlled by track warrants or Direct Traffic Control (movement instructions transmitted by voice radio), with signals used only to control train spacing.

Centralized traffic control (CTC)

In CTC territory, train movements can be made on signal indication alone. CTC also provides remote control of switches and signals, and permits closer train spacing, quicker meets between trains on single track, and higher line capacity than even double-track ABS.

Double Track CTC

Double track CTC permits operation on either track in either direction, by signal indication.

ZETA-TECH previously calculated a practical maximum line capacity for each of these types of signal systems. This was done by using a methodology that used signal type, operating speed, number of trains, and frequency and severity of train delays to construct a scalar number called "dispatching effectiveness" for each of a number of line segments[13]. The study used actual train movement data and minimum train running times (developed through use of computer simulation) for 33 Class I line segments to develop statistical estimates of the effectiveness of operation of railroad line. Dispatching effectiveness could range from 0.0 to 1.0; in practice, the lowest effectiveness was about 0.35, the highest about 0.8. Examination of the results of the analysis of the 33 line segments allowed conclusions to be drawn regarding the traffic levels at which specific segments were beyond their practical capacity. From these observations, the thresholds in Table 9 were developed. Specific segments where traffic exceeded these thresholds for current signal systems were then identified using the Volpe model, and a total mileage for the segments in each category was calculated. To estimate the cost of increasing capacity, a set of rules was developed for adding line capacity in the most cost-effective manner. If traffic on a dark segment exceeded capacity, the most effective remedy was the addition of block signals. On ABS lines, the signals were upgraded to CTC. On CTC lines, a second track was added. On double-track CTC, a third main track was added.

Table 9
Criteria for Capacity Improvements

Type of Signal Control	**Maximum Capacity**	**Track Miles**	**Remedy to Increase Capacity**	**Cost per Mile**
Dark territory (no signals)	15 MGT	8,697	Install CTC	$125,000
ABS territory	35 MGT	1,789	Install CTC	$65,000
CTC single track	75 MGT	4,452	Add double track	$1,015,000
CTC double track	150 MGT	3,942	Add additional track	$1,015,000

NOTE: CTC capacity enhancement reflects cost of additional track at $1 million per mile plus cost of CTC signaling on new track at $15,000 per mile.

13 Randolph R. Resor, Michael E. Smith, and Pradeep Patel, *op. cit.*

2. Cost of Increasing Capacity

Railroads can increase network capacity either by improving the signal system or by adding track. Control system enhancements are certainly less costly than adding track. An industry signal expert provided rough estimates of the cost of upgrading signal systems shown in the last column of Table 9[14]. Obviously, a railroad will select the least costly alternative for increasing capacity. In dark and ABS territory, this will mean adding CTC (at the appropriate cost per mile). For single- or double-track CTC, the signal system is already state of the art. The only way to increase capacity further, without use of some new control technology (such as PTC), is to add additional main track. Construction cost for track is about $1,000,000 per mile, plus $15,000 per mile for signals.

Of course, PTC also offers a capacity increase, and is certainly less costly than additional main track. However, absent the installation of PTC, railroads will have no option but to add main tracks as traffic continues to increase. Table 10 shows the total one-time capital cost of adding this track. It should be noted that the mileages shown in Table 9 are track that is *already* at or above capacity. Future traffic increases will require additional investment.

Table 10
Estimated One-Time Cost of Enhancing Line Capacity
On Segments With Capacity Constraints

Type of *Signal Control*	Miles Over Cap.	Capacity Enhancement	Cost per Track Mile	Additional Signal Cost per Mile	Estimated Cost (000)
Single-Track CTC	4,452	Track	$1,000,000	$15,000	$4,519,780
Double-Track CTC	3,942	Track	$1,000,000	$15,000	$4,001,130
Total	**8,394**			**Total**	**$8,520,910**

Perhaps a more reasonable way to present these numbers is as an annualized cost. Table 11 shows the annualized cost of adding and maintaining 8,394 miles of additional track. There are two components to this cost: the annualized cost of the track construction, figured at $1,015,000 per mile, and the annual cost to maintain the track. The annualized construction cost is based on a life of 80 years (an AREMA standard for railroad structures such as bridges) and a discount rate of 7%. The annual maintenance cost is based on the industry average spending per track mile for capital investment plus maintenance of way operating expenses (such things as track inspection, snow removal, and minor maintenance), and comes to about $60,500 per track mile annually for all track

14 It is difficult to estimate costs precisely, since they depend on the number of controlled turnouts, the number of sidings, the availability of commercial power, etc. The numbers cited here are used for general budgetary purposes.

owned by Class I railroads. This is, if anything, an understatement because it includes all track, yard as well as main track and branch lines as well as main lines. The 8,394 miles of track added here will, of course, be heavily used mainline track.

The annualized cost per mile for track construction (an 80-year life at 7% per annum) is $71,368. The average annual expenditure for track maintenance and rehabilitation (capital plus MOW operating expense) is $60,516. Applying these numbers to the 8,394 miles of track produces the totals shown in Table 11.

Table 11: Annualized Cost of Additional Track to Address Line Segments Already at or Above Capacity

Type of Signal Control	Miles Over Cap.	Total Annualized Cost (see text)	Total Annual Maint. Cost	Grand Total
Single-Track CTC	4,452	$317,730,336	$269,417,232	$587,147,568
Double-Track CTC	3,942	$281,332,656	$238,554,072	$519,886,728
Total	**8,394**	**$599,065,303**	**$507,971,304**	**$1,107,034,296**

Clearly, the avoidance of roughly $1 billion in annual cost is a major potential benefit of PTC. It is important to note, once again, that the costs in Table 11 are for addressing current, not future, capacity constraints. In the absence of an industry decision to install PTC, even more investment will be required as if traffic continues to increase. Projections by the American Association of State Highway and Transportation Officials predict a 57% increase in freight movement by 2020.[15]

This is, of course, an estimate based on global assumptions for the nationwide system. Obviously, site-specific analysis of a particular rail line may yield fixed plant investment options (e.g., the addition of specific short stretches of track) that collectively might resolve bottlenecks for that line as cost-effectively as the installation of PTC. On the other hand, on densely-used railways, it is possible that PTC alone would not provide sufficient capacity enhancement to reliably meet current or future needs, in which case the provision of additional trackage or new or reconfigured interlockings may be inevitable, albeit deferrable for some years by PTC's presence. Hence, while offering a modicum of capacity improvement, PTC cannot—in the absence of site-specific studies— be fairly viewed as invariably more cost-effective than fixed plant betterments, or permanently affording ample capacity.

B. Retention or Removal of Wayside Signals

A recurring issue in the various business case analyses conducted over the last decade has been the removal or retention of wayside signals. Since PTC A is an overlay

[15] **Freight-Rail Bottom Line Report,** American Association of State Highway and Transportation Officials (Washington: 2003)

system, existing signals would be retained in any case in a PTC A installation. PTC B, however, is another story.

One of the larger benefits of PTC B is the presumed avoidance of capacity additions on more than 8,000 miles of Class I track, as discussed in the previous section. The moving block capability of PTC B allows trains to follow more closely in most cases, increasing line capacity. However, retention of wayside signals will constrain this benefit, since there must always be at least one unoccupied block between trains if the wayside signals are to continue to provide broken rail protection.[16] Average block length on U.S. main lines is about two miles; short, fast trains like passenger or intermodal trains can operate closer than this under PTC B.

In general, it has been assumed that signals will be retained where they currently exist, even in a PTC B installation. So there are two analysis issues here:

1. The extent to which signal circuits actually detect broken rails (many types of rail breaks will not interrupt signal circuits but can still derail trains)
2. The amount of trackage in the U.S. that carries sufficient traffic to require moving block operation or some other method of increasing capacity.

Item 2 was discussed in the previous section. Item 1, the extent to which signals can prevent broken rail derailments, is addressed here.

It has been difficult to obtain reliable data on the number of rail breaks actually occurring in service, and detected by the signal system, in signaled territory. The most reliable statistics were obtained from a Western Class I railroad, in the form of "wire chief trouble calls" turned in by signal maintainers. They include the maintainers' assessment of the cause of each signal problem, and are almost certainly the most accurate statistics available on broken rails detected by signal circuits.

This railroad reported a total of 213 broken rails detected by signal circuits on one division of the railroad over a calendar year. Assuming broken rails are proportionally distributed across the railroad, it can be estimated that about 958 broken rails were detected by the signal system on the entire railroad. Since there were 1,598 rail defects found in service (i.e., not found by detector cars) on signaled territory in the same period, it can be inferred that about 60% were found by the signal system.

Whenever a train crew finds a service defect by running over it, there is a derailment risk. To calculate the increased derailment risk associated with signal removal, it is first necessary to determine the probability of derailment on a previously unreported defect. (This probability is <u>not</u> the same as the ratio of derailments to service defects, since defects found by signals or by track inspectors pose no derailment risk).

[16] Conventional wayside signals use a low-voltage current through the running rails to detect trains. A rail break may interrupt this current, setting the signal to red. Each signal protects a fixed length of track, usually about two miles long.

There were a total of 6,192 service defects on signaled trackage on this railroad over a three-year period, or an average of 2,064 per year. Of these, trains found 5% of these or 103. On unsignaled track, there were 6,070 defects over three years or 2,023 per year. Trains reported 50% or 1,011 of these. Therefore, a total of 1,114 service defects were detected first by trains, rather than by signals or track inspectors. In one of these three years there were 47 broken-rail derailments. Broken-rail derailments are by definition caused by rail defects. Thus, the probability of derailment when a train finds a service defect is 47/1114 or 4.2%. It will be assumed in this analysis that each of these derailments will have a cost equal to the average 2001 cost for rail-caused derailments: $479,493 per derailment.

It is estimated that track inspectors find 20% of service defects in signal territory, and train crews report 5%. In the absence of signals the 1,548 service defects (75% of 2,064 per year) now found by signals would be found either by track inspectors or by train crews. At the current ratio, track inspectors would locate 80% of the defects now found by the signal system and train crews would find 20%. Therefore, train crews (who now report 5% of service breaks or 103 per year) would report an additional 310 defects, with track inspectors locating the remainder.

These additional 310 rail breaks reported by trains, with a 4.2% derailment probability, may be expected to result in an additional 13 derailments (0.042*310). At an average cost of $479,493, this corresponds to an additional $6.23 million in derailment costs. This railroad accounts for about 20% of Class I mileage and traffic, so this frequency would imply an additional derailment cost of about $31.15 million annually for all Class I railroads. In 2001, the total cost of broken rail derailments on all Class I railroads was about $47 million. In percentage terms, this implies an increase of 67% in broken rail derailment costs annually if PTC B is installed and all wayside signals (except at control points) are removed.

In fact, railroads choosing to install PTC B would probably choose to retain wayside signals for broken rail detection wherever possible. On the relatively limited portion of the network where moving block capability would be of real value (about 8% of route miles), alternative detection technologies might be employed. This would probably add cost, but even an increase of $31 million annually in broken-rail derailment cost pales in comparison with the estimated benefits of PTC.

V. Shipper Benefits

To this point, the PTC benefits quantified have been benefits that will accrue exclusively to railroads that choose to implement PTC. However, there will be benefits to shippers as well (or benefits that, depending on the workings of the market, will be shared between railroads and shippers). This section documents how benefits to the shipper can occur as a result of Positive Train Control (PTC) implementation by railroads based on reducing shippers' logistics cost. The most important of these logistics benefits would be associated with the ability of railroads to provide improved on-time service. There are at least three major methods by which shipper benefits from PTC implementation may be measured:

1. Determine the savings shippers might realize in terms of the reduced inventory portion of logistics cost reduction if service reliability improves. This would be one measure of the total benefit available from improved service when PTC is installed. Later, this report will show that a reduction in the cost of carrying safety stock may be a useful surrogate for a lower-bound measure of the total benefit available from improved reliability. The split of that benefit between shippers and railroads will depend on market conditions.

2. Determine what additional amount shippers might be willing to pay for improved service reliability. This would be expected to be a smaller number than the one produced in the previous method as it represents only that portion of the total benefit that would accrue solely to the railroad; however, we shall see that the disparate methods used here do not provide the expected result.

3. Determine the cross-elasticity of demand and price relative to PTC-enabled improvements in transit time and its variability as reported in a study on total logistics cost that had been prepared for the Federal Highway Administration. This method for two methods used.

There seems to be little question that PTC can improve service reliability. The issue here, however, is not how benefits might be divided between railroad and shipper, but rather on determining the total benefit to be shared by shippers and railroads. Nevertheless, this report will develop an estimate of the capital and operating cost savings that a shipper could enjoy based on a combination of the inventory and cross-elasticity methods suggested above.

Based on these analysis methods, the shipper will experience benefits in two ways:

1. Spending less capital on facilities needed to maintain inventory; and
2. Spending less money on other inventory carrying costs (taxes, insurance, and obsolescence).

The first of those two items will be measured by dividing the capital portion of annual inventory cost savings by a cost of capital for the shippers, and the second of those two items by determining the difference in the remaining carrying costs for those commodity amounts currently shipped by rail (and for which shippers will enjoy improved service).

Finally, if railroads choose to keep prices constant and simply market their services to a larger audience, the shippers will have an additional benefit. Some of the commodities that they currently ship by motor carrier will now be shipped by rail. This report also calculates the reduction in shipping costs that shippers may enjoy as a result.

An additional note about the inventory reduction technique for calculating railroad efficiency gains is important here. This report will present analysis of savings that represent a lower bound for the savings that shippers would likely enjoy from inventory reductions made possible through improved rail operations. This lower bound results from several analytic choices that are made and documented in other portions of this report. In general, a lower-bound estimate is useful here because the analytic approach focuses on only one element of logistics: inventory.

An important observation about the inventory reduction method is that it is based on product values that are prior to shipment rather than after shipment. In most instances, the value after shipment is more likely to represent the base from which inventory reduction savings could be calculated. Since the post-shipment value of a commodity is always higher than its pre-shipment value, the resulting benefit estimate still would fit with the concept of producing a lower-bound estimate.

The third techniques used for making a benefits estimate, the reduction in total logistics cost, is based on a highly theoretical construct, but is much more thorough than the inventory reduction technique used for calculating benefits. It can therefore be considered a higher-bound estimate of the benefits.

With all three methods of benefit calculation, this report will first calculate the amount of benefit if the railroad improves its reliability by 100 percent versus the current business case (that is, all shipments arrive within the promised delivery window desired by the shipper). Since 100 percent improvement is not possible, a substitute estimate is used to calculate the likely improvement that installation of PTC might actually deliver.

It is important to note that the inventory and logistics analysis methods of determining benefit depend on the reduction in standard deviation of transit time, while the elasticity method depends on increase in percentage of shipments that arrive on time. As a result of these two disparate bases, the percent of the total benefit pool achievable is different in each case. That is, using the inventory and logistics analysis methods, this report will show that about 7 percent of the total benefit available can be achieved. But under the elasticity method (based on shipper surveys), about 20 percent of it can be achieved.

It is also possible that other techniques not related to PTC will be used by the railroads to improve their reliability. In fact, certain railroads have already attained significant improvements in their process flow by using more disciplined and automated planning and execution techniques that involve the use of other technological approaches, such as car scheduling. Therefore, other chapters in this study clarify the extent to which PTC can add to the benefits produced by those techniques and technologies.

Method 1 – Calculating Benefit From Inventory Cost Reductions

One technique for determining the benefits of improved service reliability is to look at potential changes in "safety stock," the goods carried in inventory to protect against service failures. As the rise of "just in time" delivery systems indicates, a reduction in inventory is a real savings for the shipper. So rather than looking at the effect of improved service on elements of the logistics chain, here the effect is quantified in terms of reduction in safety stock inventory for the shipper and receiver.

This method addresses only the change in safety stock for several reasons:

1. The reduction in safety stock inventory can be calculated using publicly available data. It can be derived from the mean and standard deviation of transit times for railroad-delivered commodities and the improvements that could be expected from PTC-induced reliability changes.

2. The analytical approach makes a useful surrogate for the total logistics benefit available from improved reliability. An understanding of that is useful here. When reliability is improved, shippers and receivers may respond by making structural changes in all elements of their logistics chain. This will result in reducing costs associated with inventory, ordering, loading and unloading, and production. On the other hand, shippers and receivers could maintain precisely the same probability of stockout and simply reduce the amount of inventory that they hold in response to improvement in service reliability. While this approach would yield a benefit estimate smaller than the total amount available, it produces a lower-bound estimate. As this report looks at several ways to estimate this benefit, a lower bound estimate will be shown to be quite useful.

Every shipper must arrange to have raw materials, work-in-process, and finished goods at the right place at the right time. When a customer calls and places an order, the shipper will compete best if that product is available right away and in the right condition. Being out of stock can be enormously expensive, causing the production process to grind to a halt and affecting many other activities in the chain of events that runs from raw materials to finished goods. The actual transportation of the shipper's goods by the carrier is only one element in a series of activities associated with the total logistics process.

A quotation from an authoritative paper on railroad logistics provides a taxonomy of costs to consider here. (1)

> 1. Order and handling costs – all the administrative and handling costs associated with placing, tracking, and processing an order for a shipment of materials.
> 2. Transportation charges – freight and other special charges associated directly with the movement of the goods.
> 3. Loss and damage costs – including the actual value of the material lost or damaged for which the shipper is not compensated by the carrier, capital or carrying charges associated with tying the remaining material up during claim processing, and any processing charges.
> 4. Capital carrying cost in transit – includes the cost of capital of the goods while they are in transit.
> 5. Inventory carrying cost at destination – this is the capital cost of the goods at the final destination, and is a function of shipment size.
> 6. Unavailability of equipment costs – capital carrying costs due to the unavailability or late arrival of transportation equipment to make the movement.
> 7. Service reliability costs – This includes a number of costs, depending on whether a shipment arrives early or late relative to the planned time of arrival. In the event of early arrivals, it includes the cost of extra storage space and personnel to process the shipment. Late shipments are subject to either stockout costs or the carrying costs for inventory held for the purpose of avoiding stockouts.
> 8. Intangible service costs – these include the costs associated with aspects of service quality not captured in the trip time and reliability, such as the ability to trace shipments, EDI,

capability, payment and billing processing, etc. (These are often not included because of the difficulty in attaching a specific cost.)

While the preceding paper (Cook, *et. al.*) looked at the elements of logistics costs associated with rail shippers, other authors have taken a more general approach. One of the most often cited of these is Cass Information Systems. Each year, they produce a report on the state of logistics in the United States, providing a number of useful quantities that we will use for benchmarking later in this report. Their breakdown of total logistics costs includes the following: (2)

1. Transportation costs – these are the actual costs of moving the goods from one point to another. When comporting to the taxonomy in the previous list, this cost would include transportation charges and loss and damage costs.

2. Inventory carrying costs – these costs would definitely include inventory-carrying costs at destination as well as the return on capital costs associated with in-transit inventory. They also likely include the service reliability costs and the waiting for equipment costs, as those two elements of cost simply increase the amount of inventory that must be carried. Finally, most of the intangibles cost must be included here as the way these intangibles are dealt with is usually through greater amounts of inventory.

3. Administrative costs – these costs consist of the order handling costs described earlier.

From the point of view of service reliability, the shipper's benefit will come from holding less inventory. When service is unreliable, shippers will hold inventory in order to avoid running out of the product. For example, a power plant that uses coal for fuel would experience difficult and expensive problems if the supply of coal on hand were to run out. With highly variable rail transit times, the utility will be forced to keep a very large supply of coal on hand. If the railroad's service were to become more reliable, the utility would be able to maintain the same level of protection against a stockout even while keeping less coal on hand. The more unreliable the delivery time of a shipment, the larger the amount of safety stock that must be held. Ideally, all elements of the production and distribution chain would have no variability at all, making safety stock unnecessary. This state of affairs, in which the concept of Just-in-Time delivery holds sway, is a laudable, but seldom accomplished, goal.

As discussed earlier, it is possible for shippers to claim the gains of improved shipment time reliability by adjusting the amount of safety stock without affecting any other elements of the logistics chain. It is possible, therefore, to develop a lower-bound estimate of benefits from the shipper perspective by examining inventory only. The shipper's benefit will be related to the cost of carrying safety stock. As the amount of inventory that the shipper needs to carry shrinks, then the total logistics cost for the management of their supply chain shrinks as well. This reduction in cost means that the shipper will be willing to pay more for transportation.

It is important, then, to examine the various elements of inventory carrying costs in order to determine the amount of the cost that a shipper might avoid if the reliability of rail service were to improve. Inventory carrying costs consist of the following elements:

1. Interest on the capital associated with investment in the product – this cost today is quite low as interest rates, both real and nominal, are now at historically low levels. Cass estimates these costs today at 1.59 percent. And, while it may be true that the risk-free rate for capital acquisition is at levels that low, other authors point out that were the capital not tied up in inventory, the business would invest in its own operations, returning an average of 6 to 7 percent in real terms. For that reason, we consider the Cass estimate to be low.

2. Perishability and obsolescence, insurance, and taxes – these elements are highly variable by commodity, especially perishability. Coal, for example, is virtually non-perishable, while bananas will not last long at all. The Cass estimate for these three items in combination is 13.64 percent annually. We will accept that for purposes of this analysis.

3. Storage costs – while these can vary dramatically on a per ton basis, they do not vary so much on a per dollar basis. Coal, for example, requires hardly more than a pad for it to sit on while bananas require gentler handling. However, bananas cost far more per pound than coal. Thus the storage cost per dollar of inventory value does not vary greatly. The Cass estimate for this element is 5.1 percent annually.

The total of these costs, by Cass' estimate, would be about 21 percent for 2002. However, this estimate is based partly on an interest cost of only 1.5 percent. Research on the long-term cost of equity capital reveals that it is about 6 to 7 percent. (3) Using 6 to 7 percent rather than 1.5 percent as a cost of capital total carrying costs to about 26 percent of the value of inventory.

It is useful as well to compare the carrying costs thus developed with others that have been reported in the literature. Table 12 shows these values

The most frequent value cited in the literature is 25 percent and the arithmetic average of all values cited is 26 percent. When the value of the Cass estimate is adjusted for the expected long-term cost of funds, that amount is, as reported earlier, 26 percent. That amount (26 percent) will be used in this report.

Now that there is a reasonable estimate of what it costs to carry inventory, in terms of the inventory's value, a full estimate of the cost to the shipper requires knowledge of the value of the commodities held in inventory. That requires an examination of the commodities the railroads carry, quantities carried, and their value.

The most accurate way to determine these items is to take a very detailed look at all the commodities the railroads carry. An argument can easily be made that taking averages across broad categories of freight can hide some major differences in value. After all, ammonia and elemental fluorine are both chemicals, but the latter has far more value per ton than the former. While it is possible to develop some of this detail by looking at the Carload Waybill Sample, it is unlikely that the additional effort required would add to the accuracy of this exercise, given that values per ton for such a detailed list of commodities may be difficult to develop.

The method used in this report divided shipments into categories based on two-digit Standard Transportation Commodity Code (STCC). This allows for some disaggregation of rail shipments based on the characteristics of the commodity without developing an overwhelming amount of detail. It also allows for a separate analysis of three different railroad service types – unit train, intermodal, and carload. This report will show how to place each of the two-digit commodity codes into one of the three service types later.

The tons shipped and revenue received for each of the two-digit STCC groups is available on the Web site of the Association of American Railroads. Table 13 provides this information.

Table 12
Representative Values of Carrying Cost Reported in the Literature

Author	Publication	Carry Cost Estimate
L. P. Alford and John R. Bangs (eds.)	*Production Handbook,* (New York: Ronald Press, 1955) p. 397.	25 percent
George W. Aljian	*Purchasing Handbook,* (New York: McGraw Hill, 1958), pp. 9-29.	12 – 34 percent
Dean S. Ammer	*Materials Management,* (Homewood, IL: Richard D. Irwin, 1962), p. 167	20 – 25 percent
Donald J. Bowersox, David J. Closs, and Omar K. Helferich	*Logistics Management,* 3rd ed., (New York: Macmillan, 1986), pp. 189-97.	20 percent*
Joseph L. Calvinato	*Purchasing and Materials Management*, (St. Paul, MN: West Publishing, 1984), p. 144	25 percent
Thomas W. Hall	"Inventory Carrying Costs: A Case Study," *Management Accounting*, January, 1974, pp. 37-39	20.4 percent
J. L. Heskett, N. A. Glaskowsky, Jr., and R. M. Ivie	*Business Logistics,* 2nd ed. (New York: Ronald Press, 1973), p. 20	28.7 percent
James C. Johnson and Donald F. Wood	*Contemporary Physical Distribution and Logistic,* 3rd ed. (Tulsa, OK: PenWell Publishing, 1986), p. 253.	25 percent
John F. Magee	"The Logistics Distribution," *Harvard Business Review*, July-August, 1960, p. 99.	20 – 35 percent
Benjamin Melnitsky	*Management of Industrial Inventory* (Conovar-Mast Publication, 1951), p.11.	25 percent
Thamson M. Whitlin	The Theory of Inventory Management, (Princeton, NJ: Princeton University Press, 1957), p. 220.	25 percent
Additional Reference	"A Methodology for Calculating Inventory Carrying Costs," presented by RGM Associates (no date), on web site at www.remassoc.com.	25 – 55 percent

Table 13 provides the tonnage and revenue information for two-digit STCC groups that represent over 98 percent of the tons shipped via railroad. The remaining 17 commodity groups that are not individually allocated by tonnage are identified with "n/a." The number of tons shipped in these commodity groups is insufficient to warrant individual analysis. In addition to the tonnages shipped in the less common groups, STCC 99 represents shipments for which nothing is known about the commodity (data are entirely unavailable). For these 23,258 million tons, the value per ton is based on commodity averages. The revenue is the amount needed to sum up to the total revenue received by the industry after accounting for the shipments where the commodity is known.

In order to know the value of the goods that have been shipped, it is important to understand the values of commodities by two-digit STCC. For those values, this report turns to data provided in a report prepared by Reebie Associates for the Ohio Department of Transportation. (3) Since the cited report provides these values for 1998, this report adjusts those values over the intervening years using appropriate producer price indexes from the Bureau of Labor Statistics (Table 14).

Table 13
Tons Shipped and Revenue Received by Railroads by Two-Digit STCC

STCC	Product Description	Annual Tons Shipped (thousands)	Annual Revenue (millions)
01	Farm Products	137,717	$ 2,711
08	Forest Products	n/a	n/a
09	Fresh Fish or Marine Products	n/a	n/a
10	Metallic Ores	31,376	$ 285
11	Coal	785,006	$ 7,797
13	Crude Petroleum or Natural Gas	n/a	n/a
14	Non-metallic Minerals	125,643	$ 967
19	Ordnance	n/a	n/a
20	Food or Kindred Products	102,230	$ 2,657
21	Tobacco Products	n/a	n/a
22	Textile Mill Products	n/a	n/a
23	Apparel or Related Products	n/a	n/a
24	Lumber or Wood Products	47,533	$ 1,628
25	Furniture or Fixtures	n/a	n/a
26	Pulp, Paper or Allied Products	37,212	$ 1,567
27	Printed Matter	n/a	n/a
28	Chemicals or Allied Products	158,734	$ 4,707
29	Petroleum or Coal Products	40,207	$ 977
30	Rubber or Miscellaneous Plastics	n/a	n/a
31	Leather or Leather Products	n/a	n/a
32	Clay, Concrete, Glass, or Stone	49,275	$ 1,149
33	Primary Metal Products	55,905	$ 1,350
34	Fabricated Metal Products	n/a	n/a
35	Machinery	n/a	n/a
36	Electrical Equipment	n/a	n/a
37	Transportation Equipment	35,902	$ 3,626
38	Instrumentation, Photo, and Optical Equipment	n/a	n/a
39	Miscellaneous Manufactured Products	n/a	n/a
40	Waste or Scrap	39,440	$ 717
41	Miscellaneous Freight	n/a	n/a
46	Miscellaneous Mixed Shipments (mostly I/M)	97,228	$ 4,900
99	All Other Freight	23,258	$ 1,704
Total for all commodities		1,766,667	$ 36,742

Table 14
Shipment Values per Ton by Two-Digit STCC Group

STCC	Description	’02 Value/Ton
01	Farm products	$1,044
10	Metallic ores	$49
11	Coal	$29
14	Nonmetallic minerals	$21
20	Food or kindred products	$1,471
24	Lumber or wood products, excluding furniture	$2,440
26	Pulp, paper, or allied products	$1,440
28	Chemicals or allied products	$2,142
29	Petroleum or coal products	$292
32	Clay, concrete, glass, or stone products	$222
33	Primary Metal Products	$1250
37	Transportation equipment	$14,321
40	Waste or scrap materials	$28
46	Mixed Commodity Shipments	$1,606
99	Commodity unknown	$920*

* Note: rather than using the high value quoted in the Ohio Study (nearly $10,000 per ton) this value represents the average of all the commodities shipped via railroad.

Based on the preceding two tables it is possible to estimate the value of goods shipped by rail. Table 15 presents these values by two-digit STCC group (names of commodity groups for which data have not been separately calculated are suppressed in this table).

The annual value of goods shipped by rail is approximately $1.6 trillion. This amount indicates that the railroads are shipping about 16 percent of the nation’s $10 trillion annual GDP.

In order to determine how greater reliability will impact the shipper, it will be important to know how much inventory shippers must hold for each of these kinds of freight in order to guard against the variability of transportation service. For the most part, shippers will wish to avoid a stockout situation. The costs of recovering from a stockout can be substantial, including lost business, higher costs for alternative transportation or substitute materials, and substantial administrative costs associated with handling a situation in a different way from normal.

Table 15
Value of Goods Shipped by Rail

STCC	Product Description	Tons/yr (000s)	Value/Ton	Total Value ($000s)
01	Farm Products	137,717	$ 1,044.00	$ 143,764,301
10	Metallic Ores	31,376	$ 49.00	$ 1,540,764
11	Coal	785,006	$ 29.00	$ 22,999,335
14	Non-metallic Minerals	125,643	$ 21.00	$ 2,583,898
20	Food or Kindred Products	102,230	$ 1,471.00	$ 150,394,531
24	Lumber or Wood Products	47,533	$ 2,440.00	$ 115,995,587
26	Pulp, Paper or Allied Products	37,212	$ 1,440.00	$ 53,588,052
28	Chemicals or Allied Products	158,734	$ 2,142.00	$ 340,041,178
29	Petroleum or Coal Products	40,207	$ 292.00	$ 11,730,881
32	Clay, Concrete, Glass, or Stone	49,275	$ 222.00	$ 10,993,620
33	Primary Metal Products	55,905	$ 1,250.00	$ 69,895,237
37	Transportation Equipment	35,902	$ 14,321.00	$ 514,135,487
40	Waste or Scrap	39,440	$ 28.00	$ 1,089,923
46	Miscellaneous Mixed Shipments	97,228	$ 1,707.00	$ 165,967,301
99	All Other Freight	23,258	$ 920.00	$ 21,397,360
Total for all commodities				$1,626,057,466

A graphical depiction of the demand for commodity shipment, value of commodities shipped, and revenue received by the railroads is provided in Figure 6.

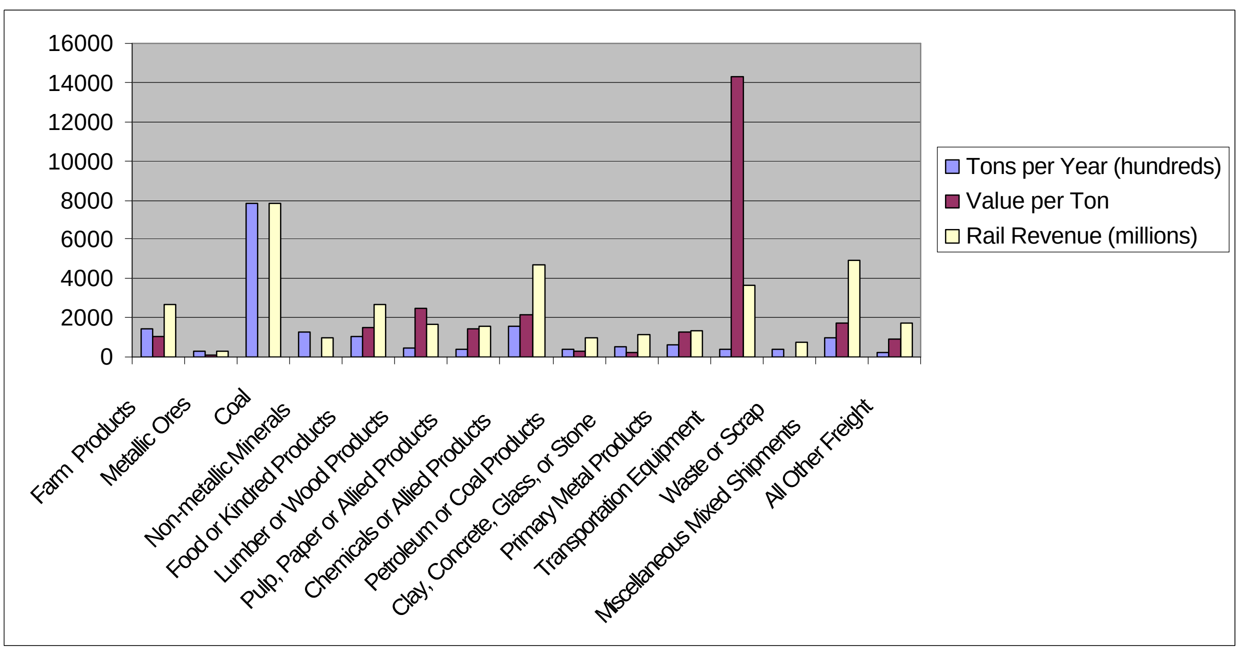


Figure 6. Demand, Value, and Rail Revenue in 2002 for Selected Commodity Groups

While there has been considerable discussion in recent years regarding concepts associated with Just-in-Time (JIT) delivery of commodities for use in further manufacturing or sale, the fact remains that some stock must be carried by someone to guard against unforeseen circumstances. The movement toward JIT is, more than anything else, a way of looking at the situation to see how the stock to be carried can be minimized. After all, at a carrying cost of 26 percent or so annually, it is expensive to carry stock when it is not needed.

To guard against stockout due to slow transportation, a shipper will want to maintain a bit of inventory and the question is how much. In the case of the railroad that inventory can be estimated by determining the standard deviation of travel time. The shipper will want to make sure that a stockout occurs due to shipping failure no more than a certain percentage of the time. This will depend on the variance in delivery time for the product. The higher that variance is, the larger will be the amount of stock that the shipper holds to guard against the variance.

Reasonable analysts may differ over how much protection against shipping time variance is the right amount. If the shipper wants to reduce the probability of a stockout due to shipping failure to less than 2 percent, then a safety stock of two "standard deviations" of days would be sufficient. For example, if the standard deviation in railroad service time were two days, then a stock of four days' worth of product would be sufficient. If, on the other hand, the shipper wants to reduce the probability of stockout due to shipping failure to less than 0.5 percent, then an inventory containing at least three standard deviations of shipping time would be necessary.

Mean and variance of railroad transit times were found in a very thorough study of the Waybill Sample for 1991. (5) Table 16 summarizes the findings of this study. From this information, it is possible to develop the amounts of safety stock that shippers will need to guard against stockouts caused by transportation failure.

There are a number of reasons to believe, though, that this approach is likely to underestimate the amount of safety stock that is needed in the supply chain:

1. The study that determined the mean and variance of railroad transit times noted that these times are not normally distributed. Indeed, the time distribution is skewed toward the long end. This would generally cause shippers and receivers to increase the amount of safety stock that they would hold. Figure 7 shows why the assumption of a normal distribution is a conservative[17] approach. Note that although the mean travel times are about the same, the amount of traffic arriving in a short amount of time is reduced, while the amount of traffic taking longer is substantially increased. As a result, the amount of safety stock needed is much larger than would otherwise be computed.

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[17] In this context, the term "conservative" means an approach that would tend to give a lower estimate of avoidable inventory costs for shippers of goods moved by the railroad and thus a lower estimate of the benefits available from Positive Train Control.

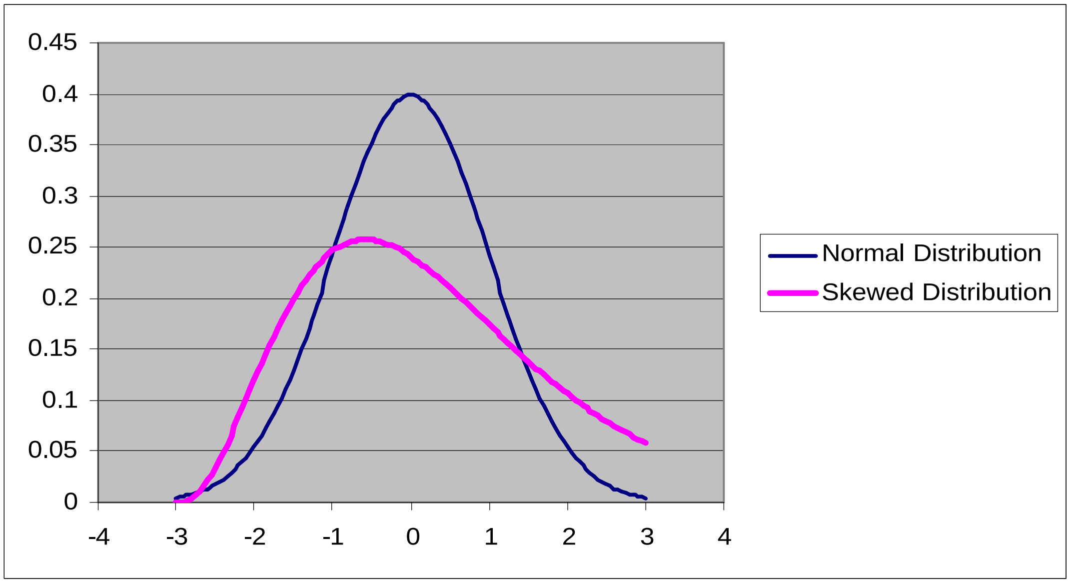


Figure 7. Comparison of Normal Distribution with a More Representative Distribution of Transit Times

2. There are additional elements to the transit time of a rail car that should be accounted for here. In particular, the variance of empty time could be important. That is because the shipper may order an empty car for loading and have to wait for days before it arrives. On the other hand, the railroad may have a car close by so that the order for the car can be filled right away. Since railroads distribute their empty cars in anticipation of where demand may exist, the variance of the empty portion of the car's cycle has not been considered here; however, the uncertainty of car supply is likely to add considerably to the amount of inventory kept in the supply chain.

3. Certain elements of service quality (such as the ability to trace a shipment) may play an important role in how much inventory is held. When shipment tracing is difficult, shippers may respond by holding more inventory. The amount by which this happens is not well known. However, it is known that PTC will make shipment tracing easier.

4. The mean and standard deviation of times shown in the table are not for the full set of movements extracted from the Waybill Sample, but are instead only for the 100 largest shippers. The result is that the mean travel times shown are less than the mean for the entire population of movements. For example, the mean transit time for all boxcar movements is 8.8 days. The reason for using the figures shown is that the standard deviation of transit times for the entire sample was not reported in the article. Using the amounts shown in this report is considered conservative.

Table 16
Mean and Standard Deviation of Trip Times for Rail Service

Equipment/Service Type	Average Travel Time (Days)	Standard Deviation of Travel Time (Days)
Boxcar	7.19	2.62
Unit Hopper Car	5.25	2.04
Double-stack Container Car	2.53	0.50

The standard deviation of trip times in Table 5 can then be used as a basis for determining the quantity of inventory that a shipper must hold to guard against stockouts caused by late shipments. This inventory would vary from one day to five days if the shipper wishes to keep stockout probability due to late shipment below 2 percent. It will vary from one and a half days to eight days if the shipper wishes to keep stockout probability due to late shipment to less than 0.5 percent. Since stockouts are very expensive, this report will base its analysis on the latter approach.

There will be one exception to that approach, though. The only commodity that is not used in any further processing or that does not need to be sold afterward is Waste and Scrap. There will be no inventory calculation prepared for that commodity.

To perform the analysis, it is necessary to assign each of the commodities to a type of car. The largest difference in standard deviation of travel time is between the intermodal shipments and all other shipments.

The commodity shipped via intermodal is nearly always STCC 46. And, most STCC 46 is shipped via intermodal. For that reason, this report will use the intermodal travel time variance to calculate inventory amounts that will need to be held for STCC 46 commodities. This is conservative to the extent that some intermodal shipments are made via single carloads and via single-stack operations. Railroads also provide special service for STCC 37, Transportation Equipment, because of its high value. Transportation equipment is often moved either in special trains or on intermodal trains, and has, therefore, been grouped with STCC 46 in intermodal service.

Unit train hopper car variance is used for the following commodities: Metallic Ores, Coal, and Non-metallic Minerals. All other commodities have been assigned to carload freight, and will be evaluated using the variance in travel time for boxcar traffic. While these commodities are not all shipped in that type of equipment, they are, for the most part, shipped in single-car service. This type of service would have similar characteristics to boxcar service. While grains (a farm product) often move in unit trains, the study which determined the mean and standard deviations of transit times found that less than 5 percent of covered hoppers move in true unit trains. The rest are moving as loose cars or large blocks. Therefore, the mean and standard deviation of car days found in the referenced study for unit trains is used for ores and coal, while the boxcar values are used for farm commodities.

It is now possible to calculate the value of the inventory that is held to guard against variations in rail transit time. This calculation appears in Table 17.

Table 17
Total Value of Safety Stock for Rail-Shipped Commodities

STCC	Product Description	Total Value ($000s)	Days Inv.	Value of Safety Stock ($000s)
01	Farm Products	$ 143,764,301	7.86	$ 3,095,856
10	Metallic Ores	$ 1,540,764	6.12	$ 25,834
11	Coal	$ 22,999,335	6.12	$ 385,633
14	Non-metallic Minerals	$ 2,583,898	6.12	$ 43,325
20	Food or Kindred Products	$ 150,394,541	7.86	$ 3,238,633
24	Lumber or Wood Products	$ 115,995,587	7.86	$ 2,497,878
26	Pulp, Paper or Allied Products	$ 53,588,052	7.86	$ 1,153,978
28	Chemicals or Allied Products	$ 340,041,178	7.86	$ 7,322,531
29	Petroleum or Coal Products	$ 11,730,881	7.86	$ 252,616
32	Clay, Concrete, Glass, or Stone	$ 10,933,620	7.86	$ 235,447
33	Primary Metal Products	$ 69,895,237	7.86	$ 1,505,141
37	Transportation Equipment	$ 514,135,487	1.50	$ 2,112,886
40	Waste or Scrap	$ 1,089,923	0	$ -
46	Miscellaneous Mixed Shipments	$ 165,967,301	1.50	$ 682,057
99	All Other Freight	$ 21,397,360	7.86	$ 460,776
Total for all commodities		$1,626,057,466		$27,298,674

Table 18 converts this inventory value into annual inventory carrying costs using the 26 percent estimate arrived at earlier. In addition, this table shows the ratio of that inventory carrying cost to the revenue that the railroads receive for shipping the commodity. This can be thought of as a "tax" burden on the shipping rate. That is, the shipper must not only pay the railroad for moving the product, but must as well incur a certain amount of expense associated with storing it. If railroad service were to become more reliable, the size of this adjustment would decline, raising the amount that the shipper would be willing to pay for rail service.

One of the more important conclusions to draw from this table is that the cost of extra inventory, as a percentage of the amount spent directly for rail service, is much higher for high-valued commodities than it is for low-valued ones. Thus, it is possible to use rail service, for example, to ship coal without adding a substantial burden to the rail rate just for holding inventory.

Certain commodities that have much higher values are provided superior rail service. Both mixed commodity shipments and automobiles are shipped with intermodal-quality service. This allows the high-valued products to meet schedule with a much higher level of reliability than the service provided for shipments of, for example, paper.

Table 18
Safety Stock Carrying Costs as a Percent of Rail Revenue, by Commodity

STCC	Product Description	Carry Cost (millions)	Rail Rev. (millions)	Carry Cost as Percent of Revenue
01	Farm Products	$ 805	$ 2,711	29.69
10	Metallic Ores	$ 7	$ 285	2.36
11	Coal	$ 100	$ 7,797	1.29
14	Non-metallic Minerals	$ 11	$ 967	1.16
20	Food or Kindred Products	$ 842	$ 2,657	31.69
24	Lumber or Wood Products	$ 649	$ 1,628	39.89
26	Pulp, Paper or Allied Products	$ 300	$ 1,567	19.15
28	Chemicals or Allied Products	$ 1,904	$ 4,707	40.45
29	Petroleum or Coal Products	$ 66	$ 977	6.72
32	Clay, Concrete, Glass, or Stone	$ 61	$ 1,149	5.33
33	Primary Metal Products	$ 391	$ 1,350	28.99
37	Transportation Equipment	$ 549	$ 3,626	15.15
40	Waste or Scrap	$ -	$ 717	0.00
46	Miscellaneous Mixed Shipments	$ 177	$ 4,900	3.62
99	All Other Freight	$ 120	$ 1,704	7.03
Total for all commodities		$ 5,983	$ 36,742	16.28

Relatively high valued goods shipped with boxcar-like service have the highest ratio of inventory cost to rail freight cost. This is most especially true of chemical traffic. Chemicals are very frequently shipped by rail due to safety issues. However, there is seldom a sufficient quantity to justify a unit train. As a result, the service levels for chemical traffic look more like the service levels for boxcar traffic. When that fact is combined with the fact that the commodity value is quite high, the inventory “tax” on rail shipments of chemicals exceeds 40 percent.

Reducing the amount of inventory could obviously provide real savings to shippers and they, just as obviously, would be willing to pay a higher shipping rate for transportation that could reliably deliver the service needed to accomplish this. In order to quantify the amount that shippers would be willing to pay, it is only necessary to make an estimate of the amount of inventory that shippers could avoid keeping due to a more reliable service.

Table 19 classifies these potential shipper benefits by the category of service involved. As the table shows, the amount of benefit potentially available for the intermodal and transportation equipment commodities is about $700 million and the amount available from unit train commodities is only about $100 million. On the other hand, improving the reliability of delivery for carload commodities and farm products could yield more than $5 billion per year, if railroad service were to become 100 percent reliable.

Table 19
Costs of Carrying Stock for Three Types of Rail Shipments

Commodities Shipped in…	Annual Safety Stock Carrying Cost ($000s)
Carloads	$ 5,138,342
Unit Trains	$ 118,246
Intermodal	$ 726,685
Total	$ 5,983,273

Table 19 shows the maximum possible benefit. How much of this benefit might actually be achieved will be addressed in later sections of this paper.

Method 2– Calculating Benefits Based on Elasticity of Demand

A second method for calculating the savings from improved rail service is the "stated preference" method. Unlike a revealed preference analysis, which involves a study of actions actually taken by shippers in response to changing price and service levels, a "stated preference" method can achieve the same kind of results using a survey.

In 1989, the Burlington Northern Railroad (BN), predecessor to Burlington Northern and Santa Fe Railway (BNSF), completed a stated preference study to determine the amount of revenue improvement that the railroad would likely enjoy due to service quality improvements that could possibly be achieved with an implementation of what they referred to as the Advanced Railroad Electronics System (ARES). The results of the study were developed into two case studies by Harvard Business School on the potential for ARES. (6) The study looked exclusively at shipment of commodities that could be reasonably expected to travel either by rail or by truck. That is, if the shipper had a choice between those two modes, what levels of service improvement would cause the shipper to consider switching from truck to rail?

Certainly, the reader may expect that this question could be examined in a broader sense. That is, there are cases in which the railroad may see increases in demand if grain shippers would switch from barge to rail or if shippers of higher valued commodities might switch from a completely motor carrier alternative to one involving both motor carrier and railroad transportation (that is, intermodal). In some cases, the shipment will be handled by a freight broker who will choose the method of transportation (third-party logistics provider). In these cases, the shipper likely does not even know if an intermodal solution is used. These latter arrangements were not examined in the BN study. As such, the study addresses only a fraction of the gains that railroads could consider achieving from improved service.

There is still a considerable amount of freight movement represented by this fraction of the market and the numbers generated in the BN study provide a useful attempt at quantifying the additional revenue for this type of freight that railroads might see if they were to improve their service offerings in various ways.

The technique used to measure this elasticity is known as Stated Preference (SP). While preferences may actually be revealed through studies on actual data from controlled experiments it is very difficult to ensure that proper controls are maintained. Although examination of actual choices could be useful as well, finding cases in which fully measured service variables are changed within the ranges desired is a daunting and expensive task. In the case of railroads, however, much of the needed data variation could be revealed through an analysis of data from the Union Pacific as it recovered from its 1997 service difficulties. In 1989, however, the BN did not have the good fortune of having field information available that covered such a broad range of service quality offerings. For these reasons, the BN study relied on survey data.

In performing the study, the John Morton Company used a technique known in the industry as *conjoint.* The conjoint technique relies on asking customers questions about more than one service attribute, as well as price, all at the same time. For example, the shipper may be asked a question such as "Would you prefer a shipment that is 10 percent more on time 15 percent slower and 10 percent more expensive or one that is 15 percent less on time 10 percent faster and 5 percent more expensive?" An answer to this question provides insight as to how the user is trading off the various attributes of the service, including price.

The survey was taken on a computer, and the questions asked of each participant varied based on the responses provided. Specifically, the changes in price and service attributes presented to each shipper were varied. The survey was designed so that the questions converged on an answer. That is, the choices presented were intended to get closer and closer to ones that the user would find indifferent. At that point, the survey was terminated as the trade-off values for that particular shipper had been calibrated.

As previously mentioned, this study was limited to shippers of commodities who could switch with relative ease from trucks to rail and *vice-versa.* This included shippers of the following commodities:

1. Paper Products
2. Pet Foods
3. Aluminum
4. Plastics
5. Tires

The shipper universe in this case was shipping 10.8 percent of its traffic by rail and 89.2 percent of its traffic by truck (as measured in tons). The study then measured the change from those levels of market share based on *perceived* changes in price and service quality variables. Then the measured potential market share changes that would result from perceptual changes in the following price and service dimensions:

1. Price
2. Reliability of Transit Time
3. Usability of Equipment
4. Transit Time
5. Loss or Damage
6. Presence of Electronic Data Interchange
7. Payments and Billing
8. Responsiveness
9. Ease of Doing Business

Only the first three items are elements that provided a large opportunity for improvement in revenues; this summary is limited to those elements. The BN analysis found the following as elasticities for certain service elements, as shown in Table 20.

Table 20
Service Elasticites Measured for Burlington Northern Railroad

Service Attribute	Elasticity Estimate	Cross Elasticity with Price
Price	-1.3	--
Transit Time	-1.2	-0.9
Transit Time Reliability	5.3	4.1
Equipment Usability	2.5	1.9

Note: some of the elasticities in this table represent ratios of ratios; this arrangement could lead to results that are less accurate than may otherwise be expected.

Because elasticity[18] for price is included, the information in this table can be used to determine a minimum on the amount by which profit can increase as a result of the service improvement. That is done in the following steps:

1. Determine the amount of market share that is lost from a price increase using the price elasticity and a presumed increase in price.

2. Determine the change in a service attribute required to regain the market share lost due to the price increase.

3. Multiply the new price by the amount of market share.

These steps are represented mathematically by the following formula:

$?_{ip} = - ?_i / ?_p$, where

[18] The discussion on this page gives a brief overview of the concept of elasticity. A more thorough discussion, with examples, is provided in the addendum.

$?_{ip}$ = cross-elasticity of variable *i* with respect to price
$?_i$ = elasticity of variable *i*
$?_p$ = elasticity of price

The approach just described presumes that the railroad will elect to take the service improvement benefit in the form of higher prices and not in the form of greater market share. Presumably, the railroad would take an alternate course of action only in the event that a higher profit would be obtained. Therefore, this approach will yield the minimum benefit value from a service improvement. This amount may be determined simply by dividing the service elasticity by the price elasticity. This yields the cross-elasticity with price that is reported in the third column of the table.

PTC is likely to be able to improve transit time, transit time reliability and equipment usability, depending on how the technology is used. It may be used to lower costs, improve performance, or, more likely, some combination of both. The elasticity analysis, however, suggests that if the railroad can improve its on-time service by just two or three percentage points (that is, about 3 to 4 percent better than it is now), the incremental profit could be as much as 12 to 16 percent while keeping the quantity constant. Improvements in transit time itself, or in equipment usability (through better car distribution) could also increase revenue. The remainder of this discussion, though, will focus on the larger of the dimensions – transit time reliability.

It is important to remember that this analysis applies only to the carload portion of the rail market. This report breaks down the service characteristics of the various commodities in accordance with Table 21.

Table 21
Service Types for Various Commodities

Commodity	Service Type
Metallic Ores	Unit Train
Coal	Unit Train
Non-metallic Minerals	Unit Train
Transportation Equipment	Intermodal
Mixed Commodity Shipments	Intermodal
All Other Shipments	Carload

Table 21 has a few anomalies to be explained. First, only the ores are shown as moving in unit trains. This is not always the case. It is especially true that grains (one of the farm products) will move in unit trains. Also, when quantities are large enough, even chemicals can be moved in unit trains. However, chemical traffic is rarely that intense, and farm commodity traffic, even when moving in unit trains, has service characteristics more similar to the carload operation than to a unit train operation. As evidence, note that this report showed earlier that less than 5 percent of covered hopper car movements are unit-train oriented. Finally, it is notable that transportation equipment service is included with intermodal. That is because its service characteristics tend to parallel those of intermodal more closely than those of carload service.

Based on the classifications shown in Table 10 and some revenue information by commodity that was discussed earlier, the railroads handle about $18 billion per year in carload freight. As a result, we can expect a benefit to the railroads that would be approximately $750 million annually for each percent increase in the proportion of on-time shipments in this sector of the market. While it is important to remember that the customer must perceive adequately the improvements made and that competing modes must not similarly improve (which they have been doing), it is also the case that there will be an effect in the intermodal and bulk commodity markets that is not measured here. Furthermore, this brief summary provides information only on the transit time reliability dimension. It is very likely that PTC will also create improvements in the actual transit times and the usability of equipment (through better car distribution decisions). These elements have not been accounted for in this summary.

Comparison of Benefit Calculation Methods

Observations regarding the difference between the estimates made here and the ones made using elasticity estimates are in order at this point. Table 22 shows a comparison. This table is prepared assuming that the railroad captures the maximum benefit possible from improving service. That is, travel time variance is reduced to zero, essentially ensuring that all shipments arrive precisely on time. Note that the table includes a third column for a compromise value. That column will be discussed later.

Table 22
Comparison of Maximum Inventory Benefit and Maximum Elasticity Benefit
(Millions of dollars per year)

Commodities Shipped in…	Annual Safety Stock Cost (millions)	Annual Elasticity Benefit (millions)	Annual Compromised Elasticity Benefit (millions)
Carloads	$ 5,138	$15,642	$ 7,630
Unit Trains	$ 118	-	-
Intermodal	$ 726	-	-
	$ 5,983	$15,642	$ 7,630

Note the relative size of the benefit calculated using elasticities as compared to the inventory method. It appears quite unlikely that shippers might pay higher rates that are three times the actual inventory savings. The probable cause of this overstatement is that the survey asked shippers to value “on time” delivery, where “on time” was defined as when the shipper wanted the shipment. For the shipper, “on time” might have meant “yesterday,” or all the times he had insufficient stock on hand to meet demand, even when the transportation system was functioning correctly and the stockout was the result of a sudden surge in demand.

Logistics costs that are not associated directly with the rate paid for transportation certainly increase when the shipment does not arrive when the shipper wants it to arrive. However, the amount of time required for the product to get to its destination is only one source of variance associated with the calculus of “on time.” Here are two others:

1. Variance of demand: the shipper needs to get product to market when the customer wants it there. If the customer wants it there today, the railroad certainly cannot move it in that short a period of time. Nevertheless, the shipper may consider the shipment’s arrival to be “late,” even if it then fits the shipping schedule exactly. This variance is often much larger than the variance in shipping time itself.

2. Variance of supply: A customer may place an order but there is no product in stock to send. The shipper may then have to procure or make some of it especially to fill that order. This has no relationship to the railroad’s shipping performance. Nevertheless, a shipper or consignee may consider the final arrival of the product to be “late.” This variance can also be much larger than the variance associated with shipping time itself.

Essentially, the ability of the railroads to perform perfectly will reduce, but will not eliminate, the need for a shipper or consignee to hold “safety stock,” that is, the amount of stock that a shipper or consignee must hold to protect against all the elements of lead time variability: shipping time, demand variance, and supply variance. It is possible that the shippers interviewed in the conjoint study on elasticity were responding under the assumption that all the elements of lead-time variability would disappear were the railroad to function perfectly “on time.”

It is for this reason that executives at the Burlington Northern had been highly skeptical of the elasticity estimates developed by John Morton Company. As reported in the Harvard Business School Case Study, BNSF managers’ estimates of price elasticity with respect to service ranged from zero to 0.4. In response to the need to move forward with a study on ARES, they compromised on a value of 2.0. The pool of available benefits using this compromise value for elasticity is shown in Table 21 as well.

How Much of the Benefit Pool Can PTC Get?

One of the more important elements to consider at this point, then, is how much of the railroad’s variability in delivery time will vanish as a result of implementing PTC. Literature suggests that the railroad’s greatest problem with unreliable service is the result of the number of connections that a car makes when proceeding from origin to destination, as opposed to the number of miles between the two locations. (7) This is due to the fact that the amount of freight needed to justify an entire train is large enough that specific trains tend to run only once per day. This causes a car that may be only a few minutes late for a connection to become a full day late as it waits for that train to run on the next day. For that reason, the extent to which a PTC implementation could improve connection reliability is an important element in determining the reliability improvements that could accompany its implementation.

Several studies have been conducted to determine what this effect would be. One such study was done for Burlington Northern Railroad in 1989. In that study, the Service Planning Model (SPM) was used to determine the extent to which connection reliability could be improved through the implementation of Precision Dispatching (an improvement made possible by the precise positioning and dispatch automation procedures that accompany PTC). That study's results, as reported in the Harvard Business School Case Study, indicated that end-to-end travel times could decrease between about 7 and 8 percent. Assuming that the coefficient of variation for travel time would remain the same, this would result in a decrease in the standard deviation of 7 to 8 percent as well.

Combining a 7 percent reduction in standard deviation with the inventory model for benefit to the shipper, the amount of benefit that shippers of carload and farm products commodities could expect would be about $350 million annually. Shippers of bulk ores, intermodal, and automotive commodities could expect an inventory cost reduction of about $50 million annually. This would total about $400 million annually.

Determining the percent of improvement in on-time performance is a bit more challenging. The Harvard Case Study report on the BN project shows an annual benefit of $199 million in enhanced revenue on a base of $2.942 billion in carload freight revenue. This implies a 6.8 percent improvement in price, which would in turn result from a 3.4 percent increase in the percentage of shipments arriving on time.

Using the higher elasticity estimates from John Morton Company, this level of on-time and revenue improvement for the nation's entire railroad network in 2002 could yield a revenue gain for carload traffic of about 14 percent, or $2.6 billion annually. (Note that this is more than 7 percent of the maximum benefit available as the improvement in on-time performance is more than 7 percent of the total amount by which carloads were late on the BN).

The compromise approach to elasticity is provided by the third column of Table 23, expressed in terms of the total benefit pool available. The inventory method and the compromise elasticity method each show nearly equal potential benefit pools. However, the two methods use different measures of performance. The compromise elasticity method is based on improvements in percent of shipments that arrive on time. On the other hand, the inventory method is based on standard deviation of transit time. While the standard deviation can be reduced by 100 percent (all shipments arrive after an identical amount of in-transit time), a decrease in the percent of cars arriving later than desired is limited by the percent that currently arrive later than desired. For that reason, the benefit available here due to installation of PTC would be $1.25 billion annually for carload freight (about 20 percent of the total shown under the compromised elasticity method). While significantly lower than the original elasticity method, it is still over three times the amount estimated by the inventory method. This argues for the use of a third distinct benefits estimation method as a form of arbitration.

In this process, the reader should realize that there are no estimates here that can be taken to great degrees on precision. If we are to accept the calculations as given, we will find that the revenue enhancement available to the railroads and the benefit available to the shippers are quite similar. When markets are competitive, this is expected. A shipper will not be able to keep, for its own bottom line, any of the gains that result from reduced inventory holdings. The theory of perfect competition tells us that competitors would appear who would be willing to give away the inventory benefit in the form of lower prices. The exception to this would be, of course, inventory reductions made possible by trade secrets or patents. Those, however, are not part of this report.

In the event that perfect competition exists, the exercise of computing a separate amount of benefit for the shipper will not yield a result for adding to the amount of the benefits, but will give us a check on the amount of the benefit and an understanding of how the shipper would use it. No doubt, the benefit could be tracked through to the shipper's customer and ultimately to the final consumer. It is useful, however, to focus on the exercise conducted here as a way to check the amount of benefit that could be available from PTC.

Method 3 – Logistics Analysis

A check on the value of service is available from a draft government document on the effect of freight on the United States economy. (8) That draft document contains a chart showing the elasticity of transportation demand with respect to price as well as the elasticity with respect to "transit time and transit time variability." The latter elasticity does not distinguish between transit time and its variance. Since evidence exists that customers are more concerned about transit time variance than about transit time itself, use of this elasticity would be conservative in the sense that actual elasticity is likely to be larger. Further, the study focuses primarily on motor carrier transportation, which is already reliable to an extreme degree; therefore, variability in reliability itself may not be sufficient to observe the sensitivity to reliability that customers will experience.

The report indicates that elasticity of demand with respect to own price is -0.97 and that elasticity of demand with respect to transit time and its variability is -0.52. Combining these yields a cross elasticity of -0.54, which will be used to determine the price gain available from improved service.

As reported earlier, a service gain of 7 percent can be expected in transit time with PTC-style improvements. Appling a cross-elasticity of -0.54 to the entire $36 billion annual railroad market yields an increase of $1.4 billion annually in price for a 7 percent transit time and variability improvement. When applied to carload freight only, the price improvement would be limited to $700 million annually. While the elasticity developed by the John Morton Company was high, the skeptical review offered by BN managers seems to have resulted in bringing that elasticity estimate down to more reasonable levels, though still a bit high. The following cross-elasticities with respect to transit time variance are implied by the three methods used in this paper (note that the Harvard number is smaller and expressed with a different sign since it is now being related to standard deviation as opposed to percent on time):

1. Inventory method: -0.28 for carload freight
   -0.01 for unit train freight
   -0.09 for intermodal freight

2. Harvard Business School Case Study: -0.97 for carload freight
   -0.00 for other service

3. Logistics Analysis Method: -0.54 (independent of freight type)

Based on the preceding list, the figure of -0.54 appears to be a reasonable compromise. However, since the gains available to the railroad from PTC may be more substantial in the area of carload service as opposed to unit train or intermodal service, application of the elasticity figure should be limited to that market sector. This report will therefore use that approach for further analysis.

Calculation of Shippers' Capital and Operating Cost Savings

The scope for this task originally had envisioned determining which of the benefits of the shipper may be unique to the shipper. However, it is apparent from this analysis that any benefit of improved service may accrue entirely to the shipper, entirely to the railroad, or in some measure to both. There are no unique "shipper only" benefits.

The proposal indicated that we would compute the reduction in transportation costs that the shipper would enjoy. As this scenario has been formulated, however, no transportation cost reduction would exist. The assumption here is that the railroads would simply charge an additional amount that would be equal to the shippers' savings in inventory costs. As a result, transportation costs would increase by an amount equal to the shippers' reduction in inventory cost. Hence, there would be no change in dollar outlay on the part of the shipper.

It is possible, however, that the railroads would prefer to take their benefit in the form of higher share as opposed to higher prices. Were that to be the case, shippers would find their transportation costs reduced for the commodities that would be shifted in mode. A discussion of this item is provided in the next section.

It is possible, though, to determine how much of the logistics benefit calculated earlier is capital cost and how much is operating cost. The capital elements of the carrying cost are interest and a portion of the warehousing cost. In our previous analysis, we used 7.0 percent to represent interest costs and 5.4 percent to represent warehousing costs. The warehousing costs can be further categorized into two components: the capital cost of the facility and its operating costs. The extent to which these elements would be different will vary by commodity. However, as it is the smaller portion of the cost, little error would be introduced by assuming them to be equivalent. The result then, is a capital cost of 9.7 percent.

The remaining 16.3 percent of inventory carrying cost is assumed to be operating in nature. Thus, the shippers' savings due to reduced inventory costs are 37.3 percent capital in nature (0.097/0.260) and 62.7 percent operating in nature. The costs that have been identified as capital in nature are then divided by the assumed corporate discount rate (7.0 percent as in the earlier discussion) to yield a potential capital savings for the shipper. The remaining shipper savings are then presumed to be operating savings.

Table 23 shows the results of the computation that splits the inventory carrying cost savings into capital and operating components. As Table 12 shows, the capital cost savings for shippers would be approximately $2.2 billion. That is no small amount, and is certainly larger than the capital cost of the entire installation of PTC for the railroad network in the United States. However, this is a one-time reduction in cost.

Aside from the capital benefit, shippers will enjoy an annual operating benefit of $263 million, as shown in Table 23. This benefit is due to the improved service offered by railroads, which makes it possible for shippers to move some additional traffic from truck to rail. The $263 million is the estimated difference between truck rates and rail rates for this traffic.

Table 23
Shippers' Capital and Operating Benefit of Improved Rail Service

STCC	Product Description	Carry Cost of Unneeded Inventory ($000s)	Capital Benefit ($000s)	Operating Benefit ($000s)
01	Farm Products	$ 56,345	$ 300,298	$ 35,324
10	Metallic Ores	$ 470	$ 2,506	$ 295
11	Coal	$ 7,019	$ 37,406	$ 4,400
14	Non-metallic Minerals	$ 789	$ 4,202	$ 494
20	Food or Kindred Products	$ 58,943	$ 314,147	$ 36,953
24	Lumber or Wood Products	$ 45,461	$ 242,294	$ 28,501
26	Pulp, Paper or Allied Products	$ 21,002	$ 111,936	$ 13,167
28	Chemicals or Allied Products	$ 133,270	$ 710,285	$ 83,550
29	Petroleum or Coal Products	$ 4,598	$ 24,504	$ 2,882
32	Clay, Concrete, Glass, or Stone	$ 4,285	$ 22,838	$ 2,686
33	Primary Metal Products	$ 27,394	$ 145,999	$ 17,174
37	Transportation Equipment	$ 38,455	$ 204,950	$ 24,108
40	Waste or Scrap	$ -	$ -	$ -
46	Miscellaneous Mixed Shipments	$ 12,413	$ 66,160	$ 7,782
99	All Other Freight	$ 8,386	$ 44,695	$ 5,257
	Total for all Commodities	$ 418,829	$2,232,221	$ 262,574

Calculation of Reduced Transportation Costs

In the event that railroads could improve their on-time performance capability, the economic transactions could respond in one of two extremes, or somewhere in-between. At one extreme, the one already analyzed, railroads could raise prices to the point where their market share would remain constant, but they would receive more revenue from each shipper. In the competitive marketplace that exists in this country, that extreme is unlikely.

In the other extreme, the railroads could maintain the rate schedules that currently exist and enjoy a larger market share. That extreme is more likely; however, increased congestion on the railroad would increase costs, resulting in a reaction that is closer to, but not exactly on, this particular line, probably resulting in some sort of rate increase.

Even though the increased market share approach is the more likely reaction, the increased price approach made calculation of the total benefit much easier. By taking the increased market share approach, the benefit computation would of necessity involve computing the profit level for the traffic that is attracted to the rail system. However, to determine the amount by which the shippers' bills from the carriers will decrease, the approach of changing market share must be examined.

In order to do that, consider the table of market demand for the various commodities that has been used so far (restated as Table 24, without extraneous commodities).

Using the figure for service elasticity of demand reported in the previous section (-0.54), we conclude that market share will increase by 0.54 percent for every percent reduction in travel time variance. Combined with a performance improvement of about 7 percent, this will yield a share improvement of about 3.64 percent. Since we are assuming no change in price per ton here, that percent improvement can be applied directly to the number of tons shipped.

This report now restates rail demand by commodity group in Table 24. This is followed by Table 25, which shows the range of potential modal diversions to railroads on a commodity-specific basis. No improvement is shown, however, for STCC 40 (Waste and Scrap) as inventory of that commodity is unlikely, nor is any improvement shown for STCC 37 (Transportation Equipment) and STCC 46 (Miscellaneous Mixed Shipments) as those commodities are shipped with premium service quality (intermodal style) and finally, no improvement is shown for STCCs 10, 11, and 14, as these are low-valued commodities that tend to use unit-train service.

Table 24: Demand for Rail Shipments by Commodity – 2002

STCC	Product Description	Annual Tons Shipped (thousands)	Annual Revenue (millions)
01	Farm Products	137,717	$ 2,711
10	Metallic Ores	31,376	$ 285
11	Coal	785,006	$ 7,797
14	Non-metallic Minerals	125,643	$ 967
20	Food or Kindred Products	102,230	$ 2,657
24	Lumber or Wood Products	47,533	$ 1,628
26	Pulp, Paper or Allied Products	37,212	$ 1,567
28	Chemicals or Allied Products	158,734	$ 4,707
29	Petroleum or Coal Products	40,207	$ 977
32	Clay, Concrete, Glass, or Stone	49,275	$ 1,149
33	Primary Metal Products	55,905	$ 1,350
37	Transportation Equipment	35,902	$ 3,626
40	Waste or Scrap	39,440	$ 717
46	Miscellaneous Mixed Shipments	97,228	$ 4,900
99	All Other Freight	23,258	$ 1,704
Total for all commodities		1,766,667	$ 36,742

Table 25
Railroad Modal Diversion, by Two-Digit STCC

STCC	Product Description	Tons/Year (000s)	Pct Share Increase	Additional Tons/Year (000s)
01	Farm Products	137,717	3.6%	4,903
10	Metallic Ores	31,376	0.0%	0
11	Coal	785,006	0.0%	0
14	Non-metallic Minerals	125,643	0.0%	0
20	Food or Kindred Products	102,230	3.6%	3,639
24	Lumber or Wood Products	47,533	3.6%	1,692
26	Pulp, Paper or Allied Products	37,212	3.6%	1,325
28	Chemicals or Allied Products	158,734	3.6%	5,651
29	Petroleum or Coal Products	40,207	3.6%	1,431
32	Clay, Concrete, Glass, or Stone	49,275	3.6%	1,754
33	Primary Metal Products	55,905	3.6%	1,990
37	Transportation Equipment	35,902	0.0%	0
40	Waste or Scrap	39,440	0.0%	0
46	Miscellaneous Mixed Shipments	97,228	0.0%	0
99	All Other Freight	23,258	3.6%	828
Total		1,766,666		23,214

As Table 25 shows, the railroads could expect a minimum increase in volume of about 23 million tons, were they able to decrease travel time variance by 7 percent. Additional increases in volume would be available in the categories of commodity not considered in this portion of the analysis (10, 11, 14, 37, 40, and 46). However, those increases would likely be smaller.

Table 26 translates this additional volume into a dollar savings for the shippers. This table presumes that the additional tons shipped by rail were all formerly shipped via motor carrier. While that is likely not true for all the additional tonnage that would be captured by the railroads in this scenario, it is true that the motor carrier is the primary rail competitor and that the vast majority of new rail traffic proposed here would come from that mode. Further, the table does not make distinctions by commodity carried. While the rail revenue varies quite substantially by commodity, that information is not readily available for the motor carrier mode. As a result, the estimate given here is based on an average, and is therefore, an indicator, as opposed to an exact forecast.

If the railroads were to decide that a larger market share is preferable to a higher price, they would be able to capture between about 3.64 percent additional market share on the commodities for which the shipper finds service to be a premium characteristic. In quantity, this translates to about 23 million tons per year. Calculating the incremental reduction in fare rates paid by the shipper requires multiplying this increased quantity by the difference between the cost per ton for shipping by rail and the cost per ton for shipping by truck.

Total rail revenue has already been reported, with the source being the Association of American Railroads (AAR) web site. Rail revenues are relatively easy to obtain, as nearly all rail shipments are for-hire. Rail customers who have private fleets of cars still must ship those cars over the infrastructure of a private railroad. Motor carrier shipments are another matter, however. Shippers who maintain their own fleet of trucks may run them at their own expense over the public highways, thereby resulting in motor carrier haulage for which there is no recorded transaction.

The Service Annual Survey from the Census Bureau provides data on trucking industry revenues. However, those revenues do not include private carriage. The American Trucking Association has performed that task and reports their findings in *U. S. Freight Transportation Forecast to 2014.* (8) According to that report, the trucking industry generates a total of $585 billion in annual "revenue equivalent" while shipping a total of 8.9 billion tons of freight, for an average rate of $65 per ton.

This is far higher than the rate that shippers pay for railroad transportation. In fact, based on the information obtained from the Association of American Railroads' web site, the railroads shipped 1,767 million tons of commodities and received $36,742 million for it, or about $20.80 per ton. This is less than one-third the amount received by motor carriers for shipping freight.

Were it possible, a breakdown of this information by commodity would be helpful. As railroads ship commodities that motor carriers would ship only in whole truckload lots, the reader may concludes that the difference in revenue per ton should be smaller than the one calculated (because trucking cost per ton is much higher when shipping in less-than-truckload lots). On the other hand, railroads shipments tend to have a much longer length of haul than truckload ones; so, the reader may conclude that the difference between the truck rate per ton and the rail rate per ton should be larger (truck rates would be higher for longer lengths of haul).

A more thorough and sophisticated analysis could be useful in determining the exact amount that shippers may save as a result of switching some of their product from the motor carrier mode to the railroad mode. Nevertheless, the first-cut estimate here shows that if railroads were to choose a market share gain, as opposed to a price per unit gain, from an improvement in reliability that would result in shippers saving about $1 billion annually in transportation costs.

It is important for the reader to understand that these savings are in addition to the capital and operating cost savings shown in the preceding section. That is, if the railroad pursues increased market share only without lowering any prices, the shipper will enjoy the following benefits:

1. A capital savings of $2.2 billion based on the ability to avoid investment in inventory and warehouse space for items that are currently shipped by rail and continue to be shipped by rail (a one-time savings).

2. An annual savings of $262 million for reduced carrying costs on the inventory of freight currently shipped by rail.

3. A reduction of $1 billion annually on the amount paid for freight transportation for items currently shipped by motor carrier that may in the future be shipped by rail. This last amount assumes that the railroads would take the benefits of improved reliability and reduced travel times in the form of larger market share. In such case, the market share (modal diversion) of commodities shipped in carload service would increase about 3.6%, or 23,214 million tons annually. This represents approximately 1.3% of today's total rail shipments. It is possible that modal diversion from installation of PTC could be smaller, if the railroad were to pursue capture of the available benefits through price increases rather than market share gains. For that reason, the 3.6% modal diversion to carload traffic should be considered the maximum possible diversion. This amount of diversion would be expected to follow the phase-in percentages for the benefits analysis as a whole. This report discusses that portion of the analysis in more detail along with derivation of cash flows.

In the event that railroads should choose to pursue benefits through higher prices rather than larger share, shippers would receive only the first two of the benefits in the preceding list. Remember that items one and two in the above list are a translation of the amounts that railroads could charge for improved service into the benefits that the shipper would enjoy, counting both the higher prices charged and the benefits to the shipper would be double counting and should not be done. Additional benefits, in the form of lower costs to the shippers, are available should the railroad choose to redeem benefits in the form of higher share rater than higher price.

Summary and Conclusions

The value of reliable service has been a subject of disagreement in the railroad industry. By examining the subject from the point of view of shipper benefit, it is possible to make a more reasonable estimate of the value of improving service. Looking at it from that point of view, it would seem clear that the market gain benefit values reported by Burlington Northern's consultant in the ARES Case Study were too high. Similarly, it appears that the values being stressed by the railroad management at that time were too low. The analysis presented here would indicate that the compromise figure they then used in the case, as reported by the Harvard Business School, is quite similar to the value suggested by current analytical approaches to the problem.

The value of service generated by the inventory method, while low, was sufficiently satisfactory to allow for computation of inventory "tax" rates, providing a better understanding of the types of commodities best suited for rail transportation. A compromise method, based on an analysis of total logistics cost appears to develop the best estimate of service quality benefits.

Table 25 shows the amount of benefit calculated for each element considered in this paper, the method by which it was calculated, and the reasons for using the method shown on that row.

From Table 26 it is obvious that the benefits of installing PTC should exceed $400 million annually (the amount of benefit estimated using the inventory reduction method) and are likely less than $2.6 billion annually (the amount suggested by a highly subjective elasticity estimate). The amount of benefit based on the elasticities reported by Harvard Business School Case Study (a subjective compromise chosen by managers at the Burlington Northern in 1990) is $1.25 billion annually. This amount is remarkably similar to the $1.4 billion calculated from a mathematical model that was constructed to account for all elements of logistics cost. That amount is therefore selected as being representative of the total shipper benefits of installing PTC.

The last three rows of the table provide a representation of the size of benefits that shippers may likely see as a result of installing PTC. As mentioned earlier, there are no "shipper-only" benefits because the railroad's pricing strategies would make separating the amount that shippers would enjoy from the amount that railroads would enjoy impossible. However, some of the inventory reduction techniques used to estimate total railroad-efficiency benefits can be used to determine the capital and operating benefits that shippers may enjoy.

As noted in Table 26, benefits measured by the inventory reduction method are "conservative," that is, the actual benefit is likely higher. Based on that estimate, the shippers would expect to see $2.23 billion in one-time benefits resulting from the need to invest less capital for holding inventory and a $262 million dollar benefit annually associated with the operating costs of holding less inventory. To the extent that railroads would raise prices to recoup some of their investment costs for PTC, the actual amount that would accrue to the shippers could be less. Since these two elements of savings are simply a re-statement of the railroad efficiency benefit as measured by the inventory reduction method, these savings elements should not be combined with anything else in measuring total benefit to the economy.

The compromise elasticity method is useful for determining the amount that shippers could enjoy in smaller payments for the movement of freight. As noted in Table 15, this method is not as conservative. That is, the estimate could be either low or high. Based on that method, shippers could find that they are paying as much as $1.0 billion per year less to move their freight. Again, to the extent that the railroads would raise prices to recoup their investment, this amount would decline. Further, since there would be a cost to the railroads of supplying the service and since the service may involve additional logistics costs for the shipper that have not been quantified, these savings cannot be considered a net benefit to the economy,

Table 26. Benefits of Installing PTC on Railroads in the United States

Benefit Category	Calculation Method	Reasons for Selecting Method	Reservations	Amount
Railroad Transportation Efficiency Benefit	Inventory Reduction	Shippers see transportation efficiency gains based on holding less safety stock	Other elements of gain may be possible (e.g., improve efficiency of operations due to better product flow)	$0.4 billion annually
Railroad Transportation Efficiency Benefit	Elasticity Method	Shippers provide information as to exactly how they will respond to service improvements	Stated Preference survey uses many subjective elements Amount of elasticity is quite large	$2.6 billion annually
Railroad Transportation Efficiency Benefit	*Compromised Elasticity Method*	*Shippers provide information as to exactly how they will respond to service improvements*	*Stated Preference survey uses many subjective elements* *Elasticity estimate further adjusted based on judgment*	*$1.25 billion annually*
Railroad Transportation Efficiency Benefit	Total Logistics Analysis	Contains all elements of logistics cost	Highly theoretical; makes no distinction between types of railroad service	$1.4 billion annually
Railroad Transportation Efficiency Benefit	Total Logistics Analysis – Carload Freight Only	Contains all elements of logistics cost	Highly theoretical; applying estimate to carload only may produce low benefits	$0.7 billion annually
Shipper Capital Benefits	*Inventory Reduction*	*Allows techniques for splitting capital and operating savings*	*Inventory Reduction method gives very conservative estimates*	*$2.23 billion (one time)*
Shipper Operating Benefits	*Inventory Reduction*	*Allows techniques for splitting capital and operating savings*	*Inventory Reduction method gives very conservative estimates*	*$262 million annually*
Shipper Transportation Rate Savings	*Compromise Elasticity Method*	*Provides elasticity estimates to determine change in demand for rail service*	*Applies only to carload freight*	*$1.0 billion annually*

Note: italicized entries are the items recommended for use in further analysis

Based on the data in Table 26, several conclusions are clear:

1. The value of improving service to railroad customers, while potentially large, is not precisely known. It is clear, however, that shippers will pay more than three times the amount for motor carrier shipping that they pay for rail shipping. Significant study of the exact differences between rail and motor carrier service, along with its value to the customers, would be very useful.

2. With the entire range of values tested, using reasonable and known techniques, it would appear that the value of customer service is high enough to warrant significant investment.

3. Additional specific demand elasticity studies should be undertaken to narrow the range of values that can be presented here. Only in that way will railroad decision makers then have the intelligence that they need to make appropriate investment decisions.

Addendum: Elasticity Definition And Examples

Elasticity is a concept that is based on the relationship between the amount of a good consumed and the price of that good. For example, a railroad may sell 1000 train tickets today at a price of $200, but if the price for the same ticket is raised by $100, it may sell only 500 tickets at its new price of $300 each. That is, when the price is raised by 50%, the demand falls by 50%. The elasticity with respect to price is, in this example, -1.0. That is, the percent of volume change is equal exactly to minus one times the percent of price change.

The concept of elasticity extends in just the same way to understanding the relationship between product attributes and the demand for the product. For example, consumers may find a transportation that is faster preferable to transportation that is slower. As a result, they may choose to consume larger quantities of fast transportation than they would of slow transportation. This can be measured in a manner similar to the way in which price elasticity was just measured. If a train can get a passenger from city A to city B in five hours, perhaps 2000 passengers will make the trip. If the railroad improves its service offering so the trip will take only four hours, then perhaps 3000 passengers will make the trip. The elasticity in that case is equal to the percent change in demand (the relative increase in the number of passengers – in this case, 50%) divided by the percent change in the attribute (travel time decreases by 25%). So, the elasticity of demand with respect to travel time is -2. That is for every one percent decrease in travel time, there is a two percent increase in demand.

Of course, this approach to elasticity can be used for any desired attribute of a commodity. It is then possible to see how important certain attributes are compared to others. For example, suppose the elasticity of demand with respect to age of transportation equipment is only -0.1. The analyst may then conclude that decreasing transit time may be far more important than buying new rolling stock (this concluding would depend as well on the cost of these alternatives).

Another useful variant of the elasticity tool is the cross-elasticity. A manager at a transportation company may want to know, for example, how much the company should invest in the improve transportation infrastructure and equipment needed to create the fast and efficient transportation system to achieve the reduced transit times that customers would like. Cross elasticity is a concept that is available to help answer this question.

Consider the price elasticity and the travel time elasticity measures discussed earlier. A transportation provider could improve travel times by 25% and see demand rise by 50%. At the same time, the provider could raise prices by 50% percent and see demand fall by 50%. So, if prices are raised 50% and travel times are decreased 25%, both at the same time, there will be no change in demand. That is, the reduction in travel time of 25% would yield a pure price gain of 50%. This is because the cross-elasticity of travel time with respect to price is -2. That is, for every percent by which the travel time falls, the price charged can rise by two percent. This cross elasticity is found using the following formula:

$$?_{cross} = - ?_{attribute} / ?_{price}$$

In this particular case, the attribute elasticity is -2 and the price elasticity is -1. So, the cross elasticity is –(-2)/(-1), or -2.

VI. Costs of Positive Train Control

Definitions of PTC A (overlay) and PTC B (stand alone) may be found on pages 5 through 12 of this report. The following tables recap the cost of each of the three segments (vehicle, wayside, central office) of each system. Costs have been obtained from manufacturers and railroads. They are expressed as ranges, since there remains some uncertainty over what the price of each component might be in an industry-wide deployment.

PTC A

PTC consists of a digital radio link between locomotives, wayside, and central office, an on-board computer (OBC), wayside interface units (WIUs) to monitor signal indications, switch positions (powered switches), and defect detectors, and central office software to track train movements, issue movement authorities, and intervene as necessary to enforce authorities. Table 27 provides estimates of these costs. CSXT advises a cost of $20,000 per locomotive for the South Carolina pilot project. Several potential vendors estimated a cost of up to $35,000. Cost per mile of wayside equipment is from CSXT; the "high" cost has been increased 50% from the CSXT figure because the South Carolina test segment has relatively low train traffic. More robust communications might be required on a busier line.

Table 27: Cost per Segment, PTC A
(2001 $)

Segment	Unit	Estimated Cost Per Unit	
		Low	High
Vehicle	Each	$20,000	$35,000
Wayside	Track Mile	$8,000	$12,000
Central Office	Each	$100 million	$500 million

The greatest unknown is the central office cost. Until one of the PTC test sites enters full operation, the full cost of the necessary programming, graphical user interface, and other equipment and software will not be clear. In the BN and CN benefits studies of more than a decade ago, the cost of the central office, the cost of the vehicle segment, and the cost of the wayside segment were approximately equal. However, both BN and CN proposed to build entirely new dispatch centers for their PTC installations. Those dispatch centers have been constructed, so in all probability a PTC migration would involve replacing existing equipment in an already-existing building. This should reduce the cost somewhat. However, it was thought prudent to maintain a very large range for the possible central office cost due to the uncertainty.

It is also doubtful that the Class I railroads will all share a common dispatching center (although this is technically feasible). Rather, PTC equipment will be installed in the dispatch centers already used by each railroad, and the costs may be expected to vary with the number of track miles and number of trains operated by each.

PTC B

PTC B will incorporate a central safety system and will be "vital" in the sense that existing signal systems are vital. This will necessitate some additional on-board equipment, as follows:

- An additional OBC CPU
- Accelerometers
- A gyroscope

Collectively, this equipment should add perhaps $10,000 to the cost per locomotive. However, vendors for the Illinois project are reporting a cost of as high as $75,000 for on-board equipment. Accordingly, a range from $30,000 to $75,000 has been used for on-board equipment. This cost is per locomotive, installed.

The cost of wayside equipment has been doubled from PTC A to reflect the need for more frequent and more complex communications.

Again, the central office cost remains the greatest unknown. Here, the cost has been estimated to be the same as for PTC A, since much of the work to write vital code has been done as part of the Illinois project, and could presumably be modified at relatively low cost for use in other installations. However, it should be emphasized that the software requirements for a vital PTC B are completely different than those for PTC A.

Table 28: Cost per Segment, PTC B
(2001 $)

Segment	Unit	Estimated Cost Per Unit	
		Low	High
Vehicle	Each	$30,000	$75,000
Wayside	Track Mile	$16,000	$24,000
Central Office	Each	$100 million	$500 million

Total Estimated Cost

For both PTC A and PTC B, a low and high estimate has been made. These estimates are based on the number of Class I railroad locos in service, route miles in service, and an estimate of the central office cost.

Table 29: Total Estimated Cost, PTC A, Class I Railroad Network (2001 $)

Segment		PTC A Low	PTC A High	System Cost	
				Low	High
Locos	20,506	$20,000	$35,000	$410,120,000	$717,710,000
Route Mi	99,250	$8,000	$12,000	$794,000,000	$1,191,000,000
Central Office				$100,000,000	$500,000,000
Total PTC A cost				$1,304,120,000	$2,408,710,000

Table 30 shows the same information for PTC B. Cost per locomotive is estimated to be about double PTC A, due to the need for a second CPU as well as accelerometers and a gyroscope. Cost per route mile is doubled as well because of the need for a more robust communications system.

Table 30: Total Estimated Cost, PTC B, Class I Railroad Network (2001 $)

Segment		PTC B Low	PTC B High	System Cost	
				Low	High
Locos	20,506	$30,000	$75,000	$615,180,000	$1,537,950,000
Route Mi	99,250	$16,000	$24,000	$1,588,000,000	$2,382,000,000
Central Office				$100,000,000	$500,000,000
Total PTC B cost				$2,303,180,000	$4,419,950,000

These costs may be overstated, since some investments in PTC-compatible equipment have already been made. Union Pacific Railway reports that 2,600 of its 6,847 locomotives, or 38%, are equipped with ATCS radios. About 25% of UP route miles (9,600 route miles) are covered by ATCS UHF repeaters.

BNSF reports that about 1,900 route miles are covered by ATCS-type radio, used for switch and signal control (pole line replacement). CSX Transportation has about 3,000 route miles of radio coverage, also used for switch and signal control. Whether this equipment might need to be replaced or upgraded to be compatible with PTC B is unknown at this time.

Note that the costs in Table 30 are capital costs only. In addition to these costs, an annual charge equal to 15% of the total capital cost of PTC has been taken against operating expenses once PTC is fully implemented. This charge, set at a typical level for the electronics industry, is intended to cover training, maintenance, and technological obsolescence.[19]

[19] BN used a 10% additive to cover training, maintenance, and capital replacements for its ARES project.

VII. Implementation Issues

Alternate Means for Attaining PTC Benefits

PTC is not the only way to obtain some of the benefits explored here. However, it must be noted that the two largest sources of benefits, up to $1.4 billion in benefits to railroad customers and roughly $1 billion per year in avoided costs for capacity expansion, would be extremely difficult to approach, much less replicate, by any other combination of systems.

Work order reporting can be handled by a number of technologies, including digital cellular, "meteor burst" communications, and satellite transmission. Prices change constantly in the communications market, so it is difficult to say whether any of these technologies might be price-competitive with a PTC-supported work order reporting system. However, the PTC data link and on-board computer can support work order reporting at what is likely to be a small incremental cost, easily justified by the benefits.

Locomotive diagnostics are a somewhat more complex issue. About half the locomotive fleet is already equipped with on-board diagnostic computers. Here the analysis issue is whether real-time reporting of diagnostic information can deliver value in excess of diagnostics that can be downloaded by technicians at locomotive shops. A study for Canadian National Railways in 1990 found a significant benefit to real-time reporting of diagnostic information, principally in the avoidance of en-route locomotive failures. Burlington Northern's internal analysis appeared to confirm this.

From the point of view of PTC deployment, the existence of a diagnostic computer and sensors simplifies the task of installing PTC components, and the additional communications load can be easily accommodated by the PTC data link. Again, a number of different communications paths could be selected, but the PTC data link is available and capable.

Other functions such as track forces reporting can be (and in some cases, already are being) accommodated by other technologies. However, tying track forces into the dispatching system (as would be done with PTC B) achieves a higher level of safety for roadway workers and provides them with accurate data on train locations. The potential benefits of "track forces terminals" have not been specifically quantified because they will be route- and railroad-specific, but even a 5% improvement in MOW gang productivity could potentially yield an annual savings of $500 million.

Recently, one large North American railroad has been publicly advertising the significant gains in efficiency it has achieved by operating a "scheduled railroad". Basically, this railroad has developed a "zero base" operating plan, which it adjusts on a quarterly basis as traffic volume and mix fluctuates. The improvements in efficiency appear substantial; about 10% fewer resources are being used to produce the same amount of transportation service as prior to the scheduling of the railroad.

The obvious question is whether these gains duplicate those possible with PTC, or are additive to them.

The authors of this benefits analysis believe these gains are at least partially additive. The gains achieved by scheduling the railroad have been made within the limits of the existing train control and management systems. No new hardware has been installed, and no new information systems have been put in place. The PTC benefits quantified here result directly from the capabilities of a new type of control system. Installation of such a system should produce efficiency gains beyond what can be supported by current technology. That having been said, implementation of improved operations planning tools may indeed produce a portion of the benefits of PTC. The extent to which those service improvements duplicate the benefits of PTC as quantified in this analysis will probably not be known until PTC is actually implemented.

Reasons for Non-Adoption by the U.S. Railroad Industry

Positive Train Control, as a concept, has existed since the mid-1980s. The first PTC architecture was proposed to Burlington Northern Railroad by Rockwell International's Collins Avionics Division in 1983. Called the Advanced Railroad Electronics System (ARES), it made use of then state-of-the-art computers (with Intel 8086 processors) and a VHF digital radio data link with a bandwidth of only 4800 baud. Nevertheless, the equipment was demonstrated successfully in the Iron Range of northern Minnesota for several years. The demonstration included seven equipped locomotives, a dispatcher console, and the capability for both real-time locomotive diagnostics and work order reporting. Location was by GPS (without differential enhancement), but because the GPS satellite constellation was not complete, 24-hour location information was not available. Nevertheless, the demonstration did prove the functionality of the system.

A parallel effort by the Association of American Railroads and Canadian National Railways produced a large number of technical specifications for a PTC system known as the Advanced Train Control System (ATCS). Similar in some ways to ARES, ATCS used transponders as well as GPS for location, and relied on six 900 Mhz radio channels rather than the VHF Railroad Radio Service frequencies for communications. CN conducted a limited test of ATCS on its British Columbia North line in the late 1980s.

The ARES and ATCS demonstrations ended almost 15 years ago, but no railroad has yet implemented PTC. Tests of two additional installations are now underway: the North American Joint PTC project in Illinois, and the Incremental Train Control System (ITCS) in Michigan. Of these, the former is viewed as a test bed for numerous features of PTC that could interest both the freight and passenger railroad industries, and the latter has as its primary objective the safe operation of passenger trains at higher speeds. Neither line currently carries substantial freight traffic.

Two Class I railroads also have PTC A installations under test. CSXT is testing a system between Spartanburg, SC and Augusta, GA. The primary function is train control, with the objective of positively enforcing movement authorities in dark territory.

In summer 2003, BNSF signed a contract with Wabtec Railway Signaling to deploy a similar system. Again, the functionality is confined to train control and safety.

The question that must be asked is: With the great improvements in computer and communications technology in the last 15 years, why has progress toward PTC been so tentative? There are several possible explanations. The railroad industry is, by its own admission, capital-constrained. That is, the industry does not at present earn a return on investment as high as the cost of debt or equity financing. In this circumstance, a potential $4 billion investment is difficult to justify even when the potential return appears large. There is also a perception of significant technical risk. Although some aspects of PTC technology have been proven in tests, no railroad has implemented PTC on a large scale, and therefore no one can know whether it will work.

Other issues include the competitive situation of the railroad industry, as well as its culture and organization. Each is addressed in the following sections.

The Railroad Competitive Environment

The railroad industry in North America is made up of six very large railroads (the Class I railroads) and hundreds of much smaller companies. The Class Is account for about 70% of the track mileage in the United States, but more than 90% of revenue. For a host of reasons too complex to discuss here, these railroads have become, for the most part, wholesalers rather than retailers of transportation. The large railroads move products for a limited universe of large shippers, including third-party consolidators and freight forwarders.

More than half of rail revenue now comes from services that have developed, in their present forms, over the last three or four decades and especially since the passage of the Staggers Act in 1980. These are: unit trains for bulk traffic, especially coal and grain; intermodal service; and highly specialized services for the automobile industry. The talent and energy of railroad management, as well as railroad capital, have been largely focused on development of these “new” rail services while carload service has continued to function much as it always has.

The bulk and intermodal services on which management has focused have grown rapidly since railroad deregulation, while carload freight traffic has grown much more slowly. Innovation has tended to occur in markets where a small number of customers—trans-Pacific container lines, automobile makers, for example—tender very large amounts of traffic. There are some large carload shippers, e.g., chemical companies, but carload is mostly a market of relatively small shippers; and it is entirely a market of firms that will never load a whole train and, typically, load no more than a few cars at a time. Carload is also a market where rail traffic growth is slow and where railroads have been losing market share to trucks for years. Service is slow and not highly reliable.

The greatest beneficiary of PTC is carload traffic. Given that carload traffic has been in decline, and that some railroad staff believe carload freight consumes resources far in excess of the revenue it yields for railroads, it is understandable that a technology that benefits carload freight traffic is regarded with suspicion.

A second factor is the trend to non-railroad ownership of much rail equipment (about two thirds of the freight car fleet is now privately owned, and many locomotives are leased). Railroads have shed the capital cost associated with much of the car fleet, and in the short run are unlikely to embrace technology that improves the productivity of assets they no longer own.

Finally, railroads have been focused on cost cutting since deregulation, but have seen 80% of the savings they have achieved go to shippers in the form of lower rates. The expectation may be that PTC will be no different, and this expectation may prove to be correct. Such market share as the railroads have been able to retain has been bought with lower rates, and lower rates in turn have required a reduction in the assets used to produce transportation – principally fixed plant, but also freight cars.

For all of these reasons, railroads have questioned the benefits of PTC since BN's ARES was tested in the 1980s.

Technological Risk

Existing train control technology has been in use for more than 75 years. The first deployment of centralized traffic control was in 1927, on the Toledo and Ohio Central Railroad. Three generations of railroaders have grown up with this technology, it is reliable, and it is enshrined in a set of very detailed Federal Railroad Administration regulations covering testing and maintenance.

PTC is not precisely comparable to CTC. A computer-based system can never be comprehensively tested in the same way as the "relay logic" of a conventional signal system. The concept of moving block represents a sea change from the fixed geographic signal blocks that have formed the basis of railroad safety systems for more than a hundred years (the first electric track circuits were tested in New Jersey in 1893). Even the value of real-time train position information has been questioned by some in the railroad industry.

There may or may not be a real risk that PTC will fail to function properly when deployed. The fact is that there has not yet been a large-scale deployment, so there is no way to know for certain whether PTC will or will not work. This makes the investment technologically risky.

FRA has partially sponsored small-scale tests of PTC technology in Michigan and Illinois. But as noted earlier, the primary focus of these tests has been on operation of passenger trains. Neither line currently carries significant freight traffic.

There is some indication of renewed freight railroad interest in PTC, in the form of limited tests in South Carolina by CSXT, and by BNSF. These systems correspond approximately to PTC A as defined in this analysis. However, the CSX system, at least, has a limited objective (enforcement of movement authorities). So technological risk remains, and reasonable railroad managers may conclude that, given the size of the required investment (potentially up to $1 billion per railroad), there may be safer investments available.

Financial Risk

Another possible reason for railroads not having made a full commitment to PTC by this time is presented by the analysis of potential rates of return shown in the next section of this report. As that analysis shows, the rate of return could vary from 24% annually to 160% annually. While it is true that the smallest potential return appears to exceed typical "hurdle rates" for large capital projects, it is also true that the large range in the forecast rate of return indicates that the investment is a highly risky one.

Since the financial risk of an investment is defined by how unknowable the outcome is, not its probability of failure, investment in PTC remains quite risky. While the financial failure of PTC appears highly unlikely, the degree of its success is hard to know and will require significant changes to today's railroad operating strategies. Further, if there are no changes to railroad operating strategies to make wise use of the large quantity of data that PTC will make available, it could be difficult to achieve even the 24% rate of return indicated as the smallest potential return from investing in the new technology. In order to avoid the risks associated with a new approach to business strategies, railroads are understandably cautious, attempting at all times to ensure that they will have the best possible knowledge of an investment's outcome before they move forward with it.

As various elements of the technology associated with PTC mature, they become less expensive and the way in which they should fit into the railroad's business plan becomes better known, reducing the risks associated with investment in it. Still, as this analysis shows, the investment is hardly without risk even today. Railroads may choose to proceed cautiously as they invest in the various elements of PTC and may not achieve a fully functional "PTC-compatible" operation for quite some time.

Railroad Organization

Railroads are organized functionally. For example, one department maintains track and structures, another communications and signals, a third operates the trains, and others handle marketing, sales, contracts, and other functions. Generalists are uncommon in the railroad industry. Most senior executives spend much of their careers in one department, only being rotated among departments once they reach senior management positions. In these senior positions, they must rely on staff with detailed technical knowledge of each specialty.

PTC has many attributes; in addition to train control functions it offers a number of management functions. The difficulty is that each of these functions, even train control, can be performed using other technologies. Each railroad department approaches PTC from its own narrow technical focus, and the reaction to a presentation of PTC capabilities tends to take the form of comments such as, “We’ve already got systems that do that.”

Communications and signal employees see PTC as just another type of train control, and wonder what advantages it might provide over existing (and known) systems. Operating department employees have various existing systems for obtaining car and train location (automatic equipment identification, yard clerks, the signal system) and wonder how much better information PTC could provide. Marketing employees have a difficult time accepting that, even with better information, the operating department could really run trains more reliably, and they also doubt their ability to extract additional revenue from customers.

The benefits of PTC cover such a wide range of functions that a consensus is needed among senior railroad staff before an investment can be made. For the reasons outlined above, this consensus will be very difficult to achieve.

VIII. Conclusions and Recommendations

Summary of Benefits and Costs

The benefits of PTC are realized in a number of ways. Line capacity and service reliability are improved, in PTC A, by the availability of accurate, real time data on train location and speed. This enables train dispatchers to respond more quickly to service disruptions, and to more quickly formulate alternative dispatching plans as circumstances change.

PTC B permits trains to follow more closely, increasing line capacity even further than PTC A. Faster over-the-road running times, again, result from better “meets” between trains (since dispatchers know train position more accurately and, in PTC B, trains can follow more closely).

Again, the real-time location information provided by both PTC A and PTC B enables railroad managers to exercise more effective control of locomotives and freight cars, increasing asset productivity.

PTC A and PTC B both provide the capability to issue instructions (“work orders”) to train crews in real time. These instructions direct crews to deliver or pick up freight cars; PTC also permits the crews to report the completion of this work in real time. Again, this permits more effective management of rail equipment.

The digital data link in both PTC A and PTC B can be used to report diagnostic data on locomotives in real time, allowing shop forces to diagnose malfunctions and order necessary parts before a locomotive arrives in the shop. Diagnostics also should provide warning of impending failures, possibly allowing train crews to take actions that avoid an en-route failure that delays trains.

Real-time data on train location and speed also will allow track maintenance forces (track inspectors and others) to more effectively utilize their time. Traffic density on the U.S. rail network has increased significantly since deregulation of the industry in 1981. This has made the scheduling of track time for inspection and maintenance more and more difficult. Real-time, accurate information on train location should permit an increase in the productivity of track forces.

Finally, real-time position information will allow train dispatchers to “pace” trains between scheduled meet points, permitting fuel savings. Current practice is to run trains at maximum authorized speeds, often arriving at meet points well ahead of schedule. With real-time information on the location of opposing trains, it may be possible to slow a train down to save fuel while still arriving on schedule at the meet point.

Note that some of these benefits might be obtained by other means. For example, work order reporting might be accomplished through use of digital cellular radio and hand-held reporting devices. Use of computer tools to develop more efficient operating plans might produce increases in equipment utilization similar to those achievable with PTC. Some improvements in locomotive performance have already been obtained by use of on-board diagnostics. One Class I railroad is experimenting with an on-board computer that attempts to minimize fuel consumption subject to various schedule constraints.

Because of uncertainties over exactly how PTC will be implemented, most benefits have been expressed as ranges. As can be seen from Table 32 below, the largest benefit categories are:

- For both PTC A and PTC B, A reduction in equipment ownership cost, due to an estimated 5% to 10% increase in car velocity
- For PTC B, the avoidance of a large investment railroads would otherwise have to make to increase capacity on an estimated 8,300 route miles of railroad (about 8% of the network) that are currently operating at or above design capacity. Here, the cost of constructing the 8,300 miles of track has been annualized over a presumed 80 year life at a discount rate of 7%; to this cost has been added an annual cost to maintain 8,000 additional miles of mainline track.
- For both PTC A and PTC B, significant benefits to shippers from a presumed improvement in service quality

Other benefits are relatively much smaller.

Expected costs of PTC have also been quantified. Available information from railroads and suppliers has been used to estimate the costs of the three segments of PTC. Of these, the cost of the central dispatch office is the least certain. In earlier analyses for Canadian National Railways and Burlington Northern Railroad, the cost of the central office equipment was estimated to be about the same as that of the wayside and vehicle components of the system. However, in this analysis, central office cost is estimated to be a relatively smaller part of the total, for two reasons. First, in the past decade most of the Class I railroads have built consolidated dispatching centers, and will most likely put PTC equipment in these existing buildings (previous studies assumed the need to build new dispatching centers). Second, software for both PTC A and PTC B is now being developed at test installations on railroads. By the time any decision is made to install PTC nationwide, the necessary software should already have been developed. It will only require customization for each railroad installation.

But due to the uncertainty over central office cost, a very large range has been used. The same range has been used for PTC A and PTC B; while they will require different software, there are currently projects underway to develop software for both applications, so there seems no reason to suppose that software for a PTC B installation will necessarily be more costly than software for a PTC A installation. Benefits have been quantified separately for PTC A and PTC B. It should be understood that, while the hardware requirements for the two systems are similar, the software is quite different. There is no obvious "migration path" from PTC A to PTC B. They are simply different approaches to the same problem: management of a rail network and its assets. PTC A is less complex, less expensive, but also offers less in the way of line capacity benefits than PTC B.

The safety benefits of PTC (essentially the savings realized from elimination of most or all "human factors" rail accidents) have been quantified separately by the Federal Railroad Administration. This study quantifies the business benefits.

Table A offers a benefits quantification for the two systems. Benefits have been estimated for each of several areas. The line capacity benefits represent an avoided expense for capacity expansion, for the estimated 8,000 route miles of the U.S. network that is currently operating at or above design capacity.

"Precision dispatching" is the term given to train dispatching aided by real-time location information. In PTC A this enables dispatchers to make better decisions regarding how trains are to pass each other on single track. In PTC B, there is an additional benefit realized from "moving block" operation, in which trains can run on closer geographic spacing. The result in both cases is an increase in average car velocity across the rail network, enabling the railroads to offer the same service with fewer locomotives and cars. PTC B, of course, also offers increased line capacity.

The use of real-time work order issuance provides some benefit in the form of reduced car ownership expense (since cars are moving more expeditiously). Locomotive diagnostics allow some en-route locomotive failures to be prevented, and also reduce shop time by providing shop forces with the ability to diagnose problems prior to the arrival of locomotives in the shop.

Finally, a fuel savings estimated at 2.5% to 5% is realized through better control of operations: better timing of meets between trains, and pacing of trains rather than operation at maximum authorized speed where it is unnecessary.

A comparison of costs and benefits has been undertaken to determine the expected return on investment (ROI) from a deployment of PTC nationwide on the Class I railroad network.[20]

Although the potential benefits of "track forces terminals" in terms of increased productivity for track maintenance forces are acknowledged here, they have not been quantified because they will be route- and railroad-specific, and dependent upon traffic volume. However, it should be noted that the railroad industry spends more than $10 billion annually on maintenance and renewal (operating and capital costs) of its fixed plant (track and structures, communications, and signals). If the availability of real-time information on train location can improve track workforce productivity by 5%, this equates to an annual savings of $500 million for the industry.

Most of the benefits quantified in Table 32 are savings to the railroads from more efficient operation. In the case of line capacity, the annual amounts shown are an annualization of the capital cost of 8,300 miles of second main track, plus the annual cost of maintaining that track. Car and locomotive savings are similarly calculated. In each case, an annual ownership cost is calculated using a purchase price, an expected service life, and a cost of money.

The only benefits that are not direct savings to railroads are the "shipper benefits", which are composed of savings shippers might realize in total logistics cost if railroad service improved and rates did not increase.

It is important to note that it is by no means certain that railroads will realize all of the savings in Table 32. Railroads might choose to give some of the savings to their customers in the form of lower rail rates; historically, 80% of the savings railroads have realized since deregulation have been given to shippers. But whether the benefits flow to railroads or to their customers, in one way or another the entire U.S. economy benefits.

Table 32: Summary of Estimated Annual PTC Benefits
(All costs in 2001 $)

PTC A		Low	High
Line Capacity	Avoided Investment	N/A	N/A
	Avoided Maintenance	N/A	N/A
Precision Dispatch	Equipment Ownership	$407,996,280	$1,040,021,170
Work Order Report	Car Ownership	$10,109,900	$10,109,900
Loco Diagnostics	Loco Maintenance	$28,567,603	$28,567,603
	Loco road failure	$34,603,875	$34,603,875
Fuel		$55,949,775	$130,549,475
Shipper Benefits		$400,000,000	$900,000,000
Total Estimated Annual Benefits		**$937,227,433**	**$2,143,852,023**

[20] The analysis presented here owes a great deal to prior studies by Burlington Northern Railroad, Canadian National Railways, the Association of American Railroads, CSX Transportation, vendors of hardware and software for PTC, and the Federal Railroad Administration

Table 32 (cont.): Summary of Estimated Annual PTC Benefits
(All costs in 2001 $)

PTC B		Low	High
Line Capacity	Avoided Investment	$299,532,652	$422,005,064
	Avoided Maintenance	$507,967,244	$761,956,956
Precision Dispatch	Car Ownership	$322,065,928	$868,160,466
	Loco Ownership	$85,930,352	$171,860,704
Work Order Report	Car Ownership	$10,109,900	$10,109,900
Loco Diagnostics	Loco Maintenance	$28,567,603	$28,567,603
	Loco road failure	$34,603,875	$34,603,875
Fuel		$55,949,775	$130,549,475
Shipper Benefits		$900,000,000	$1,400,000,000
Total Estimated Annual Benefits		**$2,244,727,329**	**$3,827,814,043**

Table 33 estimates the cost of PTC. These are the total one-time costs of implementing the three segments of either PTC A or PTC B: wayside, on-board, central office. Again, because of uncertainties, a range is given.

The cost of PTC A or PTC B includes the cost of on-board equipment, wayside equipment, and the central dispatch office. Of these, the cost of the central dispatch office is the least certain. In earlier analyses for Canadian National Railways and Burlington Northern Railroad, the cost of the central office equipment was estimated to be about the same as that of the wayside and vehicle components of the system.

The cost of on-board and wayside equipment has declined significantly since the completion of the BNSF and CN studies in the early 1990s. It may be supposed that the central office software and hardware might have seen a similar decline. Notwithstanding this, a very large cost range has been used for the central office to reflect the uncertainty surrounding development of the necessary central office software. It is also uncertain how many dispatch centers may be needed, and how much customization of software might be required for each.

There is no necessity to believe that software costs for PTC B will necessarily be higher than for PTC A. There is more “verification and validation” required in the vital PTC system, but this is reflected in the hardware cost rather than in the software.

Table 33: Summary of PTC Costs
(All costs in 2001 $)

1. PTC A	System Cost	
	Low	High
Vehicles	$410,120,000	$717,710,000
Wayside	$794,000,000	$1,191,000,000
Central	$100,000,000	$500,000,000
Total	$1,304,120,000	$2,408,710,000
2. PTC B	**System Cost**	
	Low	High
Vehicles	$615,180,000	$1,537,950,000
Wayside	$1,588,000,000	$2,382,000,000
Central	$100,000,000	$500,000,000
Total	$2,303,180,000	$4,419,950,000

Of course, it would take several years to equip locomotives and routes with the necessary equipment, and to construct central dispatch offices. The following section provides cash flow projections and rate-of-return calculations for the industry based on a five-year implementation on the Class I network. Benefits lag installation costs by one year in this scenario. Internal rates of return are based on a 7% cost of money. Cash flow includes not only spending on PTC itself (a capital item) but also a 15% cost per year for training, maintenance, and technological obsolescence.

It is possible to imagine a range of different implementation strategies, but the sensitivity of the benefits remains driven by the same factors. The longer the "construction" phase, the lower the internal rate of return. The longer the lag between investment and the start of the benefits stream, the lower the internal rate of return.

Rate of Return Calculations

Internal rate of return calculations shown here include both direct benefits to the railroads and shipper benefits. Shipper benefits are included because, although they accrue to shippers, the result is that shippers are willing to increase their use of rail (and presumably decrease their use of more expensive competing modes, such as truck).

The net present value (NPV) and internal rate of return (IRR) on an investment in PTC depend, of course, on the cost of the installation and its potential benefits. However, they also depend upon the timing of cash flows.

A typical major investment (such as PTC, a double tracking project, or any large project) will require several years to complete. During that time, cash is being expended, but no benefits are realized until the project is complete and has been put into service. At that point, it will presumably start producing benefits (presumably the project would not have been undertaken without a projection of downstream benefits). At some point in the future, the flow of positive benefits will outweigh the negative flow of cash, and the project will start producing a return for its owners.

One common method for evaluating a project is to calculate the net present value of a stream of future (generally annual) positive and negative cash flows. An appropriate discount rate is assigned, and the net present value of all the cash flows is calculated by discounting each back to the current year. A positive NPV means that the project will produce a better return than money invested at the discount rate over the same period. A zero NPV indicates the two investments are equivalent, and a negative NPV indicates that the money would be better invested in a bank account than in the proposed project.

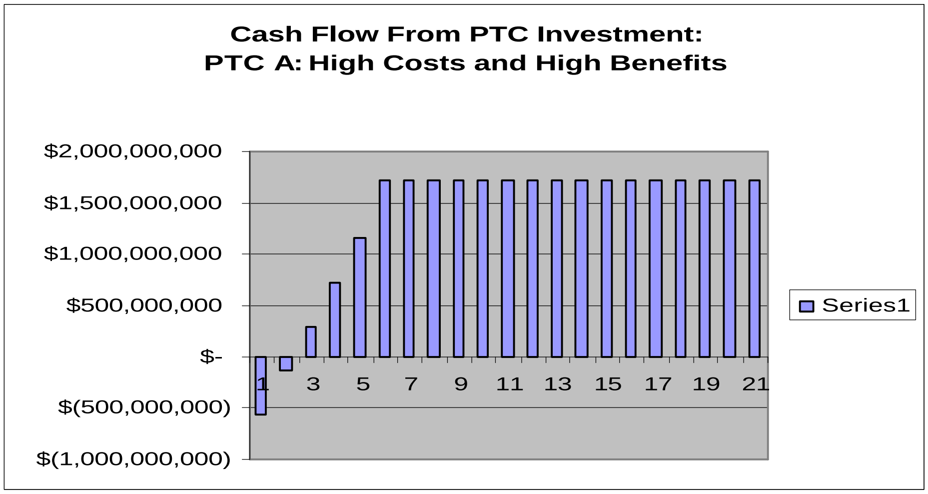
For PTC, the timing of the cash flows will depend on the phasing of the project. Clearly, every locomotive in the fleets of the Class I railroads cannot be removed from service at the same time for installation of data radios, positioning equipment and on-board computers, and displays. Installation of necessary on-board equipment is estimated to require one day (two person-days) for new locomotives already equipped with diagnostic computers, displays, or other portions of necessary equipment. For older locomotives (pre-1985) this installation is estimated to require two calendar days and five person-days.

Internal Rate of Return Computations for PTC A

To calculate an internal rate of return for this investment, it has been assumed that 20% of the total project cost is incurred each year for five years. Thus, in Year 1, there is a net cash outlay of $561,142,000. This continues through Year 5, when the total "high" project cost of $2.806 billion is expended.

The benefits stream begins in Year 2, when 20% of the benefit is realized from the first 20% of the investment. Benefits increase to 40% of the $937 million in maximum estimated benefits in Year 3, 60% in Year 4, 80% in Year 5, and 100% in Year 6. Starting in Year 6, a cost equivalent to 15% of the $2.806 billion cost, or $421 million, is added to account for maintenance and obsolescence of the equipment. This cost (and the benefits stream) continue through Year 20, at a discount rate of 7%. The results are shown in Figure 7.

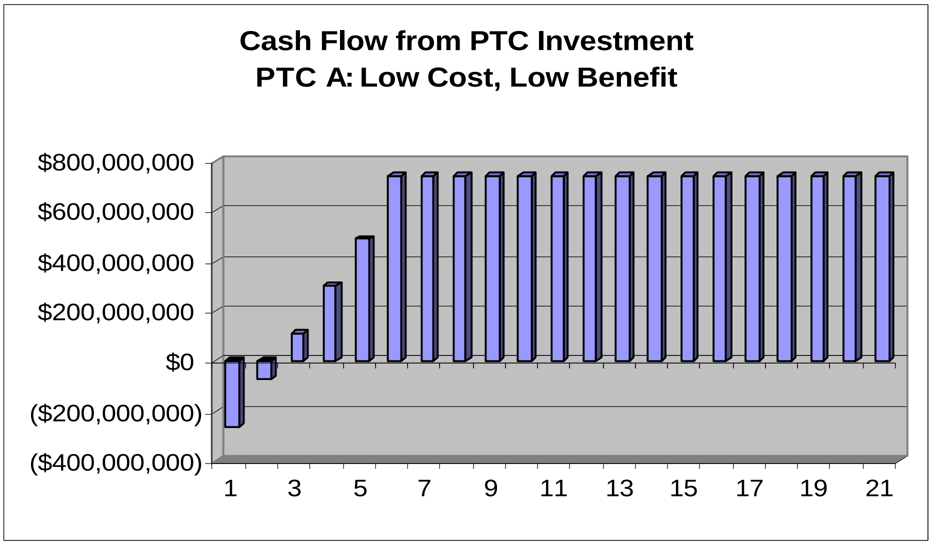
Figure 7: Cash Flow Calculation for Five – Year PTC A Implementation, Using Maximum Estimated Benefit and Maximum Estimated Cost



The internal rate of return from this investment is 73%.

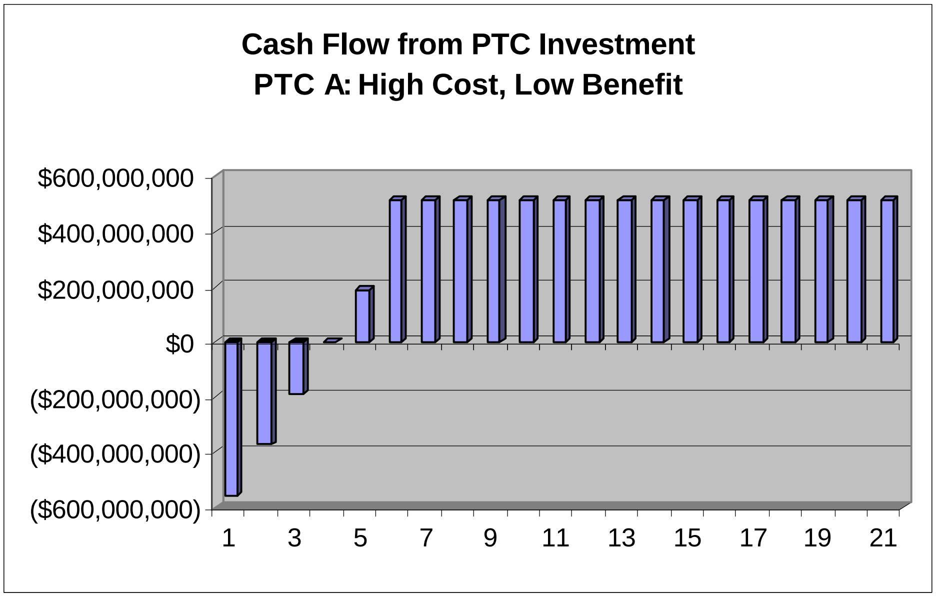
As an alternative, consider the calculation shown in Figure 8. This calculation makes the same assumptions as previously considered, except this time using the minimum expected annual benefits of about $937 million and the minimum expected costs of implementation ($1.304 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This lowers the IRR to 68% over the 20-year period.

Figure 8: Cash Flow Calculation for Five-Year PTC A Implementation, Using Minimum Estimated Benefit and Minimum Estimated Cost



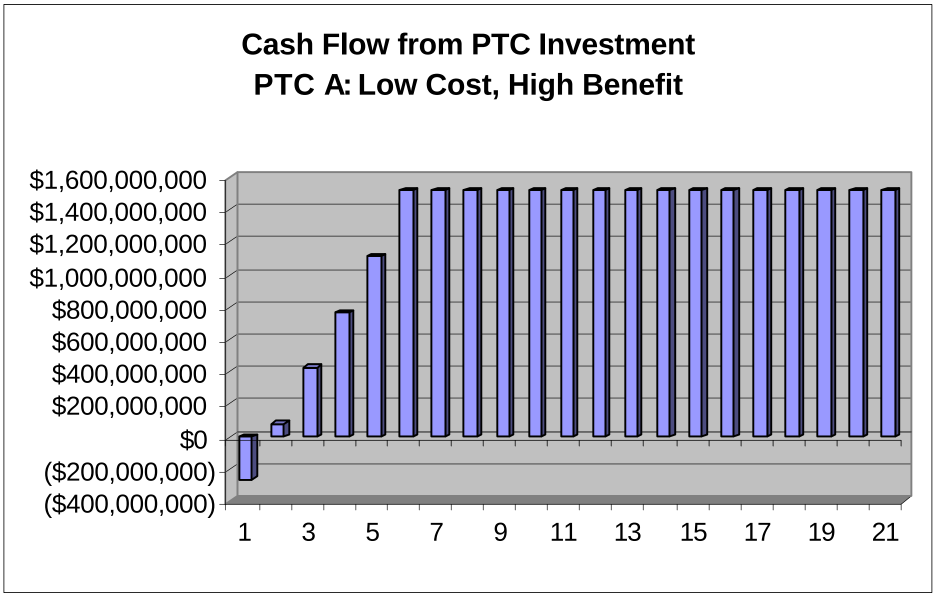
In calculating the lowest possible rate of return, consider the calculation shown in Figure 9. This calculation makes the same assumptions as previously considered, except this time using the minimum expected annual benefits of about $937 million and the maximum expected costs of implementation ($1.715 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This lowers the IRR to 24% over the 20-year period.

Figure 9: Cash Flow Calculation for Five-Year PTC A Implementation, Using Minimum Estimated Benefit and Maximum Estimated Cost



In calculating the highest possible rate of return, consider the calculation shown in Figure 10. This calculation makes the same assumptions as previously considered, except this time using the maximum expected annual benefits of about $3.828 billion and the minimum expected costs of implementation ($1.304 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This raises the IRR to 130% over the 20-year period.

Figure 10: Cash Flow Calculation for Five-Year PTC A Implementation, Using Maximum Estimated Benefit and Minimum Estimated Cost

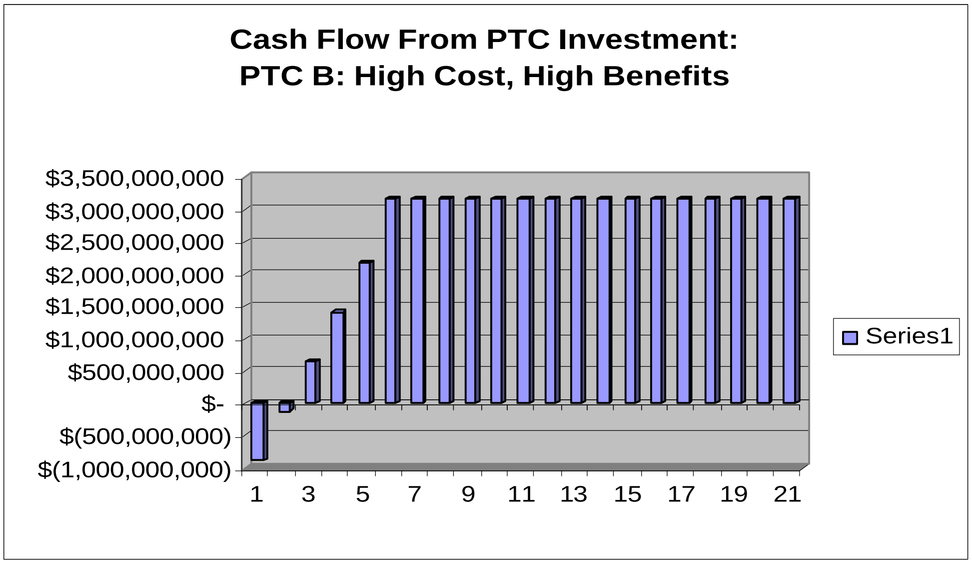


Internal Rate of Return Computations for PTC B

As in the analysis of PTC At has been assumed that 20% of the total project cost is incurred each year for five years. Thus, in Year 1, there is a net cash outlay of $876,400,000. This continues through Year 5, when the total project cost of $4.382 billion is expended.

The benefits stream begins in Year 2, when 20% of the benefit is realized from the first 20% of the investment. Benefits increase to 40% of the $3.6 billion in maximum estimated benefits in Year 3, 60% in Year 4, 80% in Year 5, and 100% in Year 6. Starting in Year 6, a cost equivalent to 15% of the $4.382 billion cost, or $663 million, is added to account for maintenance and obsolescence of the equipment. This cost (and the benefits stream) continue through Year 20, at a discount rate of 7%. The results are shown in Figure 11.

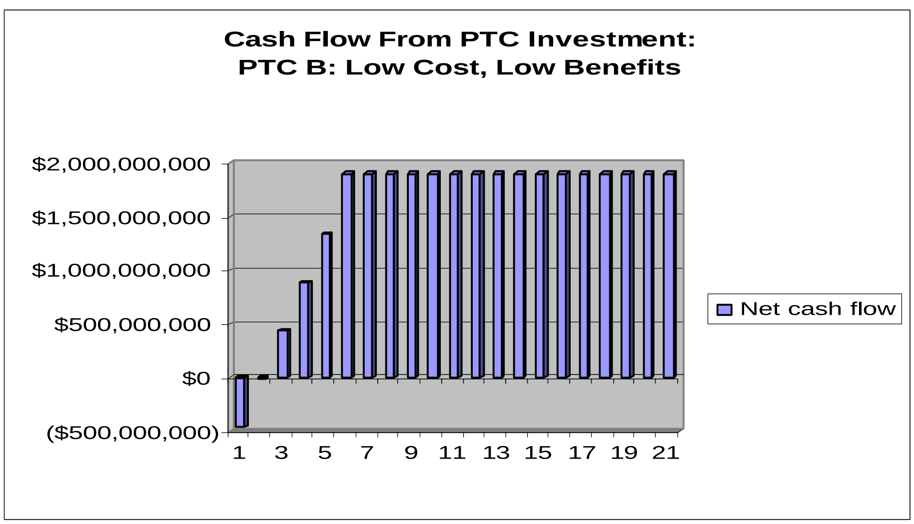
Figure 11: Cash Flow Calculation for Five – Year PTC B Implementation, Using Maximum Estimated Benefit and Maximum Estimated Cost



The internal rate of return from this investment is 79%.

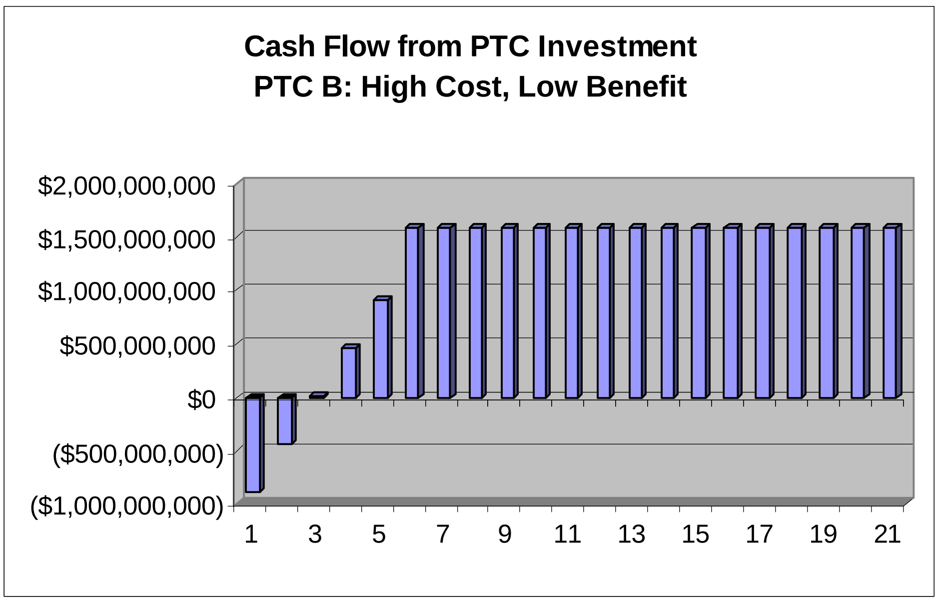
As an alternative, consider the calculation shown in Figure 12. This calculation makes the same assumptions as previously considered, except this time using the minimum expected annual benefits of about $2 billion and the minimum expected costs of implementation ($2.303 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This brings the IRR to 95% over the 20-year period.

Figure 12: Cash Flow Calculation for Five-Year PTC B Implementation, Using Minimum Estimated Benefit and Minimum Estimated Cost



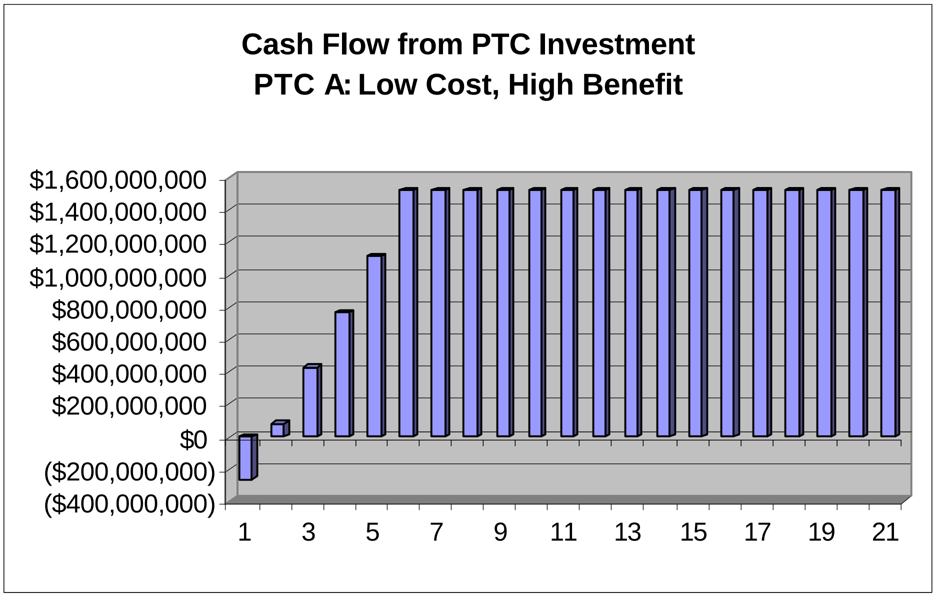
In calculating the lowest possible rate of return, consider the calculation shown in Figure 13. This calculation makes the same assumptions as previously considered, except this time using the minimum expected annual benefits of about $1.899 billion and the maximum expected costs of implementation ($4.420 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This brings the IRR to 44% over the 20-year period.

Figure 13: Cash Flow Calculation for Five-Year PTC B Implementation, Using Minimum Estimated Benefit and Maximum Estimated Cost



In calculating the highest possible rate of return, consider the calculation shown in Figure 14. This calculation makes the same assumptions as previously considered, except this time using the maximum expected annual benefits of about $3.828 billion and the minimum expected costs of implementation ($1.588 billion). The same assumptions regarding implementation and benefit stream timing are used, as is the 15% of total project cost for maintenance and replacement. This raises the IRR to 160% over the 20-year period.

Figure 14: Cash Flow Calculation for Five-Year PTC B Implementation, Using Maximum Estimated Benefit and Minimum Estimated Cost



Summary

Table 34 summarizes the IRR calculations. Cash flows prepared from the costs and benefits of PTC vary among the four cases, and between PTC A (with relatively smaller costs and benefits) and PTC B (where both are larger). However, as can be seen from the forgoing graphs, the period of negative cash flow is five years or less in all cases, and in some cases is less than two years. Cash flow then becomes positive, and stays positive, for the remaining life of the investment. This occurs despite the 15% annual charge for training, maintenance, and obsolescence.

Table 34: Calculated Internal Rates of Return, PTC Four Analysis Cases

PTC A

	Low Benefits	High Benefits
Low Costs	**68%**	**130%**
High Costs	**24%**	**73%**

PTC B

	Low Benefits	High Benefits
Low Costs	**95%**	**160%**
High Costs	**44%**	**79%**

Conclusions

PTC is a large investment by any measure. A cost of $1.3 billion to $4.4 billion might seem daunting to an industry with gross revenues of only $35 billion. However, the projected annual savings of $2 billion to $3.6 billion provides a rapid payback period. It should be noted that the value of accident avoidance (the near elimination of human factors accidents) has not been included in either benefit calculation, but is being calculated separately by the Federal Railroad Administration.

Clearly, both PTC A and PTC B offer an opportunity to U.S. freight railroads. Implementation of such a system would:

- Improve service reliability for shippers, producing a large benefit for them
- Increase the capacity of about 8,000 route miles that are now at or above capacity, enabling railroads to avoid a very substantial near-term investment in track and signals
- Produce immediate savings in car and locomotive ownership cost through improved utilization

Either PTC A or PTC B provides significant business benefits to the freight railroads, as well as unquestioned safety benefits through positive enforcement of movement authorities. PTC B additionally provides a "moving block" capability that has the potential to greatly reduce future investments in additional railroad capacity. Beyond that, moving block is especially well suited for situations in which rail traffic operating at different speeds (i.e., freight and 110 MPH passenger trains) shares a common rail route. The central safety system, along with the moving block capability, may be essential where freight trains share track with high-speed passenger trains.

This study results suggest that the railroad industry should carefully consider the opportunity presented by PTC technology, especially in view of its ongoing shortage of line capacity and the need to increase the return on invested capital.

Despite the quick payback, implementation of PTC does pose some difficult issues. One of them is staging. Obviously, the entire U.S. rail network cannot be equipped at once. Should the project be undertaken railroad by railroad, geographically, or by corridor? Is it possible to make the implementation self-financing, that is, use the benefits of one part of the installation to pay for the next? Information was not available in sufficient detail to enable the study team to answer that question, but the answer may be yes.

It may also be anticipated that PTC B, with its capability for "moving block" operation, would enable railroads to more effectively manage a mix of passenger and freight trains sharing the same rail corridor. This offers potential for future passenger service at relatively low cost.

All these benefits are in addition to the unquestionable safety benefits, which – while not large in economic terms – would produce a better working environment for railroaders and avoid deaths and injuries to both railroad workers and passengers.

This study results suggest that the railroad industry should carefully consider the opportunity presented by PTC technology, especially in view of its ongoing shortage of line capacity and the need to increase the return on invested capital.

References

1) "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).

2) Randolph R. Resor, Michael E. Smith and Pradeep K. Patel, "A Real-Time Work Order Reporting System for Rail Transportation: Benefits and System Requirements", **Selected Proceedings of the Sixth World Conference on Transport Research**, (Lyon, France: 1992)

3) Randolph R. Resor and Michael E. Smith, "Real-Time Planning: Enhancing the Value of Advanced Control Systems in Railroading", In **Committee Reports and Technical Papers**, Annual Technical Conference, Communications and Signal Division, Association of American Railroads, (Montreal: 1992).

4) Randolph R. Resor, Michael E. Smith and Pradeep K. Patel, "Train Dispatching Effectiveness With Respect to Advanced Train Control Systems: Quantification of the Relationship". **Transportation Research Record** no. 1584 (Washington, DC: 1997).

5) Cook, Peter D., Sanjay Das, Andreas Aeppli, Carl Martland, *Proceedings of the 1999 Winter Simulation Conference*, (P.A. Farrington, H. B. Nembhard, D. T. Sturrock, and G.W. Evans, eds.) "Key Factors In Road-Rail Mode Choice In India: Applying the Logistics Cost Approach." "The Case for Reconsideration," *14th Annual State of Logistics Report*, presentation by Cass Information Systems, Inc., ProLogis, to the National Press Club, Washington, D. C., June 2, 2003.

6) Reilly, Frank K., *Investment Analysis and Portfolio Management*, Dryden Press, Hinsdale, IL, 1979.

7) Ohio Department of Transportation, *Freight Impacts on Ohio's Roadways*, June 2002.

8) Kwon, Oh Kyong, Carl D. Martland and Joseph M. Sussman, "Origin-to-Destination Trip Times and Reliability of Rail Freight Services," *Transportation Research Record 1489*, Transportation Research Board, National Research Council, National Academy Press, Washington, D. C., 1995.

9) "Burlington Northern: The ARES Decision (A)," HBS Case Number 9-191-122, Harvard Business School, Boston, MA.

10) Little, Patrick and Carl D. Martland, "Causes of Unreliable Service in the North American Railroad Network," *Proceedings of the Transportation Research Forum*, 1993.

11) Federal Highway Administration, "Meta-Analysis of Logistics Costs and Transport Demand in Relation to Freight Transportation," *Freight Benefit/Cost Study* July 2002.

12) American Trucking Association, *U. S. Freight Transportation Forecast to 2014I,* January 2003.

13) *Railroad Facts, 2002 Edition* (Washington: Association of American Railroads, 2002)

APPENDIX A: Acronyms and Abbreviations

ACRONYMS AND ABBREVIATIONS

AAR	**Association of American Railroads**
ABS	**Automatic Block Signals**
ARES	**The Advanced Railroad Electronics System**
ARRC	**Alaska Railroad Corporation**
ATC	**Automatic Train Control**
ATCS	**Advanced Train Control Systems**
BN	**Burlington Northern Railroad**
BNSF	**Burlington North and Santa Fe Railway Co.**
CAD	**Computer-aided Dispatching**
CBTM	**Communication-Based Train Management**
CN	**Canadian National**
CP	**Canadian Pacific Railway**
CTC	**Centralized Traffic Control**
CSXT	**CSX Transportation, Inc.**
DGPS	**Differential Global Positioning System**
EOT	**End-of-Train Device**
FEP	**Front-end Processors**
FHWA	**Federal Highway Administration**
FRA	**Federal Railroad Administration**
GIS	**Geographical Information System**
GPS	**Global Positioning System**
IDOT	**Illinois Department of Transportation**
ITCS	**Incremental Train Control System**
MCP	**Mobile Communication Package**
MOW	**Maintenance of Way**
NS	**Norfolk Southern Corporation**
NTSB	**National Transportation Safety Board**
OBC	**Onboard Computer**
PPA	**PTC Preventable Accident**
PTC	**Positive Train Control**
PTS	**Positive Train Separation**
RAIRS	**Railroad Accident / Incident Reporting System**
RF	**Radio Frequency**
RSAC	**Railroad Safety Advisory Committee**
TEA 21	**Transportation Equity Act for the Twenty-First Century**
TFT	**Track Forces Terminal**
TRB	**Transportation Research Board**
TWC	**Track Warrant Control**
UP	**Union Pacific Railroad**
WILD	**Wheel Impact Load Detector**
WIU	**Wayside Interface Unit**

– Association

Architecture - The organizational structure of a system or component. A system is a collection of components organized to accomplish a specific function or set of functions.

Automatic Block Signal System - A block signal system where the use of each block is governed by an automatic block signal, cab signal, or both. A roadway signal operated either automatically or manually at the entrance to a block.

Automatic Train Control (ATC) - A track-side system working in conjunction with equipment installed on the locomotive, so arranged that its operation will automatically result in the application of the air brakes to stop or control a train's speed at designated restrictions, should the engineer not respond. ATC usually works in conjunction with cab signals.

Automatic Train Stop -A track-side system working in conjunction with equipment installed on the locomotive, so arranged that its operation will result in the automatic application of the air brakes should the engineer not acknowledge a restrictive signal within 20 seconds of passing the signal. If the restrictive signal is acknowledged, ATS will be suppressed.

Benchmark - A standard of measurement or evaluation.

Block - A length of track of defined limits, the use of which by trains is governed by block signals, cab signals, or both.

Block Signal - A fixed roadway signal at the entrance of a block to govern trains and engines entering and using that block. The signal may be operated either automatically or manually.

Cluster Controller (CC) - A ground network node (in ATCS) responsible for the control of base stations.

Computer Aided Dispatching (CAD) - A computer-based dispatching system providing automatic train routing and in some installations, a paperless dispatcher environment. CAD contributes by guarding against the inadvertent conflicts in train movement authorities. CAD systems typically consist of computer hardware and specialized software programs designed for railroad applications. CAD systems may have enhanced existing TCS capabilities through a number of subsystems. Trains can be tracked and recorded automatically, and written movement authorities, where necessary, can be generated, recorded and filed completely within the computer system. These activities provide an added enhancement to train operations safety.

Control System - The system for controlling train movement, enforcing train safety, and directing train operations.

Dark Territory - Trackage that is non-signaled, over which the movement of trains are governed by timetable, train orders/track warrants, or operating rules for the movement of trains in other than block signal territory.

DGPS - An enhancement to the Global Positioning System using differential techniques to improve accuracy. Differential techniques improve radio navigation system accuracy by determining position error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radio navigation system, operating in the same area.

Geographical Information System - An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working [analysis] with the data. A system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems.

Global Positioning System (GPS) - A satellite-based radio navigation system deployed and operated by the Department of Defense, which provides highly accurate three-dimensional position, velocity, and time data to users worldwide.

Grade Crossing - An intersection of a highway with a railroad at the same level. Also, an intersection of two or more railroad tracks at the same elevation.

Highway-rail crossing - means a location where a public highway, road, street, or private roadway, including associated sidewalks and pathways, crosses one or more railroad tracks at grade.

Interoperability - The capability of PTC equipped trains, locomotives or other vehicles to operate safely on other railroads while maintaining at least the minimum (or core) PTC functionalities. The intent of PTC Interoperability includes the elimination of interline delay and standardization of operator interfaces.

Interlocking - An arrangement of signals and signal appliances so interconnected that their movements must succeed each other in proper sequence and for which interlocking rules are in effect. It may be operated manually or automatically.

Manual Block System - A block signal system wherein the use of each block is governed by block signals controlled manually or by block-limit signals or both upon information by telephone or other means of communication.

Maintenance-of-Way (MOW) - Having to do with the installation and maintenance of track and related structures to facilitate the operation of trains.

Maintenance-of-Way Worker - see Roadway Worker

Mobile Communications Package (MCP) - A vehicle-carried communications package that allows transmission and reception of data with other elements of a PTC system and with the vehicle and its operator to provide the on-board information and enforcement functions.
Moving Block - ***A*** railroad operational concept whereby instead of track circuit blocks of fixed length being used to detect train position and assure train separation, blocks are determined dynamically to assure safe separation of all equipment on the line. The block length is calculated using real-time knowledge of the location, speed, direction, and braking performance characteristics of all equipment on the line.

Overlay - To supplement, or overlay, an existing system of train control with a PTC system.

Positive Train Control (PTC) - A generic term (and acronym) used to describe any processor-based system of train control that will: (1) Prevent train-to-train collisions (positive train separation); (2) enforce speed restrictions, including civil engineering restrictions and temporary slow orders; and (3) provide protection for roadway workers and their equipment operating under specific authorities.

PTC Preventable Accidents (PPA) - Accidents that a railroad industry group of subject matter experts determined to be preventable by PTC systems.

Radio frequency (RF) - Radio Frequency Spectrum - The entire range of electromagnetic communications frequencies administered by the Federal Communications Commission, including those used by radio, radar, and television. Several frequencies have been allocated to the railroad industry for the transmission of voice and digital data in connection with railroad operations. By agreement, the AAR serves as the clearinghouse for assignment of voice radio channels in order to prevent radio interference among the users.

Roadway Worker - Any employee of a railroad, or of a contractor to a railroad, whose duties include inspection, construction, maintenance or repair of railroad track, bridges, roadway, signal and communication systems, electric traction systems, roadway facilities or roadway maintenance machinery on or near track or with the potential of fouling a track, and flagmen and watchmen/lookouts.

Rolling Stock - A general term used when referring collectively to a large group of railway cars.

Severity - The degree of impact that a requirement, module, error, fault, failure, or other item has on the development or operation of a system.

Signal Indication - The information conveyed by the aspect of a fixed signal or cab signal.

Switch (Track) - A pair of switch points with their fastenings and operating rods providing the means for establishing a route from one track to another.

Track - An assembly of rails, ties, and fastenings over which cars, locomotives, and trains are moved.

Track Circuit - An electrical circuit of which the rails of the track form a part.

Train - A locomotive or more than one locomotive coupled, with or without cars, displaying markers.

Train Orders - Mandatory directives governing the movement of trains.

Validation - The process of determining whether the system or component complies with the objectives and system requirements during and/or at the end of the development cycle. That is... “Did we build the right system?”

Verification - The process of determining whether the system or component outputs of a given phase of the development cycle fulfill the requirements established at the start of that phase. That is... “Did we build the system correctly?”

Watchman/lookout - An employee who has been trained and qualified to provide warning to roadway workers of approaching trains or on-track equipment.

Wayside Equipment - Train control or movement apparatus, which is located along the track or wayside as opposed to the control center or other remote location.

Wayside Interface Unit (WIU) - An element of a PTC field system providing the interface with switches, signals, grade crossings and other devices for continuous monitoring and communication of their status to the central control offices, locomotives, or other users.

Wayside Local Area Network (WLAN) - the WIU to WIU-S’s link using spread spectrum radio.

Wayside Signal - A signal of fixed location along the track right-of-way.

Wheel Impact Load Detectors - A device consisting of a sensor or a series of sensors used to detect railroad wheels on trains that may exceed safe limits of flat spots on the tread that should normally be of constant curvature.