POSITIVE TRAIN CONTROL (PTC): CALCULATING BENEFITS AND COSTS OF A NEW RAILROAD CONTROL TECHNOLOGY

by

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ABSTRACT

The railroad industry has since the mid-1980s been investigating the potential of a group of technologies collectively known as communications-based train control. These communications-based systems have been applied to both passenger and freight operations, and also to rapid transit and "people-movers" (low-capacity automated systems typically used at airports or for downtown circulation). In the railroad industry, the term "positive train control" (PTC) is now used, reflecting the capability of such system to positively enforce movement authorities, conveying a safety benefit not found in most current railroad systems. However, the sorts of "human factors" accidents prevented by PTC are (fortunately) uncommon, and their elimination produces a relatively small annual savings. The cost of implementing PTC, by contrast, may be quite large.

The purpose of this analysis was to quantify the "business benefits" of Positive Train Control (PTC) for the Class I freight railroad industry. 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), 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

This paper presents the results of the analysis. It is important to recognize, however, that the state of the art in making these estimates is not sufficiently mature to make exact answers feasible. What is presented here are the best estimates now possible, with observations as to how better information may be developed. Benefits were estimated in the above areas and the cost of deploying PTC on the Class I network (99,000 route miles and 20,000 locomotives) were calculated. The conclusions of the analysis were as follows:

- ❑ Deployment of PTC on the Class I railroad network (99,000 route miles, 20,000 locomotives) would cost between $2.3 billion and $4.4 billion over five years
- ❑ Annual benefits, once the system was fully implemented, were estimated at $2.2 billion to $3.8 billion
- ❑ Internal rate of return was estimated (depending on timing and cost) to be between 44% and 160%

I. INTRODUCTION AND BACKGROUND

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 can include many different capabilities, covering a range of railroad functions. Through use of a digital data link and real-time train location information, PTC can be a train control system, with the digital data link and the on-board computer (OBC) used for positive safety enforcement, stopping trains if movement authorities are exceeded. The 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 safety benefits of PTC 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.

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- ☐ 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

This paper describes the estimation of these business benefits.

Definition of Positive Train Control

Any PTC installation will consist of three distinct segments:

- ☐ 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

This analysis quantifies benefits for a stand-alone "vital"[3] system, which includes OBC, digital data link, and a central safety system. The PTC system evaluated here is based on the North American Joint PTC project in Illinois, which supplements DGPS with accelerometers and a gyroscope that give locomotives the ability to resolve location down to a particular track. This location accuracy enables PTC to support "moving block"

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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.

[3] "Vitality" is a term used by railroad signal engineers to describe which is "fail safe". "Fail safe" means that any failures will place the system in a safer, rather than a less safe, state. For example, a dark signal (due perhaps to a burned out bulb or power supply failure) must be assumed to be displaying its most restrictive indication).

operation, in which the distance between following trains is reduced to that required to stop the following train short of a rear-end collision.[4]

QUANTIFICATION OF BENEFITS

The benefits of PTC are realized in a number of ways. Line capacity and service reliability are improved 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.

Moving block (or "dynamic block') permits trains to follow more closely, increasing line capacity. Faster over-the-road running times, again, result from better "meets" between trains (since dispatchers know train position more accurately and trains can follow more closely).

PTC also provides 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 PTC 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*(1)*. 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, although this benefit is not quantified here.

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.

Note that some of these benefits might be obtained by other means. For example, some railroads are now using hand-held wireless devices for work order reporting. 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.

The largest benefit categories are:

- A reduction in equipment ownership cost, due to an estimated 5% to 10% increase in car velocity
- 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.
- Significant benefits to shippers from a presumed improvement in service quality

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[4] 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 the minimum necessary to ensure safety.

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, control office software 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.

Most of the benefits identified here 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.

It is important to note that it is by no means certain that railroads will realize all of the benefits estimated here. 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 *(2)*. But whether the benefits flow to railroads or to their customers, in one way or another the entire U.S. economy benefits.

SPECIFIC AREAS OF BENEFIT

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 potentially 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.

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 needed capacity additions, a cost that may be avoided by PTC installation.

1. Lines Currently at Capacity

The Volpe Rail Network (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 *(3)*:

- ☐ "Dark" (unsignaled)
- ☐ Automatic block signals (ABS)
- ☐ Centralized traffic control (CTC)
- ☐ Double Track CTC

About half the 99,000 route miles of Class I track is dark, with trains dispatched by voice radio. ABS track typically also uses voice radio, with the signals providing protection against following trains. CTC is the current "state of the art" in train control, although first deployed in 1927 *(4)*. In CTC territory, trains move on signal indication, and double track CTC permits movement on either track in either direction under signal control.

ZETA-TECH previously calculated a practical maximum line capacity for each of these types of signal systems *(5)*. This was done by using data on type of signal control, 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. 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 1 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 1
Criteria for Capacity Improvements

Type of Signal Control	Maximum Capacity	Track Miles Above Cap.	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.

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 4[5]. 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 new 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 2 shows the total one-time capital cost of adding this track. It should be noted that the mileages shown in Table 1 are track that is *already* at or above capacity. Future traffic increases will require additional investment.

TABLE 2
Estimated One-Time Cost of Enhancing Line Capacity On Segments With Capacity Constraints

Comment [SMD1]: Page: 33
Report data in millions.

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**

A more useful number might be the annualized cost of these 8,394 miles of 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[6] 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) for all track owned by Class I railroads. Applying these numbers to the 8,394 miles of track produces the totals shown in Table 3.

TABLE 3: 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**

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[5] 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.

[6] The American Railway Engineering and Maintenance Association (AREMA) sets engineering standards for railroads. 80 years is the recommended design life for bridges and similar structures.

It is important to note, once again, that the costs in Table 3 are for addressing current, not future, capacity constraints. In the absence of an industry decision to install PTC, even more investment will be required 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 *(5)*.

Equipment Utilization

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 *(6)*. Analysis 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, rather than every 17 minutes, as would be expected under a classic CTC system.

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.*(7)* 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.

In the present analysis, more modest improvements have been assumed. For intermodal trains (which already enjoy preferential dispatching treatment) a reduction of only 5% to 10% in running times has been estimated (after accounting for a non-line-haul percentage of 52%, the dock-to-dock reduction in time becomes 2.5% to 5%). 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 4 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).

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 4: Benefits of 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

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 time before completing all scheduled work and any additional work[7]. 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.

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.
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.

A detailed description of the methodology used to develop the benefits estimates shown in Table 5 may be found in Reference 8*(8).*

TABLE 5: Estimated Annual Savings from use of Real-Time Work Order Reporting

Carloads 2002		% Saving One Day*	Cost/Car Day	Total Annual Savings
Inbound	6,260,000	5%	$12.92	$4,043,960
Outbound	6,260,000	7.5%	$12.92	$6,065,940
Total Carloads	12,520,000			$10,109,900

Locomotive Diagnostics

Locomotive diagnostics are 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 value. The analysis presented here assumes 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.

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[7] Once a crew has worked 12 continuous on-duty hours, by Federal law they must stop work.

Due to data limitations, this analysis addresses only reductions in en-route failures (and resulting delays) and reductions in maintenance hours required (with a consequent reduction in time off line per locomotive). An annual savings was 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).

To quantify the magnitude of potential benefits, a simulation model was developed by Burlington Northern to estimate the reduction in work hours required to diagnose locomotive problems. This estimate was than used in a model developed by Northrop Corporation to estimate total labor savings. To apply the Northrop model, fleet performance statistics (frequency of failures) are needed. This data was obtained from two Class I railroads for 2003.

It was calculated that availability of real-time diagnostic information could save 8.3% of total labor in a base case in which *no* locomotives had diagnostic equipment. In fact, since 1987 railroads have been purchasing new locomotives equipped with factory-installed diagnostics. The BN simulations indicated that of on-board diagnostics with no real-time transmission capability could achieve 44% of the reduction in hours estimated for on-board diagnostics with real-time transmission of diagnostic data to the repair shop. This means that for those units already equipped with diagnostics, only 44% of the 8.3% savings can be taken.

A review of locomotive purchases by major North American railroads for the years 1987 – 2001 *(1)* indicates that 9,730 of the 2001 fleet of 19,745 units have been purchased or rebuilt 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%.

Total estimated benefits are shown in Table 6.

TABLE 6: Estimated Annual Savings, Real-Time Locomotive Diagnostics

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

*Failure frequency calculated from 2003 data for two Class I railroads

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

Fuel Savings

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

- The use of an “energy management system” (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

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 *(9).*

In the quantification of benefits, it was decided to use a range rather than a point estimate for most sources of benefits. A range of 1.5% to 3.5% was selected for quantifying fuel savings. 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 1.5% to 3.5% savings produced a range of $56 million to $130 million in fuel cost savings.

SHIPPER BENEFITS

What is the value of better service? Benefits to the shipper as a result of PTC implementation by railroads can be estimated by measuring the reduction in shippers' logistics cost. The most important of these logistics benefits is associated with the ability of railroads to provide improved on-time service. Here are three methods by which shipper benefits from PTC implementation may be measured:

1. Inventory reduction cost method – Determine the savings shippers might realize in terms of the reduced inventory portion of logistics cost if service reliability improves.

2. Price elasticity method – Determine what additional amount shippers might be willing to pay for improved service reliability.

3. Logistics cost elasticity method – Determine benefits based on the cross-elasticity of demand and price relative to PTC-enabled improvements in transit time and its variability.

These methods do not all measure precisely the same thing. The first only looks at the inventory portion of logistics cost, both the size of safety stock and the value of in-transit inventory. The second looks at how much shippers are willing to pay for better service; and the third gives a measure of total logistics cost based on theoretical studies. Since the ability to measure this item with great precision does not yet exist, these techniques are merely presented as different ways of getting an estimate of potential benefits and assessing their size. In addition, analysis of the information here will assist in understanding where emphasis should be placed on improving the accuracy with which such phenomena can be measured.

There seems to be little question that PTC can improve service reliability. The issue here is one of quantifying their magnitude. These benefits are first quantified in terms of potential service improvements. These improvements can be inferred from a Harvard Business School Case Study *(10)* as follows:

- ☐ For improvement in percent of carload shipments arriving on time: 3.5 percent

- ☐ For the percent improvement in travel time variance: 7 percent

The analytic steps involved in the analysis needed to translate these service improvements into dollar benefits here may be understood through close examination of Table 7, Calculation of Shipper Benefits Due to PTC. Frequent reference to this table will be made in the next few pages while describing the computational steps involved.

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.

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. 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.

Many authorities may be consulted regarding the logistics costs associated with shipping *(10)*. However, a more general approach is provided by Cass Information Systems. Each year, they produce a report on the state of logistics in the United States *(11)*. The Cass report provides, among other elements of data, transportation costs inventory carrying costs and administrative costs.

From the point of view of service reliability, the shipper's benefit will come from holding less inventory. The more unreliable the delivery time of a shipment, the larger the amount of safety stock that must be held. Inventory carrying costs consist of interest on the capital associated with investment in the product perishability and obsolescence, insurance, taxes, and storage costs. 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. *(12*) 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.

The method used in this report divided shipments into categories based on two-digit Standard Transportation Commodity Codes (STCCs). The first few columns of Table 7 provide the tonnage and revenue information for two-digit STCC groups that represent over 98 percent of the tons shipped via railroad. In addition, 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.

The next few columns show the total amounts that the railroads shipped in 2002, classified by STCC. 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. *(13*) 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.

The next column shows the relevant values in 2002 dollars for commodities that the railroads carry. Based on this information, it is possible to estimate the value of goods shipped by rail, shown in the next column. 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. To guard against stockout due to slow transportation, a shipper will want to maintain a bit of inventory. The question is how much. In the case of the railroad that inventory can be estimated by determining the standard deviation of travel time. If the shipper wants to reduce the probability of a stockout due to shipping failure to less than 2 percent, for example, then a safety stock of two "standard deviations" of days would be sufficient. For example, if the standard deviation in railroad service time is 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.

The financial consequences of a stock-out can vary, and so, of course, can the value of avoiding one. The financial consequence of a stock-out will depend on the demand for the product, the value of it, and the cost of transporting it or carrying it in inventory. The amount of inventory kept by a shipper to avoid a stock-out will very in a manner that depends on these factors. A study by the FHWA makes a judgment as to the optimal probability of stock-out that a shipper should work toward based on all these factors *(14)*. While this amount does vary, a probability of 0.5 percent is not out of line.

TABLE 7. Calculation of Benefits from Improved Railroad Service

						Inventory Method				Service Elasticity Method					Logistics Elasticity Method		
STCC	Product Description	Tons (000s)	Revenue (millions)	’02 Value per ton	Total Value (millions)	Days Inv.	Value of Safety Stock	Reduced Variance	Annual Benefit (x10^6)	Service Type	On-time Cross Elasticity	% On-Time Incr.	Price Incr.	Revenue Gain (x10^6)	Var. Cross Elas.	Price Incr.	Revenu Gain (x10^6
1	Farm Products	137,717	$2,711	$1,044	$143,764	8.27	$3,257	7.00%	$59	Carload	2	3.50%	7.00%	$190	0.54	3.78%	$10
10	Metallic Ores	31,376	$285	$49	$1,541	6.56	$28	7.00%	$1	Unit Train	0	3.50%	0.00%	$0	0.54	3.78%	$1
11	Coal	785,006	$7,797	$29	$22,999	6.56	$413	7.00%	$8	Unit Train	0	3.50%	0.00%	$0	0.54	3.78%	$29
14	Non-metallic Minerals	125,643	$967	$21	$2,584	6.56	$46	7.00%	$1	Unit Train	0	3.50%	0.00%	$0	0.54	3.78%	$3
20	Food or Kindred Products	102,230	$2,657	$1,471	$150,395	8.27	$3,408	7.00%	$62	Carload	2	3.50%	7.00%	$186	0.54	3.78%	$10
24	Lumber or Wood Products	47,533	$1,628	$2,440	$115,996	8.27	$2,628	7.00%	$48	Carload	2	3.50%	7.00%	$114	0.54	3.78%	$6
26	Pulp, Paper or Allied Products	37,212	$1,567	$1,440	$53,588	8.27	$1,214	7.00%	$22	Carload	2	3.50%	7.00%	$110	0.54	3.78%	$5
28	Chemicals or Allied Products	158,734	$4,707	$2,142	$340,041	8.27	$7,704	7.00%	$140	Carload	2	3.50%	7.00%	$329	0.54	3.78%	$17
29	Petroleum or Coal Products	40,207	$977	$292	$11,731	8.27	$266	7.00%	$5	Carload	2	3.50%	7.00%	$68	0.54	3.78%	$3
32	Clay, Concrete, Glass, or Stone	49,275	$1,149	$222	$10,994	8.27	$249	7.00%	$5	Carload	2	3.50%	7.00%	$80	0.54	3.78%	$4
33	Primary Metal Products	55,905	$1,350	$1,250	$69,895	8.27	$1,584	7.00%	$29	Carload	2	3.50%	7.00%	$95	0.54	3.78%	$5
37	Transportation Equipment	35,902	$3,626	$14,321	$514,135	1.6	$2,254	7.00%	$41	Intermodal	0	3.50%	0.00%	$0	0.54	3.78%	$13
40	Waste or Scrap	39,440	$717	$28	$1,090	0	$0	7.00%	$0	Carload	2	3.50%	7.00%	$50	0.54	3.78%	$2
46	Miscellaneous Mixed Shipments	97,228	$4,900	$1,606	$165,967	1.6	$728	7.00%	$13	Intermodal	0	3.50%	0.00%	$0	0.54	3.78%	$18
99	All Other Freight	23,258	$1,704	$920	$21,397	8.27	$485	7.00%	$9	Carload	2	3.50%	7.00%	$119	0.54	3.78%	$6
Total for all major commodities		1,766,666	$36,742	$920	$1,626,117		$24,264		**$442**					**$1,342**			**$1,38**

Mean and variance of railroad transit times were found in a very thorough study of the Waybill Sample for 1991. *(16)* Table 8 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. Figures in Table 8 are based on a stockout probability of 0.5%.

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TABLE 8. Mean and Standard Deviation of Railroad Transit Times

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	0.5

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 savings estimate made for that commodity.

To perform the analysis, each commodity must be assigned a freight car type. The largest difference in standard deviation of travel time is between intermodal shipments, carload shipments and unit train shipments. STCC 46 (miscellaneous mixed shipments), which is nearly always shgipped via intermodal, and STCC 37 (transportation equipment), which receives intermodal-like service, are classified as intermodal. Unit trains are generally used to transport STCCs 10, 11, and 14. All other commodities are considered to be shipped in carload lots.

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 next columns of Table 7. Using the annual cost of inventory (26 percent) and the reduction in inventory that is possible (days inventory per year divided by 365 days per calendar year) yields the reduction in annual inventory carrying costs. The total annual benefit found this way is $419 million.

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 such a study to determine the revenue potentially available from service improvements resulting from adoption of the Advanced Railroad Electronics System (ARES)[8]. The results of the study were developed into two case studies by Harvard Business School on the potential for ARES. *(16)* The study looked exclusively at shipment of truck-competitive commodities. The railroad’s question was: what levels of service improvement would cause the shipper to consider switching from truck to rail?

The survey instrument used in the BNSF study was based on a definition of reliability tat is a bit different from the one used in the inventory method and logistics method for calculating this benefit. For the BNSF study, reliability was defined as the proportion of time that a shipment arrived when the shipper wanted it to arrive. This definition is consistent with the way that a shipper sees reliability. A relationship between this reliability measure and standard deviation will be discussed later.

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[8] ARES was the first PTC-type control system tested by a Class I railroad.

The results of the survey indicated that for every percent increase in transit time reliability, the railroad could expect a price gain of four percent. This is a very large number. implying 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. While these gains would apply only to carload freight, the dollar value still seemed quite high.

It is for this reason that executives at the Burlington Northern were highly skeptical of the elasticity estimates developed from the survey. As reported in the Harvard Business School Case Study, BNSF managers' own 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 used for computation in Table 7.

The total annual shippers' benefit from PTC, using this calculation method, is $1.3 billion.

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 *(16.)* 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 *(10)*. 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 reduction 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.

Total Annual Shipper Benefits

In addition to benefiting from improved service, shippers will have the added advantage of lower cost transportation through an increased use of lower-priced rail service. Rather than calculate that amount here, we elect to round up the result in Table 7, yielding an annual benefit of approximately $1.4 billion. As a low estimate, we select a number between the inventory gain of approximately $400 million annually and the high estimate of $1.4 billion annually, that is, $900 million.

COSTS OF POSITIVE TRAIN CONTROL

The following tables recap the cost of each of the three segments (vehicle, wayside, central office) of PTC. Costs are for equipping the entire Class I network and all locomotives. 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.

The FRA study defined two types of PTC; "PTC A", an overlay system, and "PTC B", a fully functional system incorporating dynamic block capability. Costs here are for the more expensive PTC B.

The central office cost remains the greatest unknown. 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, the "low" cost is probably most appropriate for any single railroad. However, it is doubtful that railroads will choose to share control centers, so the total cost for all seven Class Is could conceivably approach the "high" cost.

TABLE 9: Cost per Segment, PTCB
(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 is shown in Table 10.

TABLE 10: 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 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 Railroad 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 a full PTC installation is not known at this time.

Note that the costs in Table 10 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.[9]

SUMMARY OF BENEFITS AND COST/BENEFIT ANALYSIS

Summary of Benefits

Table 11 provides a summary of benefits for PTC. Most of the benefits quantified in Table 11 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.

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[9] BN used a 10% additive to cover training, maintenance, and capital replacements for its ARES project. The 15% is a typical number used for electronics and other products that quickly become obsolete.

It is important to note that it is by no means certain that railroads will realize all of the savings in Table 11. 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 *(2)*. But whether the benefits flow to railroads or to their customers, in one way or another the entire U.S. economy benefits.

TABLE 12: Summary of PTC Costs

Segment	Estimated Capital 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

Costs, Cash Flows, and IRR Calculations

Table 12 estimates the cost of PTC. These are the total one-time costs of implementing the three segments of PTC: wayside, on-board, central office. Again, because of uncertainties, a range is given.

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[10]
- A 7% cost of money
- A 20-year benefits period

A calculation of “internal rate of return” (IRR) and cash flow is shown in Table 13, below, for four scenarios:

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

To make the IRR calculations, a table of cash flows was prepared, showing net cash flows per year, positive and negative, during the life of the proposed investment. 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.

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[10] 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%.

TABLE 13: Calculated Internal Rates of Return, PTC
Four Analysis Cases

	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, PTC offers 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

Railroads have been reluctant to invest in this new technology, in part because of capital constraints, in part because of uncertainty about the benefits, and in part through a fear of government action to require the investment on a safety basis. However, PTC does appear to provide significant business benefits to the freight railroads, as well as unquestioned safety benefits through positive enforcement of movement authorities. There remains uncertainty as to the percentage of benefits railroads might actually realize, as opposed to shippers (in the form of lower rates). Given that there is a stated public policy objective of putting more freight on railroads, possibly there might be some consideration of public financing, since the results of this analysis suggest that the benefit to the U.S. economy as a whole (whichever stakeholder received benefits) could be substantial.

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References

1. **Railroad Facts, 2003 Edition** (Washington: Association of American Railroads, 2004)

2. "Sources of Financial Improvement in the U.S. Railroad Industry, 1966 – 1995", by Carl D. Martland (Montreal, PQ: **Proceedings**, 39th Annual Meeting of the Transportation Research Forum, pp.58 – 86.)

3. **The Railroad – What It Is, What It Does**, by John Armstrong (Omaha, NE: Simmons Boardman, 1979.)

4. "The Unofficial Toledo & Ohio Central Home Page" , http://www.members.kconline.com/plank/tocpred.htm

5. **Freight Rail Bottom Line Report** (Washington: American Association of State Highway and Transportation Officials, 2003)

6. "Train Dispatching Effectiveness With Respect to Advanced Train Control Systems: Quantification of the Relationship", **Transportation Research Record** no. 1584 (Washington, DC: 1997).

7. Resor, Randolph R, and Michael E. Smith, "The Use of Train Simulation as a Tool to Evaluate the Benefits of The Advanced Railroad Electronics System", **Journal of the Transportation Research Forum**, vol. XXIX (1989).

8. Resor, Randolph R., 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**, (World Conference on Transport Research Society: Lyon, France, 1992)

9. Resor, Randolph R., Michael E. Smith, Pradeep K. Patel, and Sunil Kondapalli "Quantification of Expected Benefits: Meet/Pass Planning and Energy Management Subsystems of the Advanced Railroad Electronics System (ARES)", **Journal of the Transportation Research Forum,** vol. XXX, no. 2 (1990).

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

11. Cook, Peter D., Sanjay Das, Andreas Aeppli, Carl Martland, "Key Factors In Road-Rail Mode Choice In India: Applying the Logistics Cost Approach.", in *Proceedings of the 1999 Winter Simulation Conference* (P.A. Farrington, H. B. Nembhard, D. T. Sturrock, and G.W. Evans, eds.)

12. "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.

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

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

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

16. 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.