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BUSINESS CASE FOR ADVANCED TRAIN CONTROL SYSTEM (ATCS):

A GUIDE TO THE ANALYSIS AND QUANTIFICATION OF COSTS AND BENEFITS

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EXECUTIVE SUMMARY

The purpose of this report is to provide an introduction to the technology known as the Advanced Train Control System (ATCS), illustrate its functions and potential benefits in freight railroad applications, and provide a guide to quantifying the benefits and costs for railroads interested in evaluating the applicability of ATCS to their operations.

ATCS is often considered to be a train control system. In fact, it has the capability to perform many different functions. It is useful to think of ATCS as a two-story house (see Figure 2). The heart of ATCS is the digital data link providing communication between central dispatch offices, locomotives, other track vehicles and wayside devices. It enables the "business applications", which include work order reporting and locomotive health monitoring, in the first story of the house. To add safety and train control, two additional elements are required: a central safety software package, and real-time vehicle location capability.

It is possible to install only selected functions; a railroad might wish to only purchase the business applications, for example. However, benefits are most strongly identified with the traffic control functions of ATCS. The sum of ATCS exceeds the value of its parts. An incremental investment in train control produces benefits far in excess of the incremental cost.

A full ATCS implementation will include:

- a digital, UHF-frequency data radio link between a control center and vehicles using the track (the Data Segment)

- an on-board display on trains and track vehicles, through which information can be transmitted using the data link (the Vehicle Segment)

- a real-time positioning and safety system, which locates track vehicles and provides enforcement of speed limits and movement authorities (the Control Segment).

If train control and enforcement are to be provided, all three elements of ATCS are required.

ATCS functions are not, however, limited to those in Figure 2. ATCS may include any other technology or application that:

- meets the ATCS specifications
- uses either the ATCS infrastructure or data produced by ATCS
- provides some sort of synergy when combined with other ATCS functions.

Build the Central System "Superstructure"

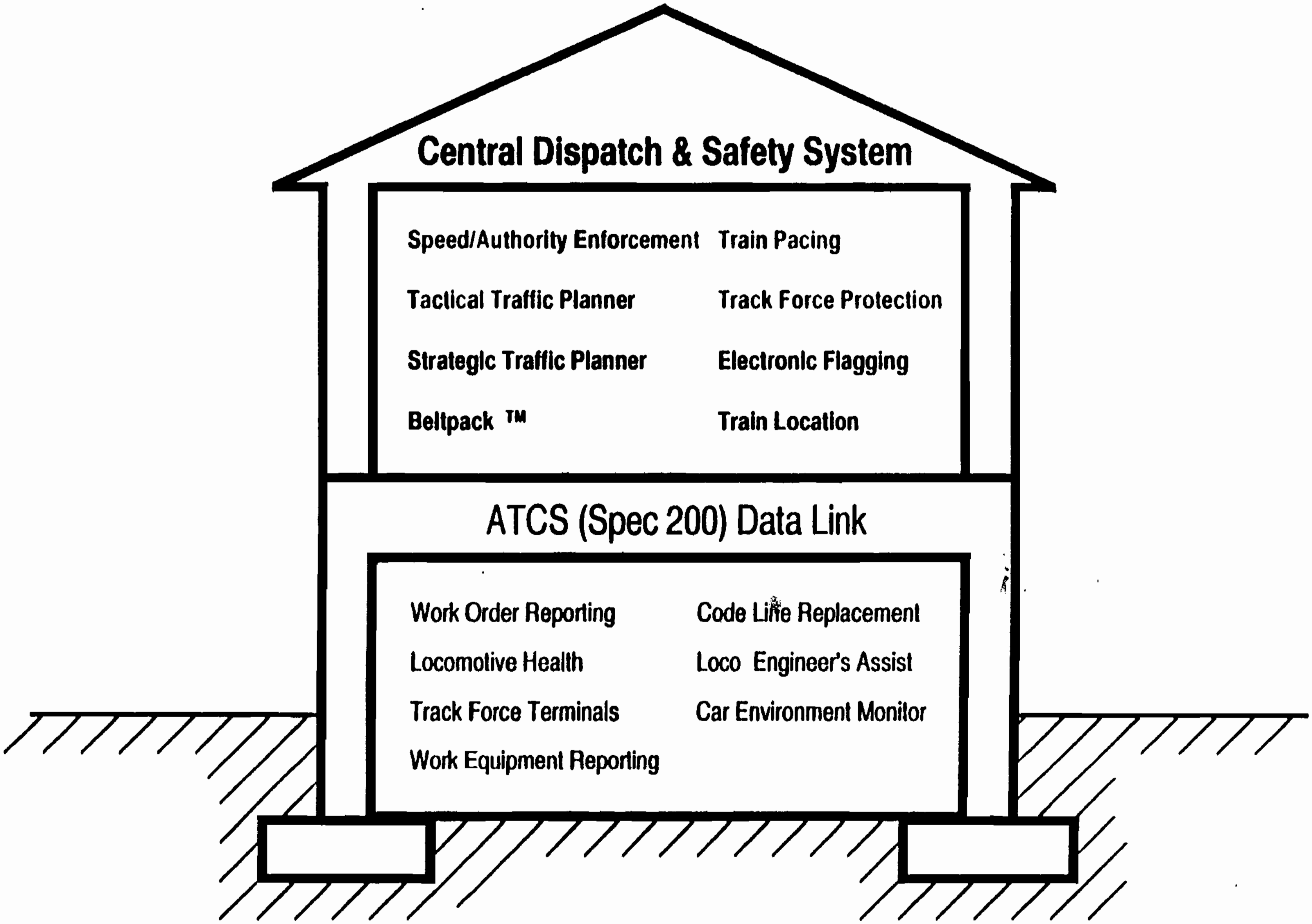

Figure 2

The real-time, accurate data produced by ATCS makes the development of effective traffic planning software possible. ATCS will use a hierarchy of planning systems. Dispatchers will be assisted by a tactical traffic planner, which will provide them with "best" movement plans for trains on their territories. A strategic planner will provide schedule targets for the tactical planners, ensuring efficient equipment utilization. The purpose of both planners is to enable railroads to meet delivery commitments to shippers.

The benefits of ATCS will depend upon which functional areas are chosen for implementation, how implementation is carried out, and how the capabilities of ATCS are used. ATCS is a command, control, communications, and information system which produces both "hard" benefits (labour, fuel, and equipment savings) and "soft" benefits (improved control of service quality, increased line capacity) for railroads. While the hard benefits are substantial, there is also significant potential for improving the quality of railroad service.

The following table shows the cost of three functional areas of ATCS: the safety system, the business applications, and traffic control. Also shown are the magnitude and sources of benefits in each area. These benefits were calculated by BN and CN, which both carried out business case analyses of ATCS technology.

COSTS AND BENEFITS OF ATCS, BY FUNCTIONAL AREA

	BN Tot. Costs ($ M)	BN Ann. Benefits ($ M)	CN Tot. Costs ($US M)	CN ** Ann. Benefits ($US M)
ATCS Safety	$ 191.0M	$ 18.0M	$ 256.6M	$ 8.1M
ATCS Business Applications	$ 56.0M		$ 31.1M	
Work Order Reporting		$ 8.0M		$ 30.8M
Locomotive Health		$ 9.5M		$ 11.7M
Pole Line Elimination		$ 6.0M		
Total Annual Benefits		$ 23.5M		$ 42.4M
ATCS Traffic Control	$ 103.0M		$ 23.4M	
Customer Service		$ 116.8M		$ 66.4M
Train Dispatch Productivity		$ 6.5M		$ 7.5M
Engineering Forces		$ 20.5M		$ 6.0M
Equipment		$ 5.0M *		$ 5.7M
Fuel		$ 9.0M		$ 5.9M
Crews		$ 40.0M		$ 6.0M
Total Annual Benefits		$ 197.8M		$ 97.5M
ATCS Total	$ 350M	$ 239M	$ 311M	$ 148M

*annualized avoidable capital expenditure, based on 30-year equipment life.
** CN Canadian dollars are converted to US dollars based on the four year average rate of .85048.

BN and CN also estimated cost, internal rate of return, and net present value of an investment in ATCS. These are shown in the following table.

CAPITAL COST, INTERNAL RATE OF RETURN AND NET PRESENT VALUE
BN and CN ATCS Business Case Findings

Railroad	Capital Cost	IRR	NPV
BN	$ 350M	28%	$ 406M (at 9%)
CN	$ 311M	24%	$ 123M (at 15%)

It should be noted that these rates of return are conservative, because:

1) Capital costs were estimated in 1989 and 1990. ATCS uses many electronic components, including computers. Prices of these components have fallen dramatically in the past several years, so the capital costs used by BN and CN are almost certainly too high.

2) Many benefits of ATCS were not quantified in the business cases. Neither BN nor CN, for example, included benefits for improved utilization of track forces equipment or car environment monitoring such as thermometers in the interior of the car or overheated bearing detectors on the wheels.

3) Each railroad included in its cost estimate the development of necessary computer software. If this development task is handled by the AAR, each railroad's share of the cost will be much less than projected in the business cases.

The BN and CN results were based on their individual operations, but it is possible to rapidly estimate benefits for any railroad. The spread sheet following this executive summary provides a quick way to determine benefits and costs for an ATCS installation in three areas:

- safety,
- business applications
- traffic control.

BN and CN costs were used as a basis. These figures were tailored to the individual roads by using the number of locomotives, miles of track and MGTMs to develop a cost, benefit and return estimate.

Details about the sources of benefits and the analytical techniques used are covered in the body of this report. For the analysis to be credible, the method of deriving the figures must be well understood. However, the spreadsheet provides a quick look at the magnitude of the benefits that may be available, at least in rough terms.

In conclusion, none of the ATCS technology is new. It has been tested. BN operated a pilot project on the Iron Range in northern Minnesota for four years. CN has been testing a prototype work order system in the Toronto area since 1990. The AAR has spent more than $12 million to develop specifications for ATCS hardware.

ATCS offers the railroad industry a higher level of safety than can be achieved by any current train control system. In addition to safety, ATCS also provides tools for achieving major improvements in railroad service quality and equipment utilization. These service improvements should produce additional revenue and increased market share.

The benefits of ATCS are realized in a number of areas and sensitivity analyses indicate they are robust. Changes in the costs, benefit values, implementation approach and traffic mix did not appreciably affect the resulting IRR.

Finally, ATCS using standard component specifications will benefit the entire railroad industry. ATCS will facilitate the Interline Service Management (ISM) initiative now under way. ATCS will enhance the value of automatic equipment identification (AEI). BN, CN, and the AAR have each identified large benefits for an ATCS investment. With costs declining, and benefits probably understated, it is time for the railroad industry in North America to make an investment in the future.

ATCS		ATSF	BN	CN
Safety				
# miles of track		9.639	23.088	18,380
Total cost of safety (US$ M)		134.6	191.0	256.6
Total cost of safety / mile of track		13.960	8.273	13,960
MGTM per year		162.385	402.526	172.693
Annual benefits of safety (US$ M)		7.6	18.0	8.1
Annual benefits of safety / MGTMs		47	45	47
3 year implementation				
Business Applications				
# of locomotives		1,686	2,340	1,599
Total cost of business applications (US$ M)		32.8	56.0	31.1
Total costs of business applications / locomotive		19,467	23.932	19,467
Annual benefits of business applications (US$ M)		44.7	23.5	42.4
WOR		32.5	8.0	30.8
Locomotive Health		12.3	9.5	11.7
Pole Line Replacement		0.0	6.0	
Annual benefits of business applications / locomotive		26,541	10,043	26,541
3 year implementation				
Traffic Control				
# miles of track		9,639	23,088	18,380
Total cost of traffic control (US$ M)		12.3	103.0	23.4
Total cost of traffic control / mile of track		1,272	4.461	1,272
MGTM per year		162.385	402.526	172,693
Annual benefits of traffic control (US$ M)		91.6	197.8	97.5
Customer Service		62.5	116.8	66.4
Train Dispatch Productivity		7.0	6.5	7.5
Engineering Forces		5.7	20.5	6.0
Equipment		5.4	5.0	5.7
Fuel		5.5	9.0	5.9
Crews		5.6	40.0	6.0
Annual benefits of traffic control / MGTMs		564	491	564
3 year implementation				
Total Costs of ATCS (US$ M)		179.6	350.0	311.1
Annual Benefits of ATCS (US$ M)		144.0	239.3	148.0
IRR	42%			

BN.XLS

ATCS	BN	BN	CN
Safety			
# miles of track	23,088	23,088	18,380
Total cost of safety (US$ M)	191.0	191.0	256.6
Total cost of safety / mile of track	8,273	8,273	13,960
MGTM per year	402,526	402,526	172,693
Annual benefits of safety (US$ M)	18.0	18.0	8.1
Annual benefits of safety / MGTMs	45	45	47
3 year implementation			
Business Applications			
# of locomotives	2,340	2,340	1,599
Total cost of business applications (US$ M)	56.0	56.0	31.1
Total costs of business applications / locomotive	23,932	23,932	19,467
Annual benefits of business applications (US$ M)	23.5	23.5	42.4
WOR	8.0	8.0	30.8
Locomotive Health	9.5	9.5	11.7
Pole Line Replacement	6.0	6.0	
Annual benefits of business applications / locomotive	10,043	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	23,088	23,088	18,380
Total cost of traffic control (US$ M)	103.0	103.0	23.4
Total cost of traffic control / mile of track	4,461	4,461	1,272
MGTM per year	402,526	402,526	172,693
Annual benefits of traffic control (US$ M)	197.8	197.8	97.5
Customer Service	116.8	116.8	66.4
Train Dispatch Productivity	6.5	6.5	7.5
Engineering Forces	20.5	20.5	6.0
Equipment	5.0	5.0	5.7
Fuel	9.0	9.0	5.9
Crews	40.0	40.0	6.0
Annual benefits of traffic control / MGTMs	491	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	350.0	350.0	311.1
Annual Benefits of ATCS (US$ M)	239.3	239.3	148.0
IRR 34%			

CP.XLS

ATCS	CP	BN	CN
Safety			
# miles of track (including D&H)	14,316	23,088	18,380
Total cost of safety (US$ M)	199.9	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	117,692	402,526	172,693
Annual benefits of safety (US$ M)	5.5	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	1,043	2,340	1,599
Total cost of business applications (US$ M)	20.3	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	27.7	23.5	42.4
WOR	20.1	8.0	30.8
Locomotive Health	7.6	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track (including D&H)	14,316	23,088	18,380
Total cost of traffic control (US$ M)	18.2	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	117,692	402,526	172,693
Annual benefits of traffic control (US$ M)	66.4	197.8	97.5
Customer Service	45.3	116.8	66.4
Train Dispatch Productivity	5.1	6.5	7.5
Engineering Forces	4.1	20.5	6.0
Equipment	3.9	5.0	5.7
Fuel	4.0	9.0	5.9
Crews	4.1	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	238.4	350.0	311.1
Annual Benefits of ATCS (US$ M)	99.6	239.3	148.0
IRR 22%			

CN figures converted to US based on an average (weighted by the volume of $ converted)

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CN.XLS

ATCS	CN	BN	CN
Safety			
# miles of track	18,380	23,088	18,380
Total cost of safety (US$ M)	256.6	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	172,693	402,526	172,693
Annual benefits of safety (US$ M)	8.1	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	1,599	2,340	1,599
Total cost of business applications (US$ M)	31.1	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	42.4	23.5	42.4
WOR	30.8	8.0	30.8
Locomotive Health	11.7	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	18,380	23,088	18,380
Total cost of traffic control (US$ M)	23.4	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	172,693	402,526	172,693
Annual benefits of traffic control (US$ M)	97.5	197.8	97.5
Customer Service	66.4	116.8	66.4
Train Dispatch Productivity	7.5	6.5	7.5
Engineering Forces	6.0	20.5	6.0
Equipment	5.7	5.0	5.7
Fuel	5.9	9.0	5.9
Crews	6.0	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	311.1	350.0	311.1
Annual Benefits of ATCS (US$ M)	148.0	239.3	148.0
IRR 25%			

CNW.XLS

ATCS	CNW	BN	CN
Safety			
# miles of track	5.573	23.088	18.380
Total cost of safety (US$ M)	77.8	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	54.285	402,526	172,693
Annual benefits of safety (US$ M)	2.5	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	796	2,340	1,599
Total cost of business applications (US$ M)	15.5	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	21.1	23.5	42.4
WOR	15.3	8.0	30.8
Locomotive Health	5.8	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26.541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	5,573	23,088	18,380
Total cost of traffic control (US$ M)	7.1	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	54,285	402,526	172,693
Annual benefits of traffic control (US$ M)	30.6	197.8	97.5
Customer Service	20.9	116.8	66.4
Train Dispatch Productivity	2.4	6.5	7.5
Engineering Forces	1.9	20.5	6.0
Equipment	1.8	5.0	5.7
Fuel	1.8	9.0	5.9
Crews	1.9	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	100.4	350.0	311.1
Annual Benefits of ATCS (US$ M)	54.3	239.3	148.0
IRR 30%			

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CRC.XLS

ATCS		CRC	BN	CN
Safety				
# miles of track		12,454	23,088	18,380
Total cost of safety (US$ M)		173.9	191.0	256.6
Total cost of safety / mile of track		13,960	8,273	13,960
MGTM per year		173,266	402,526	172,693
Annual benefits of safety (US$ M)		8.1	18.0	8.1
Annual benefits of safety / MGTMs		47	45	47
3 year implementation				
Business Applications				
# of locomotives		1,968	2,340	1,599
Total cost of business applications (US$ M)		38.3	56.0	31.1
Total costs of business applications / locomotive		19,467	23,932	19,467
Annual benefits of business applications (US$ M)		52.2	23.5	42.4
WOR		37.9	8.0	30.8
Locomotive Health		14.3	9.5	11.7
Pole Line Replacement		0.0	6.0	
Annual benefits of business applications / locomotive		26,541	10,043	26,541
3 year implementation				
Traffic Control				
# miles of track		12,454	23,088	18,380
Total cost of traffic control (US$ M)		15.8	103.0	23.4
Total cost of traffic control / mile of track		1,272	4,461	1,272
MGTM per year		173,266	402,526	172,693
Annual benefits of traffic control (US$ M)		97.8	197.8	97.5
Customer Service		66.6	116.8	66.4
Train Dispatch Productivity		7.5	6.5	7.5
Engineering Forces		6.1	20.5	6.0
Equipment		5.7	5.0	5.7
Fuel		5.9	9.0	5.9
Crews		6.0	40.0	6.0
Annual benefits of traffic control / MGTMs		564	491	564
3 year implementation				
Total Costs of ATCS (US$ M)		228.0	350.0	311.1
Annual Benefits of ATCS (US$ M)		158.1	239.3	148.0
IRR	37%			

CSX.XLS

ATCS	CSX	BN	CN
Safety			
# miles of track	18,854	23,088	18,380
Total cost of safety (US$ M)	156.0	191.0	256.6
Total cost of safety / mile of track	8,273	8,273	13,960
MGTM per year	275,352	402,526	172,693
Annual benefits of safety (US$ M)	12.3	18.0	8.1
Annual benefits of safety / MGTMs	45	45	47
3 year implementation			
Business Applications			
# of locomotives	3,123	2,340	1,599
Total cost of business applications (US$ M)	74.7	56.0	31.1
Total costs of business applications / locomotive	23,932	23,932	19,467
Annual benefits of business applications (US$ M)	31.4	23.5	42.4
WOR	10.7	8.0	30.8
Locomotive Health	12.7	9.5	11.7
Pole Line Replacement	8.0	6.0	
Annual benefits of business applications / locomotive	10,043	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	18,854	23,088	18,380
Total cost of traffic control (US$ M)	84.1	103.0	23.4
Total cost of traffic control / mile of track	4,461	4,461	1,272
MGTM per year	275,352	402,526	172,693
Annual benefits of traffic control (US$ M)	135.3	197.8	97.5
Customer Service	79.9	116.8	66.4
Train Dispatch Productivity	4.4	6.5	7.5
Engineering Forces	14.0	20.5	6.0
Equipment	3.4	5.0	5.7
Fuel	6.2	9.0	5.9
Crews	27.4	40.0	6.0
Annual benefits of traffic control / MGTMs	491	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	314.8	350.0	311.1
Annual Benefits of ATCS (US$ M)	179.0	239.3	148.0

IRR 29%

GTW.XLS

ATCS	GTW	BN	CN
Safety			
# miles of track	925	23,088	18,380
Total cost of safety (US$ M)	12.9	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	12,150	402,526	172,693
Annual benefits of safety (US$ M)	0.6	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	260	2,340	1,599
Total cost of business applications (US$ M)	5.1	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	6.9	23.5	42.4
- WOR	5.0	8.0	30.8
Locomotive Health	1.9	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	925	23,088	18,380
Total cost of traffic control (US$ M)	1.2	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	12,150	402,526	172,693
Annual benefits of traffic control (US$ M)	6.9	197.8	97.5
Customer Service	4.7	116.8	66.4
Train Dispatch Productivity	0.5	6.5	7.5
Engineering Forces	0.4	20.5	6.0
Equipment	0.4	5.0	5.7
Fuel	0.4	9.0	5.9
Crews	0.4	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	19.2	350.0	311.1
Annual Benefits of ATCS (US$ M)	14.3	239.3	148.0

IRR 42%

IC.XLS

ATCS	IC	BN	CN
Safety			
# miles of track	2,766	23,088	18,380
Total cost of safety (US$ M)	38.6	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	34,958	402,526	172,693
Annual benefits of safety (US$ M)	1.6	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	502	2,340	1,599
Total cost of business applications (US$ M)	9.8	56.0	31.1
Total costs of business applications / locomotive	19.467	23.932	19,467
Annual benefits of business applications (US$ M)	13.3	23.5	42.4
WOR	9.7	8.0	30.8
Locomotive Health	3.7	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	2,766	23,088	18,380
Total cost of traffic control (US$ M)	3.5	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	34,958	402,526	172,693
Annual benefits of traffic control (US$ M)	19.7	197.8	97.5
Customer Service	13.4	116.8	66.4
Train Dispatch Productivity	1.5	6.5	7.5
Engineering Forces	1.2	20.5	6.0
Equipment	1.2	5.0	5.7
Fuel	1.2	9.0	5.9
Crews	1.2	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	51.9	350.0	311.1
Annual Benefits of ATCS (US$ M)	34.7	239.3	148.0
IRR 37%			

KCS.XLS

ATCS	KCS	BN	CN
Safety			
# miles of track	1,682	23,088	18,380
Total cost of safety (US$ M)	23.5	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	21,880	402,526	172,693
Annual benefits of safety (US$ M)	1.0	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	241	2,340	1,599
Total cost of business applications (US$ M)	4.7	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	6.4	23.5	42.4
- WOR	4.6	8.0	30.8
Locomotive Health	1.8	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	1,682	23,088	18,380
Total cost of traffic control (US$ M)	2.1	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	21,880	402,526	172,693
Annual benefits of traffic control (US$ M)	12.3	197.8	97.5
Customer Service	8.4	116.8	66.4
Train Dispatch Productivity	0.9	6.5	7.5
Engineering Forces	0.8	20.5	6.0
Equipment	0.7	5.0	5.7
Fuel	0.7	9.0	5.9
Crews	0.8	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	30.3	350.0	311.1
Annual Benefits of ATCS (US$ M)	19.8	239.3	148.0

IRR 35%

ATCS	UP	BN	CN
Safety			
# miles of track	20,261	23,088	18,380
Total cost of safety (US$ M)	167.6	191.0	256.6
Total cost of safety / mile of track	8,273	8,273	13,960
MGTM per year	385,933	402,526	172,693
Annual benefits of safety (US$ M)	17.3	18.0	8.1
Annual benefits of safety / MGTMs	45	45	47
3 year implementation			
Business Applications			
# of locomotives	3,030	2,340	1,599
Total cost of business applications (US$ M)	72.5	56.0	31.1
Total costs of business applications / locomotive	23,932	23,932	19,467
Annual benefits of business applications (US$ M)	30.4	23.5	42.4
WOR	10.4	8.0	30.8
Locomotive Health	12.3	9.5	11.7
Pole Line Replacement	7.8	6.0	
Annual benefits of business applications / locomotive	10,043	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	20,261	23,088	18,380
Total cost of traffic control (US$ M)	90.4	103.0	23.4
Total cost of traffic control / mile of track	4,461	4,461	1,272
MGTM per year	385,933	402,526	172,693
Annual benefits of traffic control (US$ M)	189.6	197.8	97.5
Customer Service	112.0	116.8	66.4
Train Dispatch Productivity	6.2	6.5	7.5
Engineering Forces	19.7	20.5	6.0
Equipment	4.8	5.0	5.7
Fuel	8.6	9.0	5.9
Crews	38.4	40.0	6.0
Annual benefits of traffic control / MGTMs	491	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	330.5	350.0	311.1
Annual Benefits of ATCS (US$ M)	237.3	239.3	148.0

IRR 35%

NS.XLS

ATCS	NS	BN	CN
Safety			
# miles of track	14.721	23.088	18.380
Total cost of safety (US$ M)	205.5	191.0	256.6
Total cost of safety / mile of track	13.960	8.273	13.960
MGTM per year	196.492	402.526	172,693
Annual benefits of safety (US$ M)	9.2	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	2,010	2,340	1,599
Total cost of business applications (US$ M)	39.1	56.0	31.1
Total costs of business applications / locomotive	19.467	23.932	19,467
Annual benefits of business applications (US$ M)	53.3	23.5	42.4
WOR	38.7	8.0	30.8
Locomotive Health	14.6	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	14,721	23,088	18,380
Total cost of traffic control (US$ M)	18.7	103.0	23.4
Total cost of traffic control / mile of track	1.272	4,461	1,272
MGTM per year	196,492	402.526	172,693
Annual benefits of traffic control (US$ M)	110.9	197.8	97.5
Customer Service	75.6	116.8	66.4
Train Dispatch Productivity	8.5	6.5	7.5
Engineering Forces	6.9	20.5	6.0
Equipment	6.5	5.0	5.7
Fuel	6.7	9.0	5.9
Crews	6.8	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	263.4	350.0	311.1
Annual Benefits of ATCS (US$ M)	173.4	239.3	148.0

IRR 35%

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SOO.XLS

ATCS	SOO	BN	CN
Safety			
# miles of track	5,045	23,088	18,380
Total cost of safety (US$ M)	70.4	191.0	256.6
Total cost of safety / mile of track	13,960	8,273	13,960
MGTM per year	40,464	402,526	172,693
Annual benefits of safety (US$ M)	1.9	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	374	2,340	1,599
Total cost of business applications (US$ M)	7.3	56.0	31.1
Total costs of business applications / locomotive	19,467	23,932	19,467
Annual benefits of business applications (US$ M)	9.9	23.5	42.4
WOR	7.2	8.0	30.8
Locomotive Health	2.7	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26,541	10,043	26,541
3 year implementation			
Traffic Control			
# miles of track	5,045	23,088	18,380
Total cost of traffic control (US$ M)	6.4	103.0	23.4
Total cost of traffic control / mile of track	1,272	4,461	1,272
MGTM per year	40,464	402,526	172,693
Annual benefits of traffic control (US$ M)	22.8	197.8	97.5
Customer Service	15.6	116.8	66.4
Train Dispatch Productivity	1.8	6.5	7.5
Engineering Forces	1.4	20.5	6.0
Equipment	1.3	5.0	5.7
Fuel	1.4	9.0	5.9
Crews	1.4	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	84.1	350.0	311.1
Annual Benefits of ATCS (US$ M)	34.7	239.3	148.0
IRR 22%			

CN figures converted to US based on an average (weighted by the volume of $ converted)

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ATCS	SP	BN	CN
Safety			
# miles of track	12,143	23.088	18,380
Total cost of safety (US$ M)	169.5	191.0	256.6
Total cost of safety / mile of track	13,960	8.273	13,960
MGTM per year	165.365	402.526	172.693
Annual benefits of safety (US$ M)	7.7	18.0	8.1
Annual benefits of safety / MGTMs	47	45	47
3 year implementation			
Business Applications			
# of locomotives	2,064	2.340	1,599
Total cost of business applications (US$ M)	40.2	56.0	31.1
Total costs of business applications / locomotive	19.467	23.932	19,467
Annual benefits of business applications (US$ M)	54.8	23.5	42.4
WOR	39.7	8.0	30.8
Locomotive Health	15.0	9.5	11.7
Pole Line Replacement	0.0	6.0	
Annual benefits of business applications / locomotive	26.541	10.043	26,541
3 year implementation			
Traffic Control			
# miles of track	12,143	23.088	18,380
Total cost of traffic control (US$ M)	15.5	103.0	23.4
Total cost of traffic control / mile of track	1.272	4.461	1,272
MGTM per year	165,365	402.526	172.693
Annual benefits of traffic control (US$ M)	93.3	197.8	97.5
Customer Service	63.6	116.8	66.4
Train Dispatch Productivity	7.2	6.5	7.5
Engineering Forces	5.8	20.5	6.0
Equipment	5.5	5.0	5.7
Fuel	5.6	9.0	5.9
Crews	5.7	40.0	6.0
Annual benefits of traffic control / MGTMs	564	491	564
3 year implementation			
Total Costs of ATCS (US$ M)	225.2	350.0	311.1
Annual Benefits of ATCS (US$ M)	155.8	239.3	148.0

IRR 37%

1.1 - INTRODUCTION

The purpose of this report is to provide an introduction to Advanced Train Control System (ATCS), illustrate the functions and potential benefits of ATCS in freight railroad applications, and provide a guide to quantifying the benefits of ATCS for railroads interested in examining its applicability to their operations.

Two North American railroads have performed "business case" evaluations of ATCS. These two railroads are: Burlington Northern (BN), whose work on the Advanced Railroad Electronics System (ARES), a variant of ATCS, has been well covered in the railroad industry press; and Canadian National (CN), which contributed to the development of the ATCS specifications and now has several pilot installations under test. The discussion of benefits in this paper will rely primarily on BN and CN findings. However, some of the benefit areas described in this document have come to light since the business cases were completed and are not quantified.

ATCS is a system of technologies, and it includes many different capabilities covering a range of railroad functions. The benefits of ATCS to any railroad will depend upon which functional areas are chosen for implementation, how implementation is carried out, and how the capabilities of ATCS are used.

For example, ATCS can, through use of a digital radio data link and real-time train location information, serve as a train control system. The digital data link and on-board computer (OBC) can be used to enforce speed limits and movement authorities before they are exceeded. The same data link and OBC can be used to transmit work instructions to train crews, receive acknowledgment of completed work, or transmit locomotive diagnostic information in real time.

ATCS produces benefits in several areas. Many of these, such as fuel and labour savings, safety, and improved equipment utilization, are "hard" benefits in the sense that expenses are reduced or capital outlays are avoided. However, ATCS is above all a management tool which generates large amounts of detailed information about railroad operations. This information can be used to improve service quality, and the benefits of improved service are very substantial. Both BN and CN found that the service improvements made possible by ATCS will yield substantial increases in revenues. These revenue increases constituted a significant part of the identified benefits. Overall, BN and CN found the return on an ATCS investment to be in the range of 20% to 30%.

While some ATCS functions, such as work order reporting and locomotive health monitoring, may be implemented separately, there is a synergy if all the elements of ATCS are installed together. For example, the ATCS digital data link has sufficient capacity for train control, work order reporting, real-time locomotive health monitoring, and other functions as well. Alternative systems, such as cellular digital radio, may lack sufficient capacity and coverage for these functions, and with large volumes of messages, the cost of such technologies rapidly becomes prohibitive. Satellite communications systems have universal coverage but low (100 baud) data rates and high per message costs. Cellular has incomplete coverage, and uses a public access mode which is inappropriate for a vital system like ATCS train control, where message prioritization is a key element.

ATCS provides a unified framework for a railroad data system which supports functions as diverse as work order reporting and train control. It is a system whose parts can work together to provide an integrated whole, greater than the sum of the parts. Use of ATCS specifications by railroads ensures compatibility between the various ATCS functions, and compatibility with equipment installed by other railroads. Finally, the ATCS digital data link, even if initially installed only for functions such as work order reporting or locomotive health monitoring, provides capacity for expansion to full train control, enforcement of speed and authorities, train pacing and energy management, and many other functions. All can be supported simultaneously by the ATCS digital data link.

1.2 - DESCRIPTION

ATCS functions may be divided into three categories:

1) Safety
2) Business Applications
3) Traffic Control

Safety is exactly that: enforcement of speed limits and movement authorities to prevent accidents. It requires a digital data link, real-time train location, an on-board computer (OBC), and a display for the train crew.

Business applications use the digital data link and OBC, but do not require location and central safety software. They include locomotive health monitoring and work order reporting.

Traffic control functions require the same hardware as a safety system. To this must be added software for "tactical" traffic planning (meet/pass planning on dispatcher territories) and "strategic" (network) planning. The largest benefits of ATCS are associated with the traffic control functions.

These functions can be implemented separately or together. However, when the ATCS specifications are followed, all components can work together. This approach will permit a railroad to implement business applications first, for example, and later move to safety and traffic control.

Much of the benefit of ATCS, in both the BN and the CN analysis, was associated with the ATCS traffic control functions. Traffic control requires real-time train location data, and implies the existence of safety software for enforcing train separation and preventing conflicts. The synergy available once the digital data link and OBC were installed meant that the incremental cost of traffic control was relatively small, while the benefits were very large.

To understand the relationship of the various parts of ATCS, it is helpful to think of ATCS as a two-story house. The first story (Figure 1) consists of the ATCS Specification 200 data link, which is really the heart of any ATCS 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)

- 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

- locomotive engineer's assist which proposes throttle and brake settings to improve train handling

- car environment monitoring (eg. temperature, pressure, humidity) to reduce damage to lading.

These functions require a digital data link, but do <u>not</u> require real-time train location. However, they all benefit from the ability to send text messages to and from locomotives and other on-track vehicles.

Build the Data Link "Foundation"

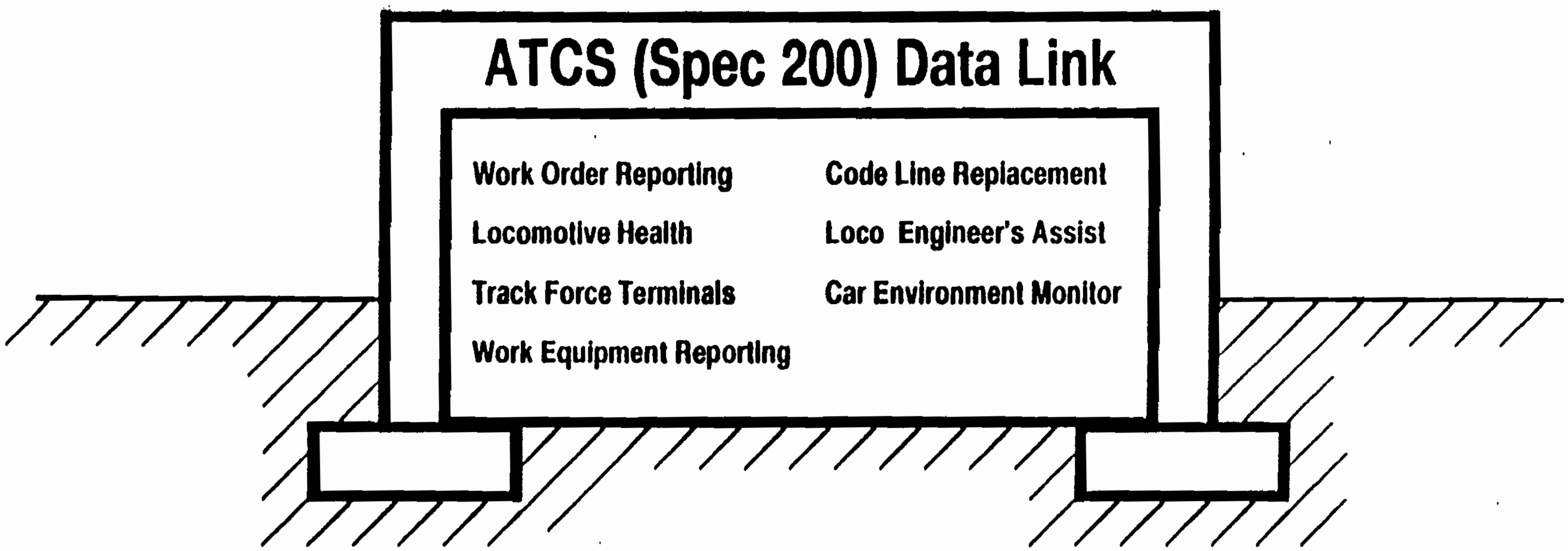

Figure 1

The second floor of the ATCS 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, track transponders, 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:

- enforcement of speed and movement authorities (through real-time position information and on-board authority enforcement)

- precision train location monitoring to optimize meet / pass planning (with OBC, odometers and transponders)

- 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)

ATCS also provides a set of industry standards for hardware and communications, insuring that any railroad adopting any level of ATCS will find its hardware compatible with that in use by other ATCS railroads.

1.2.1 - DESCRIPTION OF ATCS HARDWARE AND SOFTWARE

A full ATCS implementation will include:

- a digital, UHF-frequency data radio link between a control center and vehicles using the track (the Data Segment)

- an on-board computer on track vehicles, through which information can be transmitted using the data link (the Vehicle Segment)

- a real-time positioning system, which provides accurate location for track vehicles (the Control Segment)

Build the Central System "Superstructure"

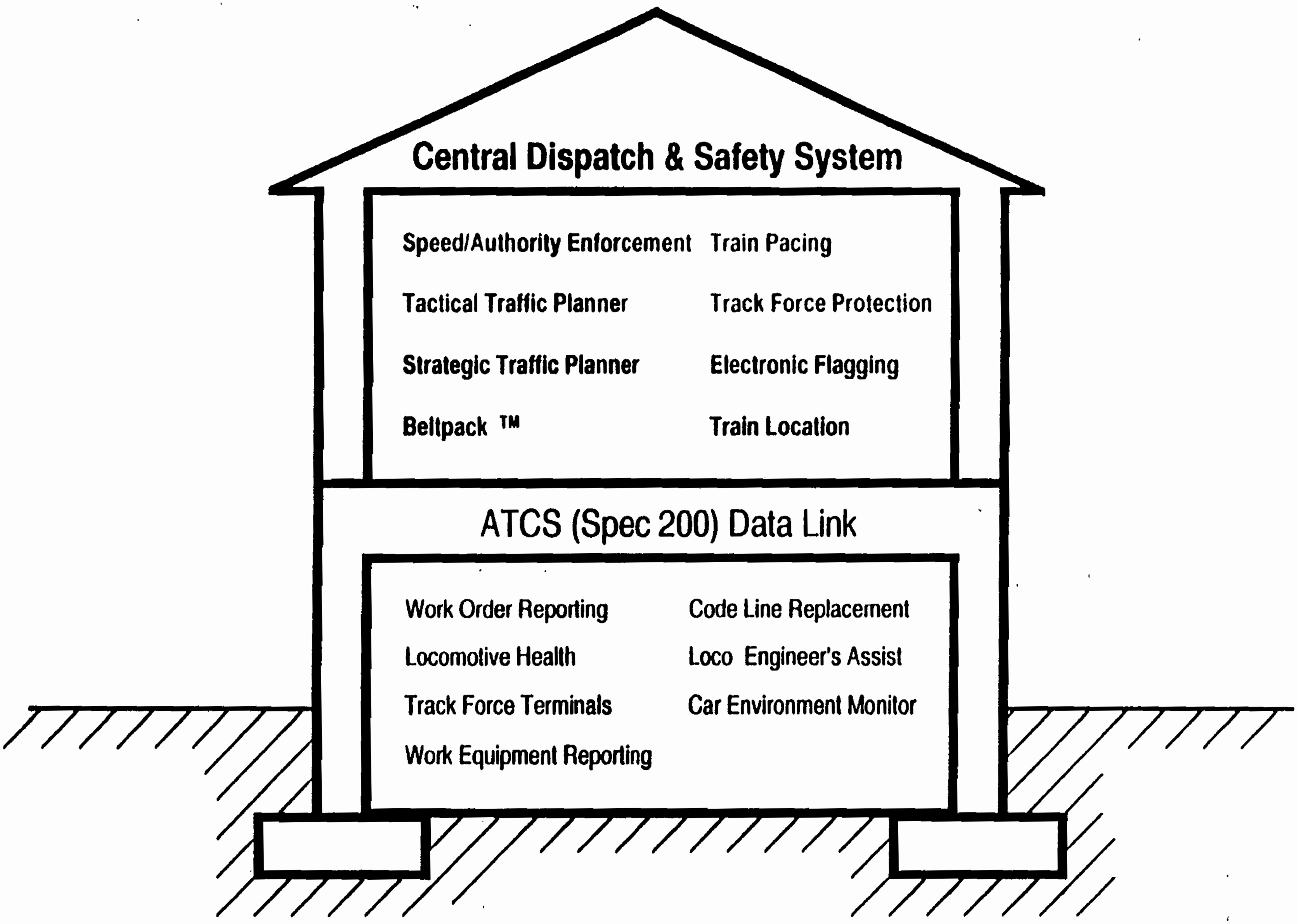

Figure 2

Some of the functions defined as the first story of the ATCS house require only the data segment, since the functions are administrative and do not involve train control. An on-board computer is not necessary for a work order system; a display will suffice. However, locomotive health monitoring will require some sort of on-board computer. Again, there is synergy since a single computer can perform multiple functions. It makes little sense to equip locomotives with entirely separate systems for work orders and health monitoring.

If train control and safety enforcement are to be provided, all three elements of ATCS are required.

ATCS functions are not limited to those shown in Figures 1 and 2. ATCS may include any other technology or application that:

- meets the ATCS specifications
- uses either the ATCS infrastructure or data produced by ATCS
- provides some sort of synergy when combined with other ATCS functions

ATCS has been described in great detail in the technical specifications themselves and in many publications. The following is a brief description how ATCS might function in a railroad environment.

The Data Segment

The ATCS specification 200 data link is the heart of ATCS, and is required for all ATCS functions, including those in both levels of the "ATCS house" shown in Figures 1 and 2. The radio network designed for ATCS uses six UHF channels which are exclusively available to railroads throughout North America. The UHF base stations in ATCS can be linked to a control center through a railroad's existing microwave and fiber-optic communication paths. Data radios at each site handle ATCS data.

The ATCS UHF radio system transmits digital data for locomotives, track vehicles, and wayside interface units to UHF receivers that access the existing communications network. Since the capacity of a channel assigned to transfer digital data is twenty times greater than that of a channel assigned to voice traffic[1], the use of ATCS should relieve some of the pressure for allocation of more radio frequencies to railroads.

The data segment can be used for the functions shown in Figure 1; it can also be used for the second story safety and train control functions in Figure 2. Digital radio is used to transmit movement authorities to the locomotive on-board computers (OBCs). It is also used to control powered switches through wayside

1 John Vanderhorst, "A Comparison of Voice and Data Link Communications on a Railroad: A Dispatcher's Perspective", Overland Park, Burlington Northern Railroad, 1991

interface units (WIUs). These units may also monitor manual switches, track integrity circuits, hot bearing detectors, dragging equipment detectors and slide fences.

Information shuttled from field to office and back must be switched properly to ensure that messages get to their intended destinations. The Cluster Controllers (CCs) and the Front-End Processor (FEP) perform these functions. An FEP at the control center routes all messages to the appropriate CC, where the messages are separated and routed to the correct train, MOW vehicle, or Wayside Interface Unit.

The Vehicle Segment

The Vehicle Segment consists of electronic equipment on trains and MOW vehicles that processes and displays instructions from and sends information back to the control center. This equipment can perform several functions.

1. Positioning

The most basic application of ATCS (shown in Figure 1) provides essentially the same functionality available in today's dispatching systems. But with central safety system and real-time location (Figure 2), the positions of vehicles on the railroad are known in real time and with great accuracy. Road locomotives, many switching locomotives, hyrail vehicles, and MOW equipment will carry on-board computers that calculate and transmit locations continuously. Position and speed information travels from the vehicle to the control center over the digital data link.

2. On-Board Computer

In a basic ATCS implementation, there may be only an On-board Display (OBT), which enables the train crew to send and receive text messages. But in a full ATCS implementation, an On-Board Computer (OBC) serves as the "brains" of the train. Information about the train consist (for example, number, type, weight and length of cars, set outs, and pickups), information about the track (for example, grade, curvature and topology), and information about schedule (desired arrival times) is available in the OBC.

The OBC may perform the following functions:

- Processing and display of Desired Time of Arrival and Estimated Time of Arrival at all significant event points on a train's route

- Calculating pacing speeds and throttle/brake setting recommendations for the engineer.

- Predicting and executing on-board enforcement before the train violates a movement authority

- Reporting train position to central dispatch

- Receiving movement authorities and providing information to the man machine interface display

- Sending releases of authorities to central dispatch

- Tracking train consist and crew information.

When the locomotive receives an authority, the OBC sends that authority to the on-board display. When the crew acknowledges the authority (if restrictive), it takes effect. The OBC then calculates the braking curve required for the train to stop before the authority runs out. If the engineer, after being alerted, continues to operate so as to cross that curve, the brakes automatically apply and stop the train.

The OBC also keeps track of the crew on duty and automatically records times of departure and arrival. This information assists in automating the crew pay process. The OBC also displays a list of setouts and pickups. This list can be dynamically updated as the train progresses, decreasing the lag between customer release of a car and railroad pick up, and expediting the distribution of empty cars to customers. By pressing a key on board, the engineer can verify that the scheduled work has been completed.

3. Train Control Display

When train control is selected as an ATCS function, each equipped locomotive will have a Train Control Display (TCD), and probably a separate work order display. The TCD will be a computer screen that provides the locomotive engineer with train status as well as command and control information.

The engineer will receive movement authorities, including speed limits, from the dispatcher, on the TCD instead of from voice radio track warrants, wayside signals, or traditional cab signals. An on-board computer automatically monitors and ensures compliance with movement authorities. The TCD has an "acknowledge" key for the engineer to acknowledge receipt of movement authorities.

It will be possible for the train crew to select a number of displays, including outstanding movement authorities, track bulletins, train consist, car set-out and pick-up instructions, special handling instructions, locomotive health information (from a locomotive diagnostic system, if installed) and any other information sent over the data link.

4. Track Forces Terminal

Locomotives will not be the only track vehicles with on-board equipment. Maintenance of Way (MOW) vehicles will be equipped with data terminals, over which they will be able to send position reports from the field to the Control Center and receive authorities to occupy tracks.

With the data terminal. MOW crews can procure track warrants without contacting the dispatcher (at some levels of ATCS implementation). To do this, the MOW crew uses the terminal to display the lineup of trains in the vicinity. The crew can then determine when the track will be unoccupied and use the terminal to request track occupancy for that time. The control center software checks the request for safety, and if it is safe, grants the authority.

Having a terminal on board the MOW vehicle and a digital data link also available allows MOW workers to send administrative data (e.g., gang time, machine usage and status, material usage and requirements, and production reporting information) to the railroad's Management Information System.

The Control Segment

The control segment of ATCS contains all the hardware and software necessary to perform real-time dispatching, traffic planning, dynamic scheduling, and information distribution tasks. Again, specific tasks to be performed will depend upon the level of implementation selected. At its simplest, ATCS prevents unsafe authorities, such as overlaps, from being issued. However, if real-time positioning and the central safety system are available, the information produced by ATCS can be used by automated dispatching and train-management software to optimize railroad operations.

The real-time location of a train is calculated by the OBC using information from two on-board odometers. The location calculated by the OBC is verified and reset (if necessary) based on information from transponders laid in the rail bed. There will be transponder interrogators on locomotives which query the transponder to transmit its identification. Each transponder identification corresponds to an exact track location. Between the OBC, odometers and transponders, the current position of the train is always known.

Since the locations of trains are known in real-time, computer-aided dispatching (in which a computer program is used to assist the dispatcher in managing train movements) can become computerized dispatching (in which a "best" dispatching plan is developed, presented to the dispatcher for review, and - with approval - automatically executed). Studies have shown that dispatchers make little use of computer aids, principally because the information they must use is often neither accurate nor timely, and as a result the dispatching plan is obsolete before it can be implemented. Real-time position information, combined with automated execution of a dispatching plan (automatic transmission of movement authorities, for example) can make computerized dispatching feasible.

At present, train movement authorities on both BN and CN are transmitted by voice radio in unsignaled and "block signaled" territory. Dispatchers prepare these authorities and read them to train engineers. With ATCS, dispatchers will prepare authorities in both signaled and unsignaled territories with the "point-and-click" capability of an advanced workstation or have them prepared automatically by the traffic planning software as described in the following sections. To ensure safety, the system will automatically check authorities for conflicts. Once issued, the authorities travel over a digital data link and are displayed on board the train or MOW vehicle. When on-board enforcement is provided (see Figure 2), authorities will be recorded by the OBC and checked against the actual progress of the train. When a train nears the limits of its authority, audible and visual warnings are provided to the train crew. If no action is taken by the crew, the OBC will stop the train.

ATCS also provides a dynamic headway capability, which has been associated with substantial increases in line capacity. Since the position, length, and consist of each train are known to both the OBC and to the central office, trains can travel as closely spaced as their braking capabilities allow. Functionally, the train control software will create a moving "window" of space around each train, representing the minimum safe braking distance. This window will change in size with train speed and with track profile.

The availability of real-time position information makes possible the use of complex and sophisticated software to optimize train operations. An ATCS railroad would use two levels of train control: tactical and strategic. Tactical traffic planners would assist dispatchers in making efficient meets and passes for trains in their territories. The strategic planner would optimize network operations, managing connections between trains, connections with other railroads and other modes of transportation, car fleet management, and locomotive distribution. The strategic planner would define objectives for each tactical planner to meet.

These planners, however powerful, will not work without a detailed service plan on which they can rely. An ATCS railroad would require a service design group, with authority to produce train and equipment schedules for the computerized planners to rely on. Service design is the vital process of tailoring railroad operations to customer needs. This is the first step required before any sort of computerized planning can be used.

In BN's scenario for ATCS train control, the service design group would supply an operating plan to the strategic traffic planner (STP). The STP would in turn supply targets for train performance to the Tactical Traffic Planner (TTP).[2] The following is a brief description of the functioning of these two planners on an ATCS railroad.

1. Tactical Traffic Planner

In an ATCS implementation, each dispatcher's workstation might contain a special set of software called the Tactical Traffic Planner (TTP). The TTP produces plans showing when trains should arrive at each point on a dispatcher's territory, where trains should meet and pass and which trains should take siding. Once the TTP prepares the plan, the dispatcher need only accept it. Then the computer-assisted dispatching system produces all authorities needed to execute the plan and send them to trains and MOW vehicles.

While the TTP eases dispatching; its main purpose is to keep trains on schedule. The TTP software defines "best" in terms of schedule and importance. It takes time from trains ahead of schedule and of less importance and gives time to trains that are behind schedule and of higher importance, thus minimizing the value of weighted "lateness."

Once the dispatcher accepts a plan, the TTP continues to monitor traffic and predicts which trains will not be able to meet schedules. If it predicts that trains will be late, the TTP alerts the dispatcher. The dispatcher then uses the TTP to develop a new plan and send new instructions to each train. If the TTP can find no plan that meets the schedule's objectives, the TTP alerts the Strategic Traffic Planner (STP), described next.

2. Strategic Traffic Planner

The TTP cannot function without knowing the schedule for each train. But although schedules note required arrival times at major stations, they do not include required arrival times at points in between, such as dispatcher territory boundaries or critical recovery points. Furthermore, day-to-day disruptions may require scheduling over several dispatchers' territories. That is the job of the Strategic Traffic Planner.

The Strategic Traffic Planner (STP) translates the printed schedule into real-time goals for daily system operations. The STP displays all trains operating on the system in colours and shapes that designate train type and lateness. The user sees detailed information about individual trains and yards by "pointing and clicking."

2 Michael E. Smith and Randolph R. Resor, "Real-Time Planning: Enhancing the Value of Advanced Control Systems in Railroading", presented at Annual Technical Conference, Communications and Signal Division, AAR, 1992

The purpose of both strategic (network) planning and tactical (traffic lane) planning is to enable railroads to meet schedules and delivery commitments to shippers. More efficient dispatching may also increase line capacity, a significant benefit to railroads - like BN -with severe capacity constraints in some areas. However, the greatest benefit of ATCS to the railroad industry is its potential for improving service.

1.3 - THE SIGNIFICANCE OF ATCS FOR NORTH AMERICAN RAILROADS

ATCS is a management tool as well as a train control system. The benefits of ATCS implementation depend on how it is used to manage a railroad. Analysis conducted by both BN and CN found the largest benefits to be in "customer service" or "revenue enhancements". In both cases, the result was the same: availability of real-time information on train movements and crew activities would enable the railroad to better manage service, improving reliability and responsiveness to customer needs.

Other substantial benefits were identified as well. BN projected a large improvement in equipment utilization. Safety improvements (resulting from a major reduction in human factors accidents) were forecast. Both railroads identified improvements in locomotive availability as a result of the use of real-time health monitoring. Fuel savings in the range of 2% to 6% were projected.

While the safety benefits were not large from an economic standpoint, the elimination of most human factors accidents is certainly important for railroads and is of interest to governments and regulatory bodies. ("Human factors" accidents are those resulting from failure to obey a warning device - passing a red signal, for example). On-board enforcement of movement authorities should virtually eliminate collisions between road trains. A recent FRA study showed that a test group of engineers using an ATCS display had no speed violations, while the alternate groups had several.[3] In addition, the on-board computer will perform other functions. For example, it will interact with the central traffic planner to minimize fuel consumption and intra-train forces, subject to schedule constraints.

A recent study indicates that ATCS will offer a level of safety that is higher than that of any alternative control system[4]. Current North American practice in train operations is to use two crew members on each train, who are supposed to "call" signal indications to each other. There is no enforcement of signal authorities in most cases; compliance depends on the train crew. In Europe, by contrast, one-person operation is common and a variety of automatic safety features are used to

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3 George I. Kuehn, "Advanced Train Control System Evaluation", prepared for the FRA, October 1992

4 Dr. W. J. Harris, "ATCS and Train Control Systems - A Status Report", prepared for the AAR, Feb. 21, 1993

stop trains which violate movement authorities. There is no statistically significant difference in accident rates between these two systems. Enforcement occurs only after an authority is violated (by penalty brake application or disciplinary proceeding).

ATCS, by contrast, enforces movement authorities predictively rather than reactively. The OBC continuously projects train location and speed at a time one minute in the future, and determines if the control strategies being employed by the engineer will keep the train in compliance with speed limits and movement authorities. If they will not (if either the speed limit or limit of authority will be violated), the train crew is alerted. If no corrective action is taken, the OBC will stop the train -- before an authority violation occurs rather than after.

The safety improvement is not limited to train crews. ATCS provides better protection to track forces by preventing trains from moving into work blocks.

The ability of ATCS to control and predict train movements with greater precision will greatly increase the predictability of work/rest cycles for train crews. More regular work hours, and more advance notice of work assignments, should produce a better rested and safer workforce. Indeed, BN presentations to train crews on the capabilities of ATCS were enthusiastically received. Improvements in crew scheduling, reductions in initial terminal delays, and more regular assignments will benefit railroad management as well, by reducing both costs and the risk of accidents.

While it is possible that regulatory pressures will drive the railroad industry to adopt ATCS for safety reasons, the economic attractiveness of the technology lies in large part in its ability to improve service quality. Today there is a great deal of talk about "total quality management" in the railroad industry. While cost-cutting continues to produce improvements in railroad financial results, there is a general recognition of the need to improve service. Implicitly, programs to improve service quality assume that some additional revenue will be obtained from the customer -- otherwise, why spend the money on quality? Despite this, railroads have faced relentless price pressure from competitors since deregulation. It is reasonable to expect some proof that improved service quality might in fact produce additional revenue.

Two studies sponsored by BN attempted to quantify the value of service in a railroad environment. They both found a very significant relationship between price and service quality (service being defined as delivering the shipment where and when the shipper wanted it). The two studies used somewhat different analytic approaches, and they produced somewhat different results. However, both indicated that improvements in rail service quality would produce revenue increases.

Based on these studies, it seems reasonable to postulate that improved service has some value. The problem for railroads is that improving service can be costly. The industry can no longer afford to have an agent at every station, a sales force on the road, and demurrage clerks to check every car released by a customer. However, improvements in service are imperative if railroads are to retain (much less increase) market share. The BN and CN business case analyses suggest that ATCS is also a cost-effective way to make the needed service improvements. If the revenue/service relationship is as strong as the BN's studies suggest, ATCS should produce a large return for the railroad industry.

2.1 - OVERVIEW OF THE BUSINESS CASE - BN

BN began development of ARES, a proprietary control system, in 1982, about the time the AAR began preparing specifications for ATCS. BN chose a different method of train location than the AAR, using the Global Positioning System (GPS) rather than transponders on the track. BN also used a VHF data radio link instead of UHF, which is the ATCS standard. The only reason these differences are mentioned is that the costs in the BN business case are based on this scenario. However, the functions of BN's system are very similar to those of ATCS. Both systems use on-board computers and digital data radio communications. Neither system uses satellites for communications.

BN's plans for ATCS included train control as well as work order reporting and locomotive health monitoring. It provides:

- enforcement of movement authorities
- data radio
- equipped engineering vehicles
- train handling assist
- local tactical traffic planning
- central safety system
- train pacing

On light-density branch lines, BN planned to install a minimum of wayside equipment. On portions of the railroad already equipped with CTC, switches would be remotely controlled by BN's ATCS. Thus, BN's implementation scenarios resembled CN's.

Work order reporting (WORS) and locomotive health monitoring (LARS) were both evaluated as add-on systems to the basic ATCS package. WORS was designed to work with the BN's Train Situation Indicator (TSI), which does not have a keyboard. LARS was designed as a separate diagnostic package, with a separate computer to monitor and record "exceedences". Both WORS and LARS, if implemented, would use the existing digital data link to transmit information to and from the central control office.

The BN benefits analysis will be discussed in a later section, but it is worth noting here that BN did not conduct a detailed benefits assessment of WORS. Because the benefits were expected to be small, it was not investigated in much detail. LARS showed a return adequate to justify its installation as a part of BN's ATCS, but not as a stand-alone system.

2.2 - OVERVIEW OF THE BUSINESS CASE - CN

In the CN business case, the two strongest projects in the first story are WOR and locomotive health monitoring. Both had sufficient return to be considered as building blocks and to be implemented before train control. However, neither project had enough payback to install data radio communication across the system. WOR was to be installed in industrial areas and supported equipping about one third of the locomotives and about one quarter of the data radio base stations. Locomotive health monitoring supported equipping the rest of the mainline locomotives with data communications and no additional data radio base stations.

Several other functions in the first story provided benefits for CN; track forces terminals, code line replacement, locomotive engineer's assist. However, they did not provide enough benefits to support themselves on an individual basis. These features (although able to function on the first story), were included in the second story in the business case.

The CN second story added the following components and functionality to data radio and the applications already covered in the first story;

- central safety system,
- data radio (in mainline areas not yet equipped),
- equipped engineering vehicles,
- train handling assist,
- local tactical planner,
- train pacing,
- full train control with train location, transmission of authorities, automatic release of authority, speed and limits enforcement, other authority information and automatic alert of an emergency stop.
- WIUs for switches, cross-overs, etc. that are currently dual controlled.

Although the second story is dependent on the central safety system, more than half of the benefits are dependent on the train location feature, the local tactical planner and the resulting improvement in run time these provide. This has implications in terms of how many locomotives are equipped and whether track forces are equipped or not.

Every locomotive that is not equipped for train location and goes on the mainline will reduce the benefits of ATCS since it will require a larger envelope than ATCS-equipped locomotives and would require manual entry of its location information. This will degrade the performance of all other trains on the same section of track. This led to the conclusion that locomotives either had to be fully equipped or would need to be restricted to non mainline territory. Since the locomotive is such an expensive asset, it was anticipated that it would be cheaper to fully equip the locomotives for train control rather than restrict them to specific areas and reduce the utilization of locomotives.

Similarly, if track force vehicles are not equipped, there is also a reduction in the run time and reliability improvements. To prevent this, at least one track force vehicle in each gang is equipped.

The following rules of thumb were used for the ATCS business case:

Signaled territories will be equipped with all the functionality of the second story except Beltpack ™. Locomotive health monitoring, TFTs, train handling and data transmission of authorities are also included from the first story. These tracks are already equipped with remote controlled switches, broken rail protection and other track detection devices.

Non-signaled territory with 2-3 or more trains per day are also equipped with the same functionality. However, they do not generally have remote controlled switches nor broken rail detection.

All other territory remains basically as it is today; a central system to prevent overlapping authorities with these authorities delivered to the train crew and field forces over voice radio.

There are two major exceptions to this. First, there is about 200 miles of non-signaled territory that is sufficiently busy to warrant an upgrade to remotely controlled switches. Second, territory that has very high levels of traffic (typically commuter areas or dense industrial areas) will not be equipped with ATCS in the first pass (ATCS-free zones). The reasoning is that these areas are very densely signaled now to cope with the traffic so the benefits on this territory will be less than on other territory and they will be the most expensive to equip because of the number of locomotive packages and WIUs that would be required.

All locomotives that travel on mainline or major branch lines will be locomotive health monitoring and ATCS equipped. Low and medium horsepower locomotives that service customers in industrial areas will be WOR equipped. Locomotives that are restricted to yards or ATCS-free zones will not be equipped.

Build the Data Link "Foundation"

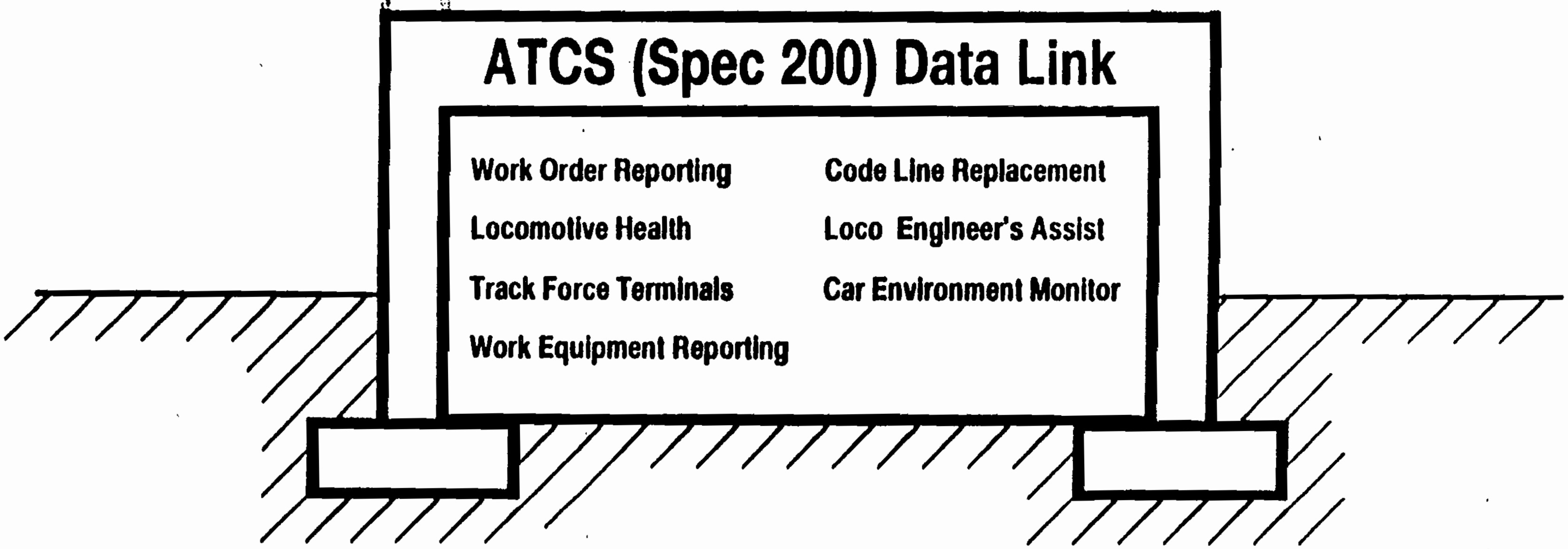

Figure 1

3.1 - BENEFITS - FIRST STORY

All the first story benefits are enabled by data radio communication. The functionality includes WOR (work order reporting), locomotive health, track force data terminals, work equipment reporting, transmission of authorities, code line replacement, locomotive engineer's assist, car environment monitoring and loss and damage detection.

Other ATCS functionality (eg. train pacing) can be added on, but is not presumed to be present. These benefits are not dependent on the central safety system, train location, local tactical planner or other ATCS functionality.

They all require the data radio hardware; locomotives (track forces vehicles, work equipment) equipped with MCP, data radio base stations, the central systems including FEP and CC, data radio software and the application software. For pole line replacement, a receiver is required at control points. If vital relays are to be replaced, then WIUs are required to control the switches. For locomotive engineer's assist, car environment monitoring and loss and damage detection, sensors are required in the cars. Locomotive health monitoring and work equipment reporting also require sensors to measure key data while the equipment is running.

3.1.1 - WOR (Work Order Reporting)

<u>Description - WOR (Work Order Reporting)</u>

Work Order Reporting includes transmitting the work to be done to a train (or local or yard assignment) crew and their reporting back the work that they did. Assigning work to a specific crew or distributing the work done to systems and individuals that need to know about it would either be included in WOR or closely interfaced with the WOR system. It could easily be expanded to include other functions such as inquiries on the status of equipment and traffic or the reporting of other information (eg. customer track inventories).

A customer releasing a loaded car is probably the most common example of where WOR is effective. The customer would call the CSC (Customer Service Center) with the car number to be released and the appropriate waybill information. The CSC clerk would enter the information into WOR (or an interfacing system). The WOR system would identify which industrial switchers serviced the customer and identify which switcher is the next available one. It could be a switcher that was out on the road but had not already passed the customer siding; or an assignment that had passed the customer siding, but could pick up the car on the way back; or an assignment whose crew had not yet reported for work. The WOR system would also transmit the work to be done to the train where it will be listed on a computer. When the crew completes work, they will enter the work done into the

WOR computer on the locomotive. WOR will send this information back to a central computer where it will be distributed to systems such as traffic control and yard planning.

WOR uses the ATCS data radio system to communicate between the central location and the trains, locals or yard assignments. A scaled down version could use cellular phones or voice radio for communications. The advantage is that it would be cheaper to set up this sort of system. The disadvantages are: 1) there are more sources of error (mishearing the information or writing it down incorrectly), 2) the timeliness of the information is dependent on manual processes (if the clerk who needs to act on the information is too busy, the information will not get passed on right away), 3) it requires more effort to make the manual process work. By contrast, with data radio the primary person need only to enter the information and it is automatically delivered to the person who will do the work or who needs the information.

Requirements - WOR (Work Order Reporting)

In terms of equipment, WOR requires:

- locomotive equipped with MCP (Mobile Communication Package), OBT (On-Board Display 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.

Software would be required to support the functions described above:

- software to select the appropriate crew for each work order
- software to send the work orders to the crews via the base stations
- software to receive the work orders on the train
- software to enter in the work done by the crew
- software to send information on the work done back to the central computer via base stations
- software to distribute the information to the appropriate systems such as traffic control and yard planning systems.

Most of this hardware can be used by other ATCS applications. The MCP, OBT (or OBC), display, keyboard, wire harness, power supply in the locomotive; the data radio base stations; the FEP/CC; leased lines; can be used for all other ATCS functions. The only exception is the OBT which can not be used for train control but could be used for Locomotive Health Monitoring, Train Handling Assist, etc.

However, locomotives that are equipped for WOR (eg. those that service customers) are not necessarily the ones that would be equipped for train control, locomotive health monitoring, etc. (eg. those that travel on the mainline). Nor will the base station locations appropriate for WOR necessarily have enough range to be used for train control, etc. Even with this caveat, there is likely to be significant synergy or cost reductions because several applications are handled by the same equipment.

Benefit Areas - WOR (Work Order Reporting)

The most tangible benefit area is the reduction of the clerical staff who currently report on the activities of WOR equipped assignments. The information will be entered directly by the crew instead of being documented by the crew, then entered later by clerks. Support services for this clerical staff (eg. supervision, training, facilities) may also be reduced.

WOR will also improve the quality of the data used by the railway for operating decisions. Under current operations, the crew writes down the work done on paper but they are not working in conditions that lead to clear, easy-to-read documentation. Rain, snow, wind and the movement of a train all contribute to potential mistakes. The clerical staff enter this information, but are not often able to question the crew if a letter or number is hard to read. When the crew enters the data directly into WOR, there are fewer sources of error. The crew can still make a mistake, but the clerks are not present to add a second source of errors. As well, the input validation checks will be sent to the crew who are on the spot and can check up and fix errors right away. With more accurate information, there is less need for clerical effort to correct bad car information. Additionally, with the information the crew enters, switches that are now being done but not charged for will be identified by the change in location of the cars. This will allow us to bill for switching work that is not currently captured.

In addition to better response and more timely pick up of cars from customers, a real-time WORS may increase demurrage collected by railroads. Demurrage is payment by a shipper for excessive car detention time. After a certain number of free hours or days, the railroad is entitled to collect a payment from a shipper for each day a car is held on the shipper's siding. This payment is intended to discourage shippers from using railroad equipment as additional warehouse space.

When a shipper releases a car for movement, demurrage stops as of the date and time the customer release is recorded by the railroad. However, it may be hours or even days before the railroad actually sends a local switcher to move the car. Thus, some shippers find that, if they release a car on a Friday afternoon, knowing that their switching service works only five days a week, the car is likely to be pulled no sooner than Monday. Thus, on occasion, a car will be released even if not fully unloaded, since the shipper can count on a long delay between release and actual pull.

In past years, railroads employed demurrage clerks whose job it was to physically verify, by inspection, that a car was unloaded when a customer released it for movement. Today, these jobs have been eliminated. While it is difficult to quantify the amount of demurrage being lost by railroads, it seems reasonable to assume that, if customers perceive that the railroad responds more quickly to release requests, they will be more careful to release only cars which are actually unloaded. Railroads may collect additional demurrage as a result.

WOR will provide more accurate information and the information will be available as soon as the crew enters it - hours earlier for some of the pickups. This will be available to the yard for planning and operating decisions that are now made either without the information, or much later as the information becomes available. This is expected to improve the productivity of the yard work by reducing the number of times a car is moved unnecessarily, by avoiding a crew stopping to do work that has already been done, by having advanced warning of unexpected work, by avoiding crews waiting for information that is not yet entered in the system and other similar situations. This improvement in yard productivity will reduce a few yard assignments and potentially some locomotives. Unfortunately, this will only be gained where there are sufficient crews to spread around the work. For example, with a 5% improvement in yard productivity, crews can only be reduced if there are at least 20 crews in one yard. But there are several savings that result from yard productivity improvement without needing a large crew base to achieve them. There should be a reduction in crew overtime, ITD (Initial Terminal Detention) and FTD (Final Terminal Detention) because crews spend less time waiting for instructions or doing unnecessary work. Similarly, there should be some fuel savings, car hire savings and a reduction in the capital cost for equipment because less time is spent in the yard or doing unproductive work. Lastly, train delays caused by terminal problems will be reduced.

For well integrated operations, the effects of accurate and timely information will flow out and impact more than just yard productivity. As an example, up to date information on car pickups and setouts will provide accurate car inventories which, in turn, will improve the reliability and efficiency of trip plans. Car management will also be able to allocate cars more effectively. If they know that cars have just been released in one area, they will not request empties to be moved from another area. Similarly, the CSC can also take advantage of the information to assign cars to customer car orders more efficiently.

Some customer releases will be picked up by an earlier assignment because the work request is automatically sent to the appropriate train or assignment. The delivery of the work order will be quicker than the manual processes now in place. In manual operation, the work order may not be delivered to a train or assignment if it has already left the yard. Automatic delivery of the work order will reduce the run time for some cars. It may also increase the reliability of the transportation too. Both these will lead to a reduction in the payment of penalties for poor service that have been written into some contracts with customers. As well, it opens the possibility of getting more business because the service is improved (or preventing a loss of business).

Quantifying Benefits - BN - WOR (Work Order Reporting)

BN performed no detailed evaluation of the benefits of a work order reporting system. WORS was evaluated only for its impact on clerical employees. It was concluded that BN could save from 2% to 50% of the labour currently expended in processing work orders. The estimated annual labour cost is currently $40 million. Therefore, BN projected savings of between $1 million and $20 million in clerical labour from implementation of work order reporting as part of BN's ATCS.

Quantifying Benefits - CN - WOR (Work Order Reporting)

CN estimates that WOR will achieve a higher return in industrial areas than across the network. Car load traffic requires the most effort in a yard and is most affected by the WOR productivity gains. It was estimated that each WOR-equipped assignment will save 1.5 hours of clerical effort. The work required for trains that don't service customers is generally known as soon as the train leaves the preceding yard and can be taken into account in the planning for the next yard long before it arrives. Unit trains do not require the same yard resources and don't change their consists en route. Container or intermodal traffic does require a higher level of effort, but pickups and set outs are generally handled by trucks or in terminals or wharves instead of in the rail yards.

Previous yard productivity initiatives have produced improvements of up to 10%. Based on the amount of information that WOR will provide, a 5% improvement in yard productivity is estimated.

As well, some industrial areas would cost less to equip than others. A yard with dedicated engines used by two or three assignments per day to regularly service customers will handle a lot of car load traffic with each equipped locomotive. However, if a customer is serviced by assignments with high horsepower locomotives, then either most high horsepower locomotives need to be WOR-equipped or the high horsepower locomotives need to be dedicated to a specific area. CN proposed to WOR-equip only the low and medium horsepower locomotives to avoid a captive high horsepower fleet. This adds up to about 546 equipped locomotives and around 268 portable OBTs.

Based on this rationale, CN is implementing WOR initially in the high payback industrial areas. It is planning to equip low and medium horsepower assignments that regularly service customers. About 90 data radio base stations will be installed. These provide coverage for the industrial areas only. It is expected that as ATCS is implemented, additional areas will become more attractive to equip. The total costs for WOR are $US 37.1M; the total annual benefits are $US 30.8M. The details of these calculations follow.

Data Entry Clerical Reductions:

- CSC Managers estimated a reduction of 57 clerks
- salary $US 44,225 (including overhead)
- training, PC replacement and space per person $US 3,189
  - full year savings about — $US 2.7M

Accurate Data:

- save 5 clerks who correct errors across the system
- salary $US 44,225 (including overhead)
  - full year savings about — $US 0.3M

- estimate additional 2% of switches will be billed at $US 85 per switch
  - full year savings about — $US 2.7M

Yard Productivity:

- 5% yard productivity improvement
- 4 assignments reduced system wide (few yards have 20 or more equipped assignments)
- 3 employees per assignment at $US 61,447 per person (including overhead)
  - full year savings about — $US 0.8M

- crew overtime about 15% of crew salaries
- crew salaries for 363 assignments * 3 people per assignment * $US 61,447 per person (including overhead)
  - 5% reduction in overtime is a full year saving of about — $US 0.5M

- fuel savings at 5%
- equates to 290 idling hours per day at $US 7.52 per hour
  - full year savings about — $US 0.8M

- car hire costs reduced by 3.3%
- car hire costs $US 61.1M (1991)
- 63% of traffic carried by WOR-equipped assignments
  - full year savings about — $US 1.3M

- 3.3% capital cost avoidance savings for cars
- 68,000 CN cars on line
- 88.7% of traffic originates on CN lines
- 63% of traffic carried by WOR-equipped assignments
- long term capital cost of a car $US .72 per hour
    - full year savings about $US 7.9M

- train delays based on records of causes and duration of delays
- a 5% reduction of delays due to yard problems (eg. terminal congestion, late makeup, remarshaling) works out to 6,580 delay hours per year
- cost of a delay hour $US 94
- 63% of traffic carried by WOR-equipped assignments
    - full year savings about $US 0.4M

- reduced ITD/FTD based on 1% of total ITD/FTD costs of $US 21.3M
    - full year savings about $US 0.3M

Customer Satisfaction:

- contractual penalties avoided
- freight rail revenue of $US 2.8B (1989)
- 63% of traffic carried by WOR-equipped assignments
- estimated that 20% of the revenue will have contracts with penalties
- estimated that 1% of the penalties are paid because of poor performance
- estimate a 20% improvement due to WOR
    - full year savings about $US 0.7M

- increased traffic due to improved service
- freight revenue impacted by WOR-equipped assignments $US 659.0M (where the customer places a high value on reliability)
- revenue and cost increase based on BN price elasticities
    - increase in profit $US 12.3M

Benefits Not Quantified:

CN has no car scheduling system and made no estimates for the impact WOR would have on improving the information and benefits of a car scheduling system nor any initiatives that depend on scheduling (eg. seamless transportation, ISM).

Quantifying Benefits - others (UP, CSX, NS, CP) - WOR (Work Order Reporting)

Little information is publicly available about studies of work order reporting on other railroads. Union Pacific has implemented an ATCS-type work order reporting system and has claimed savings of $30 million per year. These savings appear to be largely due to elimination of clerical positions.

CSX performed a detailed evaluation of real-time work order reporting in 1991. While CSX chooses not to make the results of this study public, it is useful to note some of the benefit areas that were identified for a CSX WORS application:

- reduced inbound yard time (through provision of real-time consist information)

- reduced time from customer release to pull (demurrage savings, car day savings)

- reduced outbound yard time (through pre blocking of at least some cars on local freights)

- clerical savings.

Several railroads, including Conrail, CSX, and Norfolk Southern, have pilot installations of WORS under test. Conrail and CSX have chosen non-ATCS systems, since they are conducting only limited tests of the concept. NS is testing a fully ATCS-compatible system very similar to that implemented by UP.

It may be that the largest single benefit of WORS is in improved customer service. Union Pacific indicates that the volume of data sent to and from its locomotives far exceeds projections. This appears to be due, in part, to train crews' interest in the system and in their use of it to provide information to customers. For example, UP crews can check the status of a customer car request, determine the location of the inbound car, and (through UP's car scheduling system) provide the customer with an arrival date. Crews are also able to react quickly if a customer receives fewer cars (or more) than ordered. Timely input of this information to the car scheduling system increases the efficiency of car use.

WORS will be of greatest benefit to railroads with a large volume of carload freight traffic. Real-time work order reporting is of less value for intermodal and unit trains, since train consists change only infrequently. Therefore, all benefit analyses for WORS have assumed that work order benefits, including clerical savings and car day savings, are available only for carload freight.

3.1.2 - Locomotive Health Monitoring

Description - Locomotive Health Monitoring

Locomotive health monitoring involves transmitting information about a running locomotive back to a central location where it can be accessed and analyzed to detect developing problems.

Take the case where there is a problem with oil pressure in the locomotive. It will cause no immediate problems but over time it could lead to a locomotive shut down. The gauge is in the engine room so it is not routinely monitored (whenever the engine is started, the gauge would be checked for movement, but this does not occur frequently, especially during the winter). Locomotive diagnostic sensors would detect the problem with the oil pressure and open up the following options; 1) sending a service truck out to the locomotive, 2) servicing the locomotive at the next shop, 3) checking for clogged oil filters next time it's in the shop, 4) monitoring that locomotive more closely, 5) getting another locomotive ready to replace this locomotive, or 6) logging the information only.

With respect to the timeliness of information, locomotive health monitoring can be linked to the data radio system and send information to the central location in real time, the information can be stored on the locomotive until it is down loaded when the locomotive arrives at a shop or there can be some data radio stations a few hours out from the locomotive shops where data is transmitted to central before the locomotive arrives. There are advantages to having the information available real time, but of course the additional data radio base stations make it more expensive. Some problems develop quickly and these are more likely to be detected with a real time system. Also, with real time data, Operations has more time to act (eg. get a replacement locomotive in place). This is just another way of saying that the impact of any problem is reduced when real time information is available and this will improve the service that is offered.

Requirements - Locomotive Health Monitoring

Hardware required for locomotive health monitoring:
- locomotive sensors
- locomotive equipped with MCP (Mobile Communication Package), OBT (On-Board Display or OBC (On-Board Computer)), display, keyboard, wire harness, power supply
- data radio base stations
- FEP/CC (Front End Processor / Communications Controller)
- central system
- communication between the data radio base stations and FEP/CC.

Software would also be needed to:
- convert raw sensor data into a meaningful format
- analyze sensor data to identify actionable situations
- show appropriate data to the locomotive engineer
- send information about the locomotive back to the central computer via base stations
- send information about the locomotive to other systems such as locomotive distribution, locomotive maintenance, locomotive utilization and locomotive fuel systems.

As with WOR, the majority of the hardware can be used for both locomotive health monitoring and other applications. Specifically, once locomotives are equipped with data radio, any system that needs communications (eg. information about crew work hours) can be implemented less expensively because the communication infrastructure is in place.

One of the potential drawbacks of locomotive health monitoring is that the additional information may be used inappropriately. For example, if the locomotives are sent to the shop every time a sensor detects a reading out of tolerance, then locomotive availability is very likely to suffer. One way to avoid this is to accumulate information about the time to failure, cause and effect relationship between sensor reading and failures, and the seriousness of failures before changing the shopping criteria.

Benefit Areas - Locomotive Health Monitoring

The basic benefit of the locomotive diagnostic information is that more is known about how a locomotive is running. This will benefit both Motive Power who are responsible for keeping the locomotives in good repair and Power Control who are responsible for having the locomotives in the right place to move traffic. For Motive Power it will reduce the amount of time it takes to diagnose a problem. Currently, some of this information may be available from conversations with the engineer, tests (eg. checking for traces of silver in the oil) or from event recorders, but it is unusual for Motive Power to have all the information provided by locomotive health monitoring.

Secondly, with more accurate diagnosis, the problem is more likely to be fixed the first time. This will reduce the number of failures and therefore the costs of fixing the problem twice, the cost of not using the locomotive while it is being repaired a second time and reducing the costs incurred when locomotives fail on line (eg. delay to cars, extra fuel, crew and locomotive to pull the traffic, etc.).

As well, with information about developing problems, decisions can be made to prevent the failure by fixing it before putting the locomotive in service and therefore avoid delaying traffic or fixing it before it becomes more serious and therefore more costly to fix. This may be difficult to balance because fixing too many potential failures will cause problems (too many locomotives in the shop) and fixing too few will cause problems (delays to traffic).

Some roads currently use load box testing to verify that they have eliminated a problem. This involves setup time to hook up the locomotive to the load box and the time to check out the results. Locomotive health monitoring will provide the load box information without the need for setup time. The road can either run the locomotive in the shop to get the information while the locomotive is still available, or can release the locomotive and monitor the locomotive health information as it runs over the territory.

There are also advantages for Power Control in the locomotive dispatch procedures. Currently, they take into account which classes of locomotives are most fuel efficient and use the information when choosing locomotives for service. With locomotive health monitoring, the information is available locomotive by locomotive and further fuel savings are possible. The same information could also be used to decide which types of locomotives should be purchased.

Monitoring fuel usage is also expected to discourage theft. Railways use a huge amount of fuel which is accessible and useful (in diesel automobiles, trucks and recreational vehicles). Without information about how much fuel is burned in locomotives, there is no real way to verify the amount of theft, but estimates range from 0% to 6%. Because locomotive health will monitor consumption, people will be less likely to risk non-authorized use of fuel.

When the locomotive failure rate drops low enough, fewer "extra" locomotives are needed in case one breaks down. Some traffic may be time sensitive enough to warrant an additional locomotive to ensure delivery even if there is a failure. As there will be fewer locomotive failures, the number of locomotives that are kept in the yard to replace failed power can be reduced.

With real time monitoring there is more time to act. For example, if a problem is detected on line, arrangements for a replacement locomotive can be initiated now, not in three hours when the failure actually happens. This will cut down on the impact of the delay by up to three hours.

<u>Quantifying Benefits - BN - Locomotive Health Monitoring</u>

BN's Locomotive Analysis and Reporting System (LARS) consists of a diagnostic package, a wiring harness, and an on-board computer (the train control computer can be used for this function). LARS monitors a number of locomotive functions, and the information provided by LARS can be used in a number of ways. For example, at the lowest level LARS information may only be used as an aid when a locomotive is shopped for regular inspection or for other reasons. On the other hand, an advanced diagnostic software package might be used to monitor sensor readings and attempt to anticipate problems.

To quantify the relative importance of various parts of the LARS package, the BN study examined four variants of the system, LARS 1 through LARS 4. LARS 1, the base case, made use of health monitoring simply as an aid in inbound and outbound inspections of locomotives already scheduled for shopping. LARS 2 used the digital data link to provide real-time component status when on-road failures occurred. LARS 3 assumed that the on-line data would be used to diagnose the locomotive before it entered the shop. Finally, LARS 4 was assumed to use information from the advanced diagnostic process (not yet developed) to bring units to the shop before failures could occur.

LARS 2 was felt to represent the most realistic near-term scenario for use of diagnostic information. Therefore, a simulation model was constructed to determine the effect of LARS 2 locomotive monitoring on train delays, labour hours for repairs, and "bay hours" or total hours of locomotive shop time. Results of the analysis were as follows:

- Avoidance of 1.537 train delay hours through avoided failure (20% of the locomotive-causes train delay hours):

  $307,000 @ $200 per train hour of delay

- Savings of 123.288 locomotive hours through reduction in repair time (9% of the locomotive out of service hours):

  $1,849,000 @ $15 per locomotive hour

- Savings of 118.935 "bay hours", hours of shop space (9% reduction in required shop space):

  $3,568,000 @ $30 per bay hour

- Savings of 144,449 labour hours (10% of the total locomotive labour hours):

  $3,756,000 @ $26 per labour hour

Total savings to BN from the use of LARS 2 was therefore calculated at $9,480,000 per year. The total savings was about 5% of BN's locomotive maintenance budget. This was felt to be a conservative number, since it is probable that the actual BN data from which the simulation was developed tend to understate maintenance activity.

BN also found the value of real-time, continuous diagnostic information to be very high. LARS 1, in which information was assumed to be available only when a locomotive entered the shop, was of very limited value.

LARS development has continued since the 1989 business case was completed. A comprehensive graphics package now provides easy-to-interpret readouts of vital systems for any LARS equipped locomotive on request. In addition, histories can be provided for the minutes (or sometimes hours) preceding a LARS "exceedence", to assist in troubleshooting. The history information may also be displayed in graphical format.

Incremental cost of the LARS system, once each locomotive is equipped with the WORS and train control package, is estimated at $16,000 per unit for the additional diagnostic sensors and wiring harness. The WORS OBC also handles LARS health monitoring.

Quantifying Benefits - CN - Locomotive Health Monitoring

Locomotive health monitoring appears to have enough potential benefits to be considered as a stand alone project. This implies that it would be one of the initial applications of ATCS and that some of the shared costs of equipping locomotives would be charged to the locomotive health monitoring project. Because it would bear a high proportion of the costs to equip 1,160 locomotives, it was decided to start with only a few data radio base stations around major diesel shops for locomotive health instead of real time monitoring of locomotive health. As other data radio base stations are installed, the additional benefits of real time locomotive health information will be realized. With these assumptions, locomotive health monitoring will cost a total of $US 45.7M and provide annual benefits of $US 11.7M. The details of these calculations follow.

Reduced Labour Costs to Diagnose Problems:

- about $US 7.1M direct labour costs for running repairs
- about 25% of this effort is for trouble shooting
- locomotive health sensors will provide information on about 68.7% of the failures
- estimated a 20% reduction in time to diagnose with locomotive health sensor information
  - full year savings about $US 0.3M

Reduced Failures - Less Labour Costs to Fix:

- about $US 7.1M in direct labour costs for running repairs
- about 75% of running repairs are initiated by reports from the crews (the rest are found during inspection)
- 20% estimated reduction in failures since have the locomotive health information to fix the problem correctly when it happens (prevent a second repair)
  - annual savings around $US 1.1M

Reduced Failures - Less On-Line Delays Incurred:

- annual cost due to on-line locomotive failures about $US 4.3M (includes locomotive ownership cost, car ownership costs, crew, fuel, repair truck and other costs associated with reacting to the failure)
- 20% estimated reduction in failures
  - full year savings of about $US 0.9M

Reduced Failures - Increased Locomotive Availability:

- ownership costs incurred while locomotive is being fixed a second time
- average 58 locomotive out of service due to unscheduled repairs
- 20% estimated reduction in failures
- annual ownership cost per locomotive $US 213,470
  - annual savings around $US 2.6M

Fuel Savings:

- estimated to save 2 to 3% of fuel used
- fuel budget of $US 233M
  - full year savings of $US 5.9M

Reduced Fuel Theft:

- monitoring fuel usage and discouraging theft
- 36,400 people with access
- 50% tempted to use diesel
- 1 in 8 have a use for diesel (% of diesel vs. gas sold at a gas station)
- 10.6 US gals per week
- 94.6 cents per US gal
  - annual savings $US 1.0M

Benefits Not Quantified:

CN included no estimate for reduced failures due to proactive fixing problems (instead of waiting for a locomotive to fail); nor an estimate of improved utilization based on a reduced need for "extra" locomotives in case one fails; nor any reduction in repair facilities. CN does not use load box tests, so no savings were calculated for this.

3.1.3 - Code Line Replacement

Description - Code Line Replacement

Many North American railroads still maintain wayside pole lines for communications and for transmission of CTC codes from central dispatching offices to field locations. Pole lines can be expensive to maintain.

Many railroads have been active in reducing the mileage of pole lines, replacing them with microwave systems, fiber-optic cable, or digital radio. However, considerable lengths of pole line remain on several railroads.

ATCS will substitute digital communications for pole lines. A railroad installing full ATCS (with train control functions) will be able to abandon all remaining pole lines. However, some pole lines carry power into remote sites, so ATCS is not always sufficient for the abandonment of pole lines.

As well, vital relays to the signal control locations can be replaced by WIUs once data radio is in place to provide the communication pathway.

C&NW, CP, CSX and Santa Fe are some of the railroads active in code line replacement. CSX has 48 control points and 12 base stations in place. C&NW are also replacing vital relays as well as code lines.

Requirements - Code Line Replacement

To replace pole lines used for signaling and communications requirements will involve:

- digital radio data link

- Wayside Interface Units (WIUs) at each controlled track switch or detector location, if vital field relays are to be replaced.

Benefit Areas - Code Line Replacement

Some railroads may find substantial benefits in pole line elimination. However, neither BN nor CN had large amounts of pole line that was in need of immediate replacement. As a consequence, CN took no benefit at all for pole line elimination, and BN took only a small credit because of an active pole line elimination program now underway, independent of an ATCS implementation.

It must be noted that not all railroads are in the position of BN and CN. For railroads which have essentially abandoned pole lines in place, and are facing major investments in communications and signaling technology, ATCS may offer significant benefits in the form of avoided expenses for pole line replacement. Railroads with major pole line replacement programs now underway include Santa Fe, Chicago and Northwestern, CSX and Southern Pacific.

Quantifying Benefits - BN - Code Line Replacement

BN, like other U.S. railroads, has an active program to eliminate pole lines carrying signal cable and replace them with microwave, fiber-optic, or BN'S ATCS-compatible data links. This work is ongoing, so the full credit for savings cannot be taken against a planned ATCS implementation. However, an ATCS implementation would allow faster abandonment of remaining pole lines. BN calculated in its ATCS Business Case that the additional savings from pole line elimination associated with BN'S ATCS implementation would be $6 million per year.

Quantifying Benefits - CN - Code Line Replacement

CN found very low benefits to replacing pole lines and vital field relays with data radio transmission of control information to the switches. Basically, the pole line budget is approximately a couple of million dollars per year and there are no large capital expenditures planned.

Replacement of vital relays with WIUs is also not a large item as the relays have a life expectancy of 40 - 50+ years and CN's plant is newer than most railroads. It appears that the cost to replace the vital relays at a siding is actually more expensive than a WIU if new relays are purchased. In the past, it was CN's practice to refurbish these vital relays in house as this was cheaper. (CN has since sold the shop which did the refurbishing.)

3.1.4 - TFTs (Track Forces Terminals)

Description - TFTs (Track Forces Terminals)

The Track Forces Terminal (TFT) is essentially a laptop personal computer combined with a digital data radio link from a maintenance of way (MOW) vehicle to a central office. The display permits digital (rather than voice) requests for "track and time", and gives MOW gangs the ability to directly receive train lineup information in text form. UP has installed TFTs and is using them for administrative messages.

Requirements - TFTs (Track Forces Terminals)

The TFT requires:

- An on-board computer (probably a modified laptop)

- A digital radio link from MOW vehicle to central office

Benefit Areas - TFTs (Track Forces Terminals)

Transmission of "track and time" permits by data radio rather than voice is expected to ensure that track forces obtain more timely permission to occupy track. In turn, this information should enable track forces to better plan work, reducing travel and wait time. In addition, it will be possible for track foremen and supervisors to directly enter time keeping and daily production data, reducing clerical workload.

Quantifying Benefits - BN - TFTs (Track Forces Terminals)

BN did not conduct a separate analysis of track force terminals without real-time location capability. BN's analysis (described later in this paper) assumed that enforcement and real-time location would be available to TFTs as well as to trains.

Quantifying Benefits - CN - TFTs (Track Forces Terminals)

Engineering benefits are due to the improved efficiency of data radio communications over voice. It improves engineering productive time because there is less time spent contacting the dispatcher. This will have the most impact at start and end of shifts when several engineering gangs are all competing for information or authorities at the same time. The second benefit comes from reduced clerical staff. Without data radio, the field forces write down the hours spent, work done and other administrative details on paper and these are entered into central systems by clerical staff. With data radio, the field forces would enter the data directly, reducing the need for clerical staff.

Improved Productive Time:

- $US 206.7M engineering labour budget
- 63% of engineering time is productive
- 1% improvement due to data radio communications
    - full year benefit $US 1.3M

Reduced Clerical Staff:

- 100 clerks entering engineering time keeping information
- 50% reduction in clerical effort
- salary and fringes $US 28,916
    - annual benefit $US 1.4M

    - total annual engineering benefits $US 2.7M

Benefits Not Quantified:

The remaining benefits of safety, electronic flagging and improved engineering productivity are included with the Safety and the Engineering benefits in the second story.

3.1.5 - Work Equipment Reporting

This is similar to locomotive health monitoring. It includes sensors to detect problems with work equipment, a data link to send information to and from a central system and an OBT with software. It would record administrative information such as crew hours for payroll, duty cycle times and equipment productivity (eg. number of ties tamped), as well as the health of the equipment. This would be a method of controlling and improving work equipment utilization. A company called "American" is a manufacturer of heavy work equipment. They are looking at including this capability in the design of some products. UP is also doing some work in this area.

The benefits from this functionality would be similar to both locomotive health monitoring and track forces terminals; reduced failure of work equipment due to more information, reduced diagnostic time, better equipment utilization, and reduced clerical staff to report on the administrative details. For example, monitoring of the duty cycle will allow more efficient deployment of the work equipment, similar to power control deploying locomotives.

Quantifying Benefits - BN - Work Equipment Reporting

No benefits were included.

Quantifying Benefits - CN - Work Equipment Reporting

Some of the clerical staff benefits were included under the track forces terminals benefits. CN plans to equip enough track force vehicles that each field gang have at least one vehicle equipped with data radio, so this information would already be transmitted back to a central system.

No other work equipment benefits were calculated in the business case.

3.1.6 - Locomotive Engineer's Assist

Information about fuel utilization, in-train forces, brake pressure, tractive effort and wheel slip all help a locomotive engineer handle a train with less damage to the lading, track and equipment. This is similar to a locomotive simulator which provides feedback to help train handling performance. It actually requires information about the train location to suggest throttle and brake settings. However, a less rigorous train location method can be used because train separation is not an issue here. Train location could be based on an axle alternator with the locomotive engineer correcting the train location manually, when necessary.

This requires sensors to detect problems, data radio communication to down load information such as track profile and train characteristics, some type of train location feature and an OBT to display the information to the engineer.

A recent study of locomotive engineer's train handling shows that the graphic display of data (eg. acceleration / deceleration rate, coupler slack, in-train forces) results in a run with significantly fewer train handling errors. [5]

Quantifying Benefits - BN - Locomotive Engineer's Assist

BN did not separate out these benefits gained with a less rigorous train location system. These were all included with the full benefits of train handling.

Quantifying Benefits - CN - Locomotive Engineer's Assist

CN looked at all the train handling benefits together assuming an ATCS-type train location. No attempt was made to divide these benefits between the first and second story.

3.1.7 - Car Environment Monitoring

This provides information on the state of the car or intermodal container and its contents. Car environment monitoring would focus on measurements such as the temperature, humidity, concentration of gas, etc. in the car / container. This improves customer satisfaction and reduces loss and damage claims. The data on failures could be transmitted to central systems allowing, for example, a malfunctioning cooling unit to be replaced at the next stop.

This requires sensors (which are capable of data transmission) to detect problems and the data radio communication to central applications.

Quantifying Benefits - BN - Car Environment Monitoring

The business case did not quantify the car environment benefits.

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5 George I. Kuehn, "Advanced Train Control System Evaluation", prepared for the FRA, October 1992

Quantifying Benefits - CN - Car Environment Monitoring

The business case did not quantify the car environment benefits.

4.1 - BENEFITS - SECOND STORY

The second story benefits are enabled by the central safety system. The second story functionality includes train separation and speed enforcement, tactical traffic planner, strategic traffic planner, Beltpack ™, train pacing, track force protection and electronic flagging.

As well as the data link provided in the first story, the second story requires the central safety system which uses computer hardware and software to verify each authority that the dispatcher decides to issue. The dispatcher enters the authority into the system which checks that there are no overlaps (two authorities issued for the same section of track). This verification by the safety system will virtually eliminate the number of unsafe authorities and related accidents with their associated costs (eg. lading claims, costs of fixing damage to the track and equipment). As well, accidents disrupt the service over the network and therefore affect other customers and reduce the utilization of equipment and trackage.

The central safety system also monitors switch status and aligns routes (for switches equipped with WIUs) and tracks train progress.

Note that the central safety system (without the train location feature) does not provide enforcement, which in ATCS is an on-board function.

The central software could also include some of the following; train handling assist, local tactical planner, strategic traffic planner, train pacing and automatic release of authority. Some of these functions also reside in the OBC on the locomotive; train location, automatic release of authority, enforcement of speed and authority limits and electronic flagging (automatic alert of an emergency stop).

Many of the second story benefits require the train location feature and the local tactical planner to achieve the best results.

4.1.1 - Customer Service

Description - Customer Service

ATCS will improve customer service by 1) reducing the transit time, 2) improving reliability or on-time performance, 3) improving the equipment availability and 4) improving both safety and reducing damage.

Build the Central System "Superstructure"

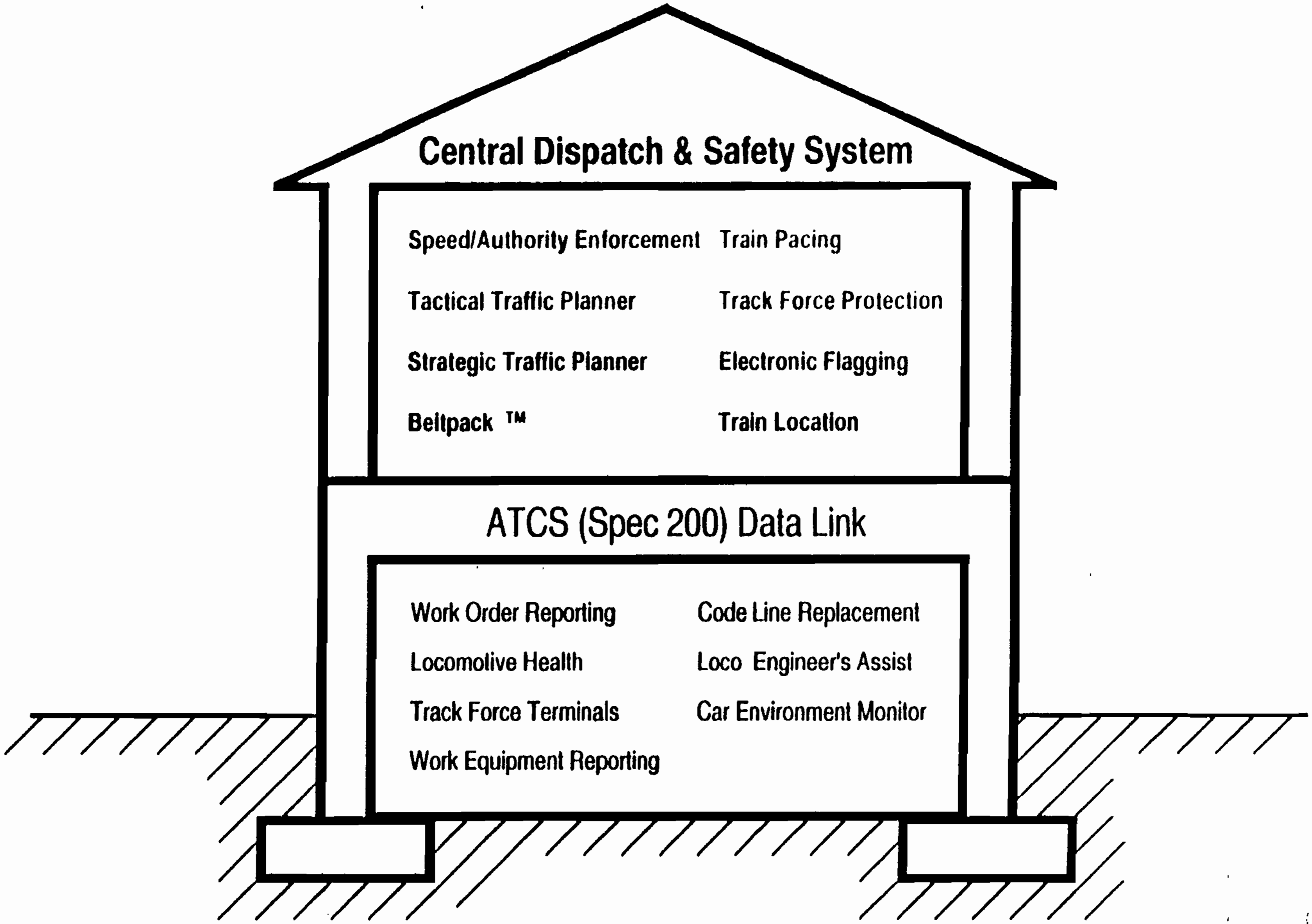

Figure 2

The run time is improved because ATCS has a local tactical planner that can optimize meets and passes much faster and better than a human being can. This local tactical planner also works with continually updated ETAs. These are more accurate than a dispatcher trying to remember when the train first entered a CTC block, the track layout (steep grade or flat territory), the length of the block and the track speed for each signal block and train on the territory. As well, dynamic headway will allow trains to start to move faster after a meet, pass or any other type of delay. This is because following trains can come in closer behind the first train and can be faster off the mark after the obstruction is cleared away. All these will reduce the run time of trains which means that the customers' goods will have a shorter delivery time on average.

ATCS will improve the reliability by reducing both the frequency and length of delays (each delay takes train performance further away from its schedule). For example, enforcement reduces the number of accidents, locomotive health monitoring reduces the number of locomotive failures and the local tactical planner improves the meets and passes; all of these contributing to fewer delays. Dynamic headway and the local tactical planner also contribute to minimizing the length or impact of a delay thus giving the goods a higher chance of being delivered on time.

Each time the run time is reduced, it frees up some equipment because cars are spending less time on the road. This is how ATCS improves the availability of equipment for customers.

Lastly, ATCS will reduce the loss and damage to customer lading and equipment. It achieves this through enforcement, etc. which reduces the number of accidents and by the train handling assist which reduces the in-train forces which act on the equipment, track and the customers' goods.

ATCS will improve customer service and there are several indicators that these improvements are of value to the customers; 1) they tell us so in customer satisfaction surveys and other contacts, 2) they negotiate reliability, run time and equipment availability bonuses or penalties into customer contracts, 3) on-time performance and equipment availability are mentioned as reasons why the railroad loses the business. The economic reality of the market place dictates that the longer it takes rail to move the goods or the less reliable the transportation is, the more it costs customer. For example, customers need to keep larger inventories, which ties up money and costs interest on that extra money.

There are some issues about customer service that can have a significant impact.

Segment Reliability vs. End-to-end Reliability:

Although each line or yard movement segment may have a good reliability, say 95%, it doesn't follow that this is the level of reliability that the customer experiences. As an example, a local picks up a customer's load with 95% reliability, yard activities have a 95% chance of getting the car on the right train, the train performance is 95%, the receiving yard has a 95% chance of putting the car on the next local assignment and the local assignment leaves the car in the right place at the right time 95% of the time. The reliability of the shipment is not 95%, but is 77% (95% * 95% * 95% * 95% * 95%) - a very discouraging result given high performance levels of each segment. Should each segment operate at 70%, the customer experiences a dismal 17% on-time performance.

Percentage of Units Equipped:

The run time and reliability benefits depend mainly on the local tactical planner and dynamic headway. If unequipped locomotives are on the territory, then these benefits will be reduced. Too many unequipped locomotives degrade the performance because train location information and the releases of authority are not entered into the local tactical planner real time. Similarly, track force equipment needs to be equipped with data radio transmission of work authorities. Otherwise, there is a potential to reduce the run time and reliability improvements for other trains in the vicinity. Because of this, it is planned to equip all locomotives and track vehicles which will run on ATCS territory.

Requirements - Customer Service

Equipment

- 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
- transponders
- 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)

Software

- 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, automatic alert on emergency stop)
- local tactical planner
- applications to send and receive information to and from other appropriate systems (eg. value of lading from marketing systems, revised ETAs to the customer service systems)

Benefit Areas - Customer Service

The benefits come in two basic forms; 1) an increased volume of traffic or prevention of the loss of traffic, 2) improved revenues for the same volume of traffic.

In the first case, customers who could not use rail transportation at the current service levels can now use it at the improved service levels. For instance, shippers whose product is perishable can switch to rail when the run time is lowered past a certain point; shippers with tight plant schedules can use rail when reliability increases past a critical point; shippers who need specific equipment for their loading docks can switch when rail can consistently have the required type of car available; and shippers with fragile, high value commodities can use rail when our damage rate falls to an appropriate level. Also, if a current rail customer is planning to switch to another mode or road because of the current service levels, preventing the loss of that customer with improved service has the same effect as gaining a new customer.

The second form of customer service benefit links the amount of money paid for the transportation to the level of service provided. This could be a bonus, penalty or incentive payment and is seen in contracts with certain customers and in passenger service agreements.

Quantifying Benefits - BN - Customer Service

The largest part of the benefits of BN'S ATCS was from a projected increase in revenue resulting from improved service. BN performed two studies of the elasticity of demand for rail freight service. The first was a survey of shippers in five commodity groups moving as carload shipments or in intermodal service. This study, conducted by the John Morton Company in Chicago, sought to quantify the relationship between railroad revenue and performance in several areas, including schedule reliability, suitability of equipment, overall dock-to-dock transit time, and billing accuracy.

The second study was a "revealed preference" analysis of rail freight rates and perceived service quality before and after the deregulation of railroad rates in 1981.

Both studies indicated that substantial additional revenue could be realized by railroads if service quality could be improved. Service elasticity estimates varied with commodity, but in general the John Morton study found the cross-elasticity of price with respect to service to be 4.0. Stated simply, a one percent improvement in service will produce a 4% increase in total revenue.

The revealed preference study found a price/service cross-elasticity of 2.0. This was chosen as the nominal value for the analysis. BN's Marketing Department felt that both estimates were too high, but was unable to provide an estimate of its own.

It seems clear from the two studies commissioned by BN that customers do, in fact, value service enough to pay a higher rate for better service. This conclusion has been borne out by a number of studies of truck and rail transportation by, for example, Temple, Barker, Sloane.

On the strength of the two studies it was concluded that the improved service made possible by ATCS might provide the following net increases in profits (additional revenue at no additional cost) for BN:

ADDITIONAL NET PROFIT FOR BN, ATCS SERVICE IMPROVEMENTS

Traffic Category	Additional Annual Profit (1989 Est.)
Merchandise Traffic	$312 million
Unit Coal Traffic	8 million
Total	$320 million

Quantifying Benefits - CN - Customer Service

CN commissioned a study to determine the effect of ATCS on run time, reliability, fuel consumption and engineering time. It used the actual performance of trains on three representative subdivisions and then simulated ATCS operation to determine its impact.

One of the basic results from this study was that run time and reliability both improved over current operations. The improvement comes about because of the local tactical planner which makes better meet / pass decisions and because dynamic headway reduces the amount of time it takes to get trains going again after they have been stopped or slowed down. As well, there are other types of delays which would be reduced. For example, enforcement will prevent accidents and avoid the delays to trains that result.

For this analysis, on-time was defined as up to the scheduled time i.e. being early is not counted as a problem. It is an appropriate definition for about half CN's customers, but a variety of alternate definitions would be more appropriate for the others. Ultimately, on-time is what the customer says it is.

The simulation results were extrapolated for the rest of the CN system trackage. The percentage improvement was calculated using a weighted average to reflect the improvement by class of train. (The study showed that the improvement was higher for some classes of trains than others.) The reductions in other types of delays were estimated and resulted in an average improvement to run time of 6.9% and an average reliability improvement of 12.2%. Unfortunately, this is an estimate of performance for train movement, only a part of the total trip. This had to be converted into an improvement for the total trip before it would be meaningful to customers.

Equipment spends roughly one third of the time in transit and the other two thirds in yards, customer sidings, repair shops, etc. The end-to-end improvement was estimated by reducing the transit improvements by two thirds, leaving an end-to-end run time improvement of 2.3% and an end-to-end reliability improvement of 4.1%.

The next step was to calculate how much these improvements were valued by customers. Each of the Business Units was asked how their customers would rank the four areas of improvement; reliability, run time, equipment availability and reduced damage; as low in importance, medium in importance or high in importance. Intermodal ranked all areas as high in importance; lumber ranked only equipment availability as high; the others were somewhere in between.

To convert these rankings into dollars, price elasticity figures were used. These estimate the revenue which will be generated for a service improvement of 1%. Market figures for CN customers were not available, so values from the BN customer studies were used as a substitute. The increase was applied only to the business unit revenues if the ranking was high. The increase was also applied to the business unit's short term, long term and asset costs to reflect the additional costs of doing the business. Allocated costs (eg. snow removal costs, building operating expenses) were not increased because they were not expected to change with the additional traffic carried. The difference between the additional revenues and the additional costs produced a benefit of $US 66.4M.

Because this was such a large value and difficult to support, CN attempted to confirm that the amount was real and in the right ballpark. CN has contracts with customers who either pay less for performance below a certain standard or who pay more for service above the standard giving weight to the idea that service is worth money to customers. The terms for one of the few contracts which had bonuses and penalties tied to different levels of reliability were applied to the total

CN revenue to calculate the amount CN would earn if customers valued reliability this way. It would increase CN revenues and profits by $US 41.2M, for the reliability improvements alone, which indicates that the calculations for the value of customer service are the right order of magnitude. Again, it demonstrates that some customers are willing to pay for an improved level of service.

The business unit revenue and costs figures are relatively sensitive material, as are the terms of confidential contracts. Because of this, the specific numbers used in these calculations are not detailed in this section.

Benefits Not Quantified:

Historically, the railroads have focused on a strategy of efficiency (longer trains, more tons per car) and worked in a relatively stable (regulated) environment. Today's competitive realities (dropping revenues per GTM, customers asking for better service) may require more flexibility than can be delivered with our current structure. For example, dispatchers can not optimize the meets and passes because there is too much data to process in too short a time. If external pressures require more frequent trains, then this problem will get worse. ATCS components such as the local tactical planner can cope with the additional complexities; indeed the benefit of ATCS increases as the problems get worse. With ATCS in place, a railroad is better equipped to operate in a more demanding market, but no value has been assigned to this benefit.

4.1.2 - Line Capacity

Description - Line Capacity

As noted previously, the second level of ATCS implementation involves more than just a digital data link. With real-time position information, train control software, local tactical planner, and enforcement become possible.

With real-time train location, sophisticated "pacing" and meet/pass planning algorithms can be used to minimize fuel consumption and optimize the movement of trains across the railroad. Effective meet/pass planning can increase the reliability of train movements; it can also increase line capacity.

Real-time location information also allows railroads to operate with dynamic, rather than fixed-length, blocks between trains. Functionally, dynamic headways in ATCS 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 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. Railroads facing future line capacity constraints may find the increased line capacity in ATCS will allow them to defer millions of dollars in capital expenditures.

Dynamic headway and the local tactical planner reduce the run time. 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.

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 a 7% improvement in equipment availability.

Note that the 20% improvement in run time can not provide a 20% increase in line capacity <u>and</u> a 7% improvement in equipment availability. It can provide 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).

<u>Requirements - Line Capacity</u>

Equipment
- 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
- transponders
- 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)

Software
- 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, automatic alert on emergency stop)
- local tactical planner
- applications to send and receive information to and from other appropriate systems (eg. value of lading from marketing systems)

Benefit Areas - Line Capacity

The following line capacity improvements follow from the ATCS improvements:

- ability to handle increased levels of traffic with the same trackage

- avoidance of capital expenditure of laying new track on sections which are operating at full capacity

- avoidance of increased delays and degraded service due to capacity constraints.

Quantifying Benefits - BN - Line Capacity

The BN business case analysis identified very significant line capacity increases available from implementation of ATCS. These capacity increases were achieved by use of sophisticated meet/pass planning algorithms, combined with the dynamic headways made possible by the ATCS train control technology.

For BN, which has experienced rapid traffic growth in recent years and is operating at or near capacity on several important route segments, increased line capacity is a valuable benefit. If ATCS can increase line capacity, major capital investments for additional sidings, double track, or conventional train control systems may be avoided.

Because of the very high densities typical of BN main lines, the additional line capacity and running time reductions associated with computerized meet/pass planning were of major importance for BN.

Studies of BN operations indicated that nearly 80% of total train delay minutes were due to meet/pass delays, rather than mechanical failures, track problems, weather, or other causes. On a single-track railroad (and most of BN is single track) meet/pass delays can never be eliminated. However, much empirical evidence suggests that dispatchers will penalize low-priority trains (coal and grain) in order to avoid delaying higher-priority services (intermodal and passenger trains). Dispatchers are human, and the average human being can effectively prioritize three to seven items. Dispatchers on BN often must deal with dozens of trains on a single territory.

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 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%.

The benefits of this reduction in running time were taken in equipment ownership savings. However, the line capacity increases resulting from use of real-time meet/pass planning were estimated to enable BN to avoid major capital investments that would otherwise be required to increase line capacity at a number of points. BN defined three possible future strategies: "focused", relying primarily on unit train and intermodal traffic, with slower traffic growth; base, extrapolating present trends; and "expansion" in which the railroad would aggressively pursue new business in all areas.

To quantify the available savings, a curve was constructed by BN Operations Planning to relate the percentage of double track on each line to its capacity. Double track (including passing sidings) ranged from 11% to 100% of route mileage, depending on segment.

Present capacity of each segment was estimated, and additional double track required to carry projected future traffic volumes was calculated. Cost per mile of double track ranges from $1 million to $3 million, depending on segment.

BN'S ATCS was found to increase line capacity by 20%, so that became the basis for calculating the avoided investment. Avoided capital investment depended on projected traffic growth. It ranged from $82 million after tax in the focused strategy to $243 million in the expansion strategy, with a base case value of $98 million.

<u>Quantifying Benefits - CN - Line Capacity</u>

CN is one of the lowest density railroads in North America. The ATCS improvements in run time were better allocated to improving customer service than to increasing the line capacity. As traffic increases in the heavy corridors, this trade off may change in favor of capacity increases to avoid heavy capital expenditures, but not at the current levels.

4.1.3 - Train Dispatch Productivity

Description - Train Dispatch Productivity

The dispatch office productivity comes from two sources; the consolidation of dispatch offices and the use of ATCS functionality such as data radio, train location, local tactical planner and full train control.

The consolidation benefits arise because there is a need for supervisors, operators, clerks and dispatchers around the clock. But there is not always a full workload for the staff in off-peak shifts. For example, a Chief Train Dispatcher can supervise all the dispatchers required in a peak shift. During off peak hours, the supervision is still required, but the individual is not fully occupied. Of course, jobs are combined to reduce this as much as possible within an office, but some inefficiencies still remain.

ATCS functionality also provides savings. Data radio, for example, reduces the amount of time a dispatcher spends telling the train crews and field forces what their authority limits are and listening to them repeat the limits to ensure they are correct.

WOR and locomotive health monitoring reduce the amount of time the dispatcher takes to send new work orders to crews and to listen to reports of problems from the crew and then passing these reports on to the appropriate people.

The local tactical planner will reduce the time it takes a dispatcher to plan meets and passes. Since the software will take into account much more information than an individual can reasonably process, it also avoids some of the problems dispatchers create when making sub optimal decisions.

Full train control reduces the dispatcher's effort by automating the routine issuing, cancelling and transmission of authorities. The dispatcher no longer has to build up a complete picture of the activity on the territory and keep it up to date so action can be taken when needed. This is automated and kept current for the dispatcher.

Requirements - Train Dispatch Productivity

Equipment
- 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
- transponders
- engineering vehicles equipped with data radio and TFDTs
- flexible voice radio (so desks can be combined on slow shifts).

Software

- 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, automatic alert on emergency stop)
- local tactical planner
- applications to send and receive information to and from other appropriate systems (eg. revised ETAs to the network tactical planner).

One of the potential problems with such an automated system is that the dispatcher will not have a lot to do most of the time. It is difficult to keep someone alert and knowledgeable in these circumstances. If something does go wrong (eg. equipment malfunction) the dispatcher will be ill equipped to jump in and sort it out and the scope of the territory affected is likely to be too much for one individual to handle.

Benefit Areas - Train Dispatch Productivity

The benefit areas are a reduction in dispatchers due to the productivity tools. Each dispatcher will be able to cover significantly more territory due to the automation of most of the current workload.

The second benefit area is the reduction of supervisory and support staff. This is mostly due to consolidation, but some is attributable to the ATCS functionality.

Quantifying Benefits - BN - Train Dispatch Productivity

BN calculated a significant productivity improvement associated with implementation of ATCS. However, facing traffic growth BN chose not to reduce dispatchers but rather to calculate the reduction in future hiring that might be achieved.

BN managers estimated that automating clerical tasks and "track warrant" transmission could improve dispatcher productivity by 25% to 50% (this finding was partially based on a study of dispatchers which revealed that 80% of a dispatcher's time is spent on communicating with trains or MOW forces). BN's labour costs for dispatchers are approximately $19 million per year. Therefore, savings are estimated at $4 million to $9 million annually.

In addition to these benefits, BN examined the changes in dispatcher workload that would occur with use of a digital radio link and computerized dispatching.

BN commissioned a detailed study[6] of dispatcher communication with trains, as a way of validating the need for a digital data link. The data link was assumed in the study to be operating in conjunction with a train control system which provided real-time train location data to the dispatcher. The advantages of data radio were found to be the following:

- 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, by avoidance of communication delays, breakdowns, conflicts, and repetitions.

- An increase in communications precision due to continuous availability of real-time information about trains.

- A change in communications focus, making problem-solving rather than routine transmission of location messages and authorities the main focus of a dispatcher's work.

The identified reduction in communications load is shown in the following table:

COMMUNICATIONS LOAD, DIGITAL VERSUS VOICE

Measure of Load	Voice Radio	Data Radio
Number of Exchanges	70	22
Number of Topics	112	24
Average Length of Exchange	01:09	0:52
Total Communications Time	80:21	18:57
Work Time Spent in Communication	74.7%	17.6%

The improvement is achieved through a reduction in conflicts (two calls for the dispatcher at one time), failures (unsuccessful attempts to contact someone), repetition (first message not understood), breakdowns (failures to transmit

6 John Vanderhorst, "A Comparison of Voice and Data Link Communications on a Railroad: A Dispatcher's Perspective", Overland Park, Burlington Northern Railroad, 1991

required data, due to misunderstandings or other reasons), and pauses (five or more seconds of delay before response to a communications attempt).

The following table shows clearly the change in the focus of communications in an ATCS environment. With conventional voice radio, almost 70% of communications concern time and location, train information, and movement authorities. With ATCS, the figure is 16.5%

DISTRIBUTION OF COMMUNICATIONS TOPICS, DIGITAL VS. VOICE

Category	Traditional Environment	Data Link Environment
Time and Location	38.4%	0
Train Information	14.3%	12.5%
Movement Authority	16.1%	4.0%
Supplemental Control	8.9%	20.0%
Special Circumstances	22.3%	62.5%

Thus, dispatchers on an ATCS railroad will spend much more of their time solving problems and dealing with unusual situations, and much less on routine functions. This should improve the overall quality of dispatching.

ATCS will reduce job stress and increase the productivity of dispatchers. It should also help produce a smoother railroad operation. None of these benefits were quantified in the BN analysis, however. Reductions in the dispatcher work force (partially due to the change in communications focus) were covered earlier.

Quantifying Benefits - CN - Train Dispatch Productivity

CN has several workload studies of the time spent on each dispatcher activity for all of the dispatching desks and all shifts at various times of the year. This made calculating the amount of time spent on each activity quite simple.

Experienced dispatchers, knowledgeable about ATCS functionality and capabilities, estimated how much reduction there would be in each of the dispatching activities. The supervision and support staff workload was also reviewed the same way. The staff required in a dispatch office to cover the remaining work was then calculated. The improvements were used as the dispatch office savings.

The percentage improvement over the current situation (after taking other approved initiatives into account) follows:

Reduction in dispatcher workload - 55%
Reduction in supervisor workload - 24%
Reduction is support workload - 54%

Some dispatch offices have voice radio communication equipment that can not be switched from one dispatch desk to another. This prevents desks being combined and manned by one dispatcher in off-peak times. Voice communications that can be switched from desk to desk are required to achieve the dispatcher reductions.

Consolidation Benefits:

- 18 support staff at $US 38,272 (including overhead) $US 0.7M
- 14 supervisors at $US 72,291 (including overhead) $US 1.0M
  - annual consolidation benefits $US 1.7M

Productivity Tools:

- 101 dispatchers at $US 57,237 (including overhead) $US 5.8M
  - annual productivity benefits $US 5.8M

4.1.4 - Safety

Description - Safety

ATCS will virtually eliminate human factors accidents associated with:

- violation of signal indications or authority limits
- excessive speed
- improper train handling.

The ATCS capacity for enforcement of movement authorities, plus assistance to the crew in train handling provided by the OBC, secure these benefits. If a train crew violates movement instructions, the train will be brought to a stop. Enforcement of movement authorities also protects track forces as trains would be stopped before violating a work block.

Electronic flagging, in the event of an emergency stop, would immediately and automatically notify vehicles in the vicinity of the danger of impassable track. Enforcement by the OBC will prevent another train being involved unnecessarily.

Requirements - Safety

A central safety system is required in order to obtain the safety benefits. It is a software package that analyzes train movement authorities for possible conflicts, issues authorities, and monitors train performance against the authorities.

In order to enforce speed and movement authority limits, the following are required:

- Real-time train location data
- An on-board computer
- The digital data link

Benefit Areas - Safety

Serious accidents resulting from human error are not common, but they tend to be very expensive. Especially in the United States, litigation resulting from a serious accident can push costs to almost unimaginable heights. The 1987 accident at Chase, MD on Amtrak's Northeast Corridor is a good example. ATCS would have prevented that accident, the loss of 28 lives, a great deal of equipment damage, and years of litigation.

There is also the specter of possible regulatory involvement. Although the safety benefits of ATCS are not, by themselves, sufficient to economically justify investment in the system, the elimination of most human factors accidents is a desirable goal. It may be reasonable to seek government funding (either in the U.S. or in Canada) for development of the central safety system.

Beyond the elimination of many human factors accidents, ATCS offers another benefit for North American railroads. There has been a rapid growth in commuter train operation in recent years. These trains are often operated by independent municipal or state authorities, using tracks which also carry freight service. There are significant liability issues involved, as the 1987 accident mentioned earlier indicates. ATCS is the only available technology which can greatly reduce (or even eliminate) the risk of expensive human factors accidents on these lines. The ATCS capability for reducing accidents (and associated liability costs) may become much more important as more "third parties" (commuter rail and other passenger rail operators) begin services on freight railroad trackage.

Quantifying Benefits - BN - Safety

BN and CN took different approaches to quantifying the impact of ATCS on safety. BN estimated the cost of human factors accidents, and calculated the savings from avoiding some very large percentage of them. BN used an average of occurrences over five years, since serious human factors accidents do not happen frequently.

BN also estimated a reduction in loss-and-damage payouts as a result of improved train handling using ATCS.

BN used a five-year history of personal injury costs. It was assumed that ATCS would prevent all accidents due to:

- rules violations
- impaired employees
- overspeed
- improper train handling

The total benefit to BN was estimated at $18 million.

Another safety-related benefit was a reduction in loss and damage to lading. BN's Assets Protection Department has found that most lading damage occurs during the line haul portion of the trip, not in yards. ATCS will provide train-handling advice to enginemen, helping them to avoid excessive buff and draft forces that can damage lading.

BN spends $14 million per year to pay claims for damaged lading. Some portion (but probably not all) of this might be saved through use of ATCS. A nominal value of $5 million was used, in the absence of any quantification of the savings.

Quantifying Benefits - CN - Safety

CN reviewed all the accident reports over an eight year period (1982 - 1989) and determined which would have been prevented by ATCS features. It is important to review information from several years because a very bad or very good year will misrepresent results.

Enforcement was the major contributor, but train handling, data radio and other ATCS features were also factors. The actual direct costs of these accidents (damage to lading, equipment and trackage) were totaled and averaged over the eight years to $US 1.8M. This is about 20% of the annual accident costs averaged over the same eight years.

The ATCS preventable accidents also had costs resulting from legislation directly related to the accidents. In one case, the rest rules changed and 150 new employees were hired. The overhead or fringe benefits (vacation, holidays, etc.) for these extra employees costs $US 2.6M per year. Other legislation forced CN to install reset safety devices in the locomotives and a computerized dispatch office. The annual payback on these projects was compared to the payback that is required by CN's hurdle rate for capital projects and the difference is included in the safety benefits. For the period studied, the legislative costs were $US 6.3M per year or 3.5 times the direct costs of the accidents that ATCS would have prevented.

Injuries and fatalities over the eight year period were not assigned a dollar value.

4.1.5 - Engineering Forces

Description - Engineering Forces

Availability of more accurate train lineups and real-time position information should enable engineering forces to move more quickly to job locations, to plan work better, and perhaps to obtain more time on track.

In addition, the ATCS can enforce MOW track occupancies in the same way as train authorities are enforced, providing a higher level of protection to work gangs. However, this requires that MOW vehicles be equipped for real-time location.

Requirements - Engineering Forces

The TFT requires:

- An on-board computer (probably a modified laptop)

- A digital radio link from MOW vehicle to central office

- If authorities are to be enforced, real-time location capability is also required.

Benefit Areas - Engineering Forces

Transmission of "track and time" permits by data radio rather than voice is expected to ensure that track forces obtain more timely permission to occupy track. The Track Forces Terminal (TFT) would enable track forces to obtain more accurate and timely information about train movements. This would be possible even without real-time location information. In turn, this information should enable track forces to better plan work, reducing travel and wait time. In addition, it will be possible for track foremen and supervisors to directly enter time keeping and daily production data, reducing clerical workload.

If used with ATCS central safety and vehicle location capabilities, track forces terminals would provide the same level of protection to track forces as ATCS provides to trains. A train violating the limits of a work area would be stopped. This capability would reduce accidents to MOW workers. The benefits have been included with the Safety benefits.

Quantifying Benefits - BN - Engineering Forces

It was originally thought by BN that MOW productivity increases would occur because use of computerized meet/pass planning would allow the scheduling of larger work blocks. However, the very high average traffic densities on BN made this impractical; other benefits, such as increased service reliability, might be reduced.

BN still identified two MOW benefits:

- Timely information on train locations, enabling more efficient scheduling of MOW work time on track

- A reduction in time required to obtain "track and time" permits from often overloaded dispatchers, for whom MOW gangs are a low priority

No rigorous analysis was performed to quantify the value of these savings. As a best guess, BN Engineering staff estimated that MOW productivity might increase by from 2.5% to 21%, saving between $4.5 million and $38.5 million per year.

Quantifying Benefits - CN - Engineering

Engineering benefits attributable to the second story are due to the improved running time to get to and from work sites. This will reduce the engineering travel and wait time and increase the productive time.

- $US 206.7M engineering labour budget
- 23% of engineering time is travel or waiting time
- 6.9% improvement in over-the-road run time
  - full year benefit $US 3.3M

Benefits Not Quantified:

No savings for improved utilization of work equipment were included. Benefits due to better planning information were also not estimated. This benefit value is felt to be significantly under estimated.

4.1.6 - Equipment

Description - Equipment

As was noted in the customer service benefits section, improved run time improves cycle time giving more use for the same amount of equipment. This gain in equipment availability can either be used to carry more goods or it can be used to defer the acquisition of additional equipment. This benefit addresses the value of not purchasing more equipment.

If the same amount of freight is carried, then fewer cars will be needed to carry it because the cars complete their cycle faster. This avoids the cost of owning and maintaining the cars. It is not practical to go out and sell cars when they are not needed, but it will reduce the cost of leasing cars, maintaining cars that are not in use and defer the purchase of new cars when more traffic is carried or cars need replacing. This value is generally called long term equipment costs or capital cost avoidance and is used to determine how much can be saved even if there are no plans to purchase cars during the next few years.

Requirements - Equipment

Equipment

- 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
- transponders
- 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 benefits included in this section)

Software

- 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, automatic alert on emergency stop)
- local tactical planner
- application to send and receive information to and from other appropriate systems (eg. revised ETAs to the car distribution systems)

Benefit Areas - Equipment

The benefits are based on a reduction in the long term equipment costs (an average of what it costs to own a car), a reduction in the costs to lease cars and a reduction in the cost to maintain the cars that are not currently needed.

The car maintenance costs relate either to maintenance required because of usage (eg. repairing doors and interiors) and the maintenance needed because of time (time-based inspections). The usage of each car will actually increase, so there will be no reduction in usage repairs, but the time based inspections will decrease because there will be fewer cars to inspect each period.

Quantifying Benefits - BN - Equipment

BN has 4,300 cars in its coal fleet, with another 15,000 owned by electric utilities and other third parties. There are 14,000 cars in the BN grain fleet. The running time reductions identified in the BN analysis will reduce cycle times for cars in these fleets, reducing total fleet requirements.

When BN owns the cars, the savings is the avoided cost of replacing cars in the fleet as they are retired, and a continuing savings from providing the same amount of transportation with fewer cars.

Utility-owned coal cars present an additional problem. Electric utilities already receive a rate reduction as an incentive to provide their own cars. If car fleet requirements are reduced, it is doubtful that the entire savings can be captured by BN. Estimates in the BN business case include an assumption that BN will capture some, but not all, of the savings from car fleet reductions.

A range of savings was calculated for each car fleet, including an estimate of the likely portion of the savings BN might realize through rate increases. Overall, BN projected the following annual benefits from the identified improvements in running time:

a. Utility-owned coal cars

Reduction in running time: 10% - 25%
Annual savings to BN: $1 million - $8 million
Savings per car: about $700 - $5,600

b. BN coal cars

Reduction in running time: 10% - 25%
Annual savings to BN: $4 million - $28 million
Savings per car: $9,500 - $65,000

c. BN grain cars

Reduction in running time: 10% - 25%
Annual savings to BN: $34 million - $84 million
Savings per car: $24,300 - $84,750

Car reductions were not calculated for intermodal and mixed freight trains, since it was assumed that BN would take the entire gain as an improvement in reliability.

In addition, BN anticipated a reduction in locomotive units required. As with the analysis of freight cars, locomotive reductions were calculated by service, as follows:

	----- Service Category ------		
	Intermodal	Carload	Unit
Number of Locos	360	710	805
Cost per Loco	$1.33 M	$1.33 M	$1.33 M
Time on Road	52%	52%	52%
Decrease, Transit Time	5 - 10%	5 - 17%	10 - 25%
Locos Saved	9 - 19	18 - 63	42 - 105
Capital Savings ($Mil)	$12 - $24	$24 - $82	$54 - $131

The ranges of savings shown represent expected low and high values for each savings area. Caution must be used in adding these benefits together, since the likelihood that benefits in all categories will be at the low end of the range is very small, as is the probability that all will be at the high end of the range.

If the midpoints of each benefit range are added together, equipment savings will total an estimated $238 million, almost enough to justify ATCS. This is a one time saving not an annual benefit.

Quantifying Benefits - CN - Equipment

CN equipment benefits were based on the run time savings simulated over the three representative subdivisions. These were extrapolated across the system and converted into a total number of hours saved. A review of train delay statistics (delays not caused by meets and passes), also produced a total number of delay hours. These were multiplied by an average long term capital cost of equipment per train hour ($US 94) giving $US 5.3M.

Note that the total run time reduction can not be used for equipment, line capacity and customer service savings, but a part of it can be used for each category of savings.

Reduced Maintenance Costs:

- $US 108M labour costs for car maintenance
- 16% maintenance estimated to be time based
- 2.3% improvement in end-to-end running time
    - full year benefit $US 0.4M

Benefits Not Included:

Car hire benefits were not calculated.

4.1.7 - Fuel

Description - Fuel

ATCS can save fuel in several ways. With train control and the local tactical planner, trains can be "paced" so that they will arrive at meet points exactly as scheduled, rather than arriving earlier and waiting. If trains are kept moving for more hours, but at slower speeds, fuel use will be reduced.

Second, the ATCS on-board computer can include an Energy Management System (EMS) that will minimize the fuel consumption required to meet a specific schedule target.

Requirements - Fuel

Both pacing and energy management will require:

- An on-board computer (OBC)
- Real-time train location
- Digital data link
- Local tactical planner
- EMS

EMS will moderate the train speed to take advantage of train and track characteristics to reduce the cost of fuel. In some circumstances, pacing will recommend a speed slower than track speed (it would never recommend a speed higher than track speed).

The rail in a curve is super-elevated to balance the wear between upper and lower rails based on a design speed. The farther away from the design speed the trains actually go, the worse the wear on the rail. CN has models that relate rail wear with train speed and tonnage. These models were run with the recommended pacing from the fuel saving study. The results of the rail wear models show that with curves of less than four degrees there is no difference in rail wear, but with curves of four degrees or more, there is an increase in rail wear. To avoid this problem, it was proposed to include a constraint in the EMS program to exclude pacing on curves of four degrees or more. It would be better, as well, to include the optimum speeds for the curves in the train handling program.

Benefit Areas - Fuel

Both BN and CN identified significant fuel savings from the use of ATCS. These fuel savings result primarily from the use of an Energy Management System (EMS) to optimize each train's velocity profile consistent with its operating schedule, and from use of a "pacing" algorithm that slows trains down so that they arrive at meet points exactly as scheduled, rather than proceeding at track speed, arriving early, and waiting in a siding. Ideally, on an ATCS railroad each train will be moving more slowly, but will spend more time moving. Thus the anticipated fuel savings is consistent with reduced over-the-road running times.

Quantifying Benefits - BN- Fuel

BN conducted a detailed analysis of both the Rockwell EMS and of train pacing. However, the Rockwell EMS was still under development when this analysis was performed, and it proved impossible to constrain trains to the same travel times in the optimized as in the base profiles. Therefore, it was difficult to determine the overall benefit of the EMS. However, subsequent research and analysis indicates that savings in the range of 2% to 4% are most likely. This is consistent with CN's analysis.

A model developed at the University of Pennsylvania was applied independently to estimate the benefits of pacing. In two separate analyses, additional fuel savings in the range of 2% to 6% were identified for pacing alone. Thus the likely range of fuel savings for use of the EMS and the ATCS meet/pass planner was set at 5.5% to 8.5% annually, a range with a probability the same as that of the EMS and meet/pass planner analyses.

BN's fuel bill is about $260 million annually, so the dollar savings will range from $14.3 million to $22.1 million per year.

Quantifying Benefits - CN - Fuel

CN fuel benefits are based on pacing to meets and passes. The train going into the siding will slow down to get in the siding just ahead of the through train instead of traveling at track speed and then idling in the siding. The savings were based on a simulation of the fuel savings for trains running on three subdivisions that are representative of the system. Train location knowledge is used in the algorithm to pick the best track location for pacing, eg. coasting on a hill.

Fuel Savings:

- fuel savings range between 13.5 US gals per meet to 28.0 US gals per meet depending on the length of time a train has to pace, the track speed and the track profile.
- simulation produced fuel savings equivalent to 2.3% of total fuel budget
  - full year benefit $US 5.9M

Benefits Not Quantified:

The simulation calculated only the fuel savings due to meet / pass delays which are about half the total delays ATCS will prevent. The fuel savings are based on the simulation results and are expected to be underestimated by half.

4.1.8 - Crews

Description - Crews

Some current crew runs are short - not a full days work. However, if these short runs were combined, they would produce a crew run that was too long. With the improvements in over-the-road time provided by ATCS, these short runs can be combined, eliminating some crew change points. But if trains run late on these new routes, then there would be other disruptions because crews could book rest or meals causing further delays and the possible need to bring in another crew. With the additional reliability of operations under ATCS, crew change points can become run throughs without these extra problems. The reduction in crew change points means fewer crews are needed to do the same work.

Requirements - Crews

Equipment
- 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
- transponders
- 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)

Software
- 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, automatic alert on emergency stop)
- local tactical planner
- application to send and receive information to and from other appropriate systems (eg. revised ETAs to the crew calling system)

Benefit Areas - Crews

The reduction in the number of crews will provide no direct savings because crews are paid mainly by the mile and the number of miles is the same. However, crews incur overhead costs as well as direct costs. Vacation, medical coverage, etc. are costs that are paid per employee and fewer employees means less overhead charges.

There will be a reduction in pay for ITD (initial terminal detention) and FTD (final terminal detention) because there are fewer crew change points. This will reduce the payments for yard "miles".

As well, with fewer crew change points, the accommodation costs and deadheading costs will fall too.

With an improved over-the-road time, a crew can cover more miles in the same number of hours. This should eventually lead to a reduction in the rate paid per mile, but union agreements and local arrangements may delay this from being realized as quickly as other benefits.

Quantifying Benefits - BN - Crews

BN believed that improvements in reliability and running time might make it possible to lengthen the miles run for a basic crew day. As an example, if ATCS were to allow trains to run 10% farther, on average, in an eight-hour day, crews would presumably be able to work 10% more miles without an increase in hours worked.

BN spends about $533 million on road train crew labour. Of this amount, about $400 million is directly or indirectly related to basic mileage pay or the time required to travel across a crew district. (This amount includes initial and final terminal delay).

BN calculated that improvements in running time might affect as little as 25% of this compensation, or as much as 75%. The identified transit time reductions of 10% to 25%, then, might produce as little as $6.7 million in annual savings or as much as $60 million, depending largely on whether ATCS produced the anticipated benefits and whether BN was able to negotiate a longer basic day.

In addition, more reliable operation would reduce the need for an "extra" board to cover trains running at unpredictable times and to protect for crews that "outlaw". Reducing the size of the board will not save wages, since the number of trains will not change. However, fringe benefits, which are associated with the number of workers on the payroll rather than directly with hours worked, might be reduced by $1 million to $2 million annually.

Quantifying Benefits - CN - Crews

A system which contains all the crew change points, the average running time between them and normal terminal times was the basis for the benefit analysis. The running times were reduced by the 6.9% over-the-road improvement ATCS would provide and possible new run through points were identified. From this, the potential crews affected were identified and the benefits calculated.

The figures used to calculate crew savings were based on historical costs when CN had an average crew of 3.5. CN's current crew size is 2.5, so the benefits have to be reduced as well to reflect the reduction in crew size already achieved. Each benefit area was reduced by a factor of 71% (2.5 / 3.5) to account for the historical costs being larger than the current costs are.

Benefit Calculations - Crews

- 6.9% reduction in run time
- 7.2% of possible run through points / total crew change points

Reduction in Overhead Costs:

- $US 117.8M in crew mile costs
- overhead rate 40%
- 7% reduction in crews
- smaller crew size factor 71%
    - total annual benefit $US 2.4M

Reduction in Terminal Detention Costs:

- $US 21.3M in terminal detention costs
- 7% reduction in crews
- smaller crew size factor 71%
    - total annual benefit $US 1.1M

Reduction in Accommodation Costs:

- $US 260.247 accommodation costs at crew change point
- 12 crew change points reduced
- smaller crew size factor 71%
    - total annual benefit $US 2.2M

Reduction in Deadhead Costs:

- $US 9.4M in deadheading costs
- 7% reduction in crews
- estimate 50% unaffected by local agreements
- smaller crew size factor 71%
    - total annual benefit $US 0.3M

    - crew annual benefits $US 6.0M

Benefits Not Quantified:

Although it was not included in the ATCS benefits, CN calculated the effect of reducing the rate of pay per mile so that the improvement in the average miles per day was balanced by the reduction in the rate of pay - essentially, paying the same amount of money for the same hours of crew effort.

- $US 117.8M in crew mile costs
- 7% reduction in crews
- shrinking size of crew reduces benefit to 71% (2.5 / 3.5)
    - total annual benefit $US 5.9M

No attempt was made to calculate a value for the contribution that ATCS will make to a reduction in the number of individuals in a crew. Because wages are a large percentage of operating costs, this benefit will be huge.

4.1.9 - Yard Productivity

Description - Yard Productivity

The only part of ATCS directly concerned with yards is the Work Order Reporting System (WORS). WORS does not directly address the functions of yards; it is a tool for enhancing the productivity of road crews and switcher crews.

Requirements - Yard Productivity

To implement WORS, a railroad must have:

- digital radio
- an on-board computer or display
- office software for issuing work orders

Benefit Areas - Yard Productivity

Both BN and CN have found some benefits in terms of increased yard productivity and better customer service. At the very least, availability of accurate information about arriving trains in real-time ought to enable yardmasters to prepare better for classifying trains. Better control of train movements on the road should reduce yard congestion by preventing the simultaneous arrival of several trains at a yard. Finally, reporting of work order information in real time will reduce the need for yard clerks.

Quantifying Benefits - BN - Yard Productivity

BN did not explicitly model changes in yard productivity in an ATCS environment. With better information and more reliable service, it seems reasonable to assume that fewer yard employees and switch engines would be required. However, yard productivity is an important element in overall service reliability. It might therefore be better, BN felt, to improve the performance of yards rather than reducing their operating costs and maintaining service at current levels.

BN conducted a service reliability analysis using the Service Planning Model (SPM) developed at the Massachusetts Institute of Technology. To use the SPM, a cumulative probability function is created for each classification yard that relates the percent of cars making scheduled connections to total available time in the yard. The basic concept is that, if tight connections are scheduled, lateness of an inbound train or a delay in yard processing is more likely to cause a car to miss its scheduled outbound connection.

In the line capacity analysis, a 23% reduction in average running times had been produced through simulations using a sophisticated meet/pass planning algorithm.

In the yard productivity analysis, two scenarios were evaluated. In one, train reliability was assumed to improve (the standard deviations of running times were reduced), but running time was unchanged. This produced a 2.7% reduction from the base case in total car hours in yards. If a 23% running time reduction was assumed, but schedules were left unchanged, a 6.8% reduction in total yard time was produced. This 6.8% remained unchanged when reliability was improved.

Benefits of this improvement are included with the equipment benefits discussed earlier. No benefits were calculated directly for yard operations.

Quantifying Benefits - CN - Yard Productivity

Some yard productivity improvements were included in the WOR benefits because of better information on the work done by the local assignments.

Both locomotive health monitoring and train control will probably impact yard performance favorably, simply because trains will go off schedule less frequently and make the yards easier to manage. However, in the business case, delays were only reduced if they were directly attributable to improved train reliability and the effects are included in the customer service benefit calculation.

5.1.- COSTS

The costs included in the business cases are generally high. The estimates were done several years ago. At that time, suppliers were just beginning to produce prototype products, so these units were priced higher than production units. Also, there was not as much familiarity with ATCS as now. Both suppliers and S&C departments were making sure the "unknowns" were covered; again pushing the price up.

Prices for computing equipment and communications hardware have been dropping in retail markets. Similar improvements should be available from ATCS suppliers too. With computers, in addition to the prices dropping, the computing power has been increasing at the same time.

These factors lead to the expectation that prices for ATCS will drop as suppliers begin to get orders and go into large-volume, production mode. The prototyping and field tests should also lead to a better understanding of the strengths and weaknesses of products. This will allow better estimates of things such as replacement rates and provide tighter estimates of the true cost.

Overall, it is expected that the cost of ATCS equipment will be lower than the totals discussed below.

5.1.1 - COSTS - BN

Costs for BN's ATCS system were calculated only for system wide implementation. The following table shows the full cost of digital communications for BN.

Cost of Digital Communications	# Units	$ / unit	Total ($M)
Front-End Processor	1	2,000,000	2.0
Ground Terminal Controller	1,350	26,000	35.1
Wayside Interface Units	4,500	12,500	56.3
Cluster Controllers	10	300,000	3.0
Radio Towers	1,000	50,000	50.0
Digital Communications Total			146.4

Locomotive equipment costs varied, depending on the functions required. BN's cost of $ 350M was based on equipping about two thirds of the locomotive fleet with a full on-board package which included locomotive health monitoring, work order transmission capability, and train control. BN estimated the cost of this package as follows:

- Basic Hardware	$14,000
- Train control computer	19,000
- GPS receiver	5,000
- Wheel tachometer	2,000
- Complex I/O device	12,000
- Locomotive health monitoring	16,000
- LIM/RIM (train control)	12,000
Total per locomotive	$80,000

The total cost for ATCS implementation system wide at BN:

ATCS implementation system wide	Total ($M)
Digital communications	146.4
Central dispatch center (increment over conventional)	6.6
Additional WIUs for CTC/ATCS compatibility on CTC routes	12.0
Right of way survey (GPS map)	8.0
Training	1.5
Remaining development cost (1989 estimate)	15.5
2,000 equipped locomotives	160.0
Total ATCS cost (1989 estimate)	350.0

Except for the on-board equipment, BN did not estimate separate costs for work order systems or locomotive health monitoring, since the focus at BN was on train control. Once necessary train control hardware was in place, the incremental cost of equipping locomotives for WORS or LARS would have been very small.

5.1.2 - COSTS - CN

CN cost figures were originally estimated in 1990 and were based on prototype price levels. Since then, there have been reviews of the costs, the most recent in mid-1992. These have taken into account an estimated reduction due to the higher volumes of a full ATCS implementation, but are still felt to be too high.

The cost figures below are grouped to reflect the most likely implementation scenario presented in the CN business case. This means that WOR would be implemented in industrial areas first, equipping 546 locomotives and installing 90 base stations. Locomotive health monitoring would follow, equipping 1,160 locomotives and using the base stations already installed.

Lastly, ATCS second story functions would be installed across the mainline and major branch lines. This includes upgrading 1,189 locomotives with OBC, speed and direction indicators; installing an additional 304 base stations; installing 16,000 transponders; and the central office hardware and software.

CN was not expecting sufficient benefits from track forces terminals to propose that the field forces' vehicles be equipped before the second story functionality was installed. Similarly, pole line and vital relay replacement was not expected to stand on its own economically, again deferring installation of the WIUs until the second story. Both these projects could be implemented as part of the first story, or deferred until after train control was implemented. However, CN included it as part of train control in order to maximize the run time and reliability improvements of train control.

There are some additional expenses for CN that would not necessarily apply to other roads installing ATCS. These include installing a flexible voice radio system so that dispatch desks can be combined in off-peak shifts and incidental expenses such as a dispatch building, relocation costs, etc.

Of course, if a different implementation strategy were chosen, these costs would be allocated differently. For example, if engineering units had already been equipped with data radio communication, then it wouldn't be considered as a cost of the second story; if pole line replacement had been done, the WIU costs would be reduced; etc.

Costs include installation and between a 5% and 10% level of spares. The following table reflects CN's expected costs for WOR.

WOR	# Units	$US / unit	Total ($US M)
Base stations	90	37,421	3.4
Locomotives (about half equipped with OBTs)	546	18,711	10.2
Central system, FEP/CC, communication lines, software, training, etc.			23.5
WOR Total			37.1

The following table includes CN's estimates for locomotive health monitoring.

LOCOMOTIVE HEALTH MONITORING	# Units	$US / unit	Total ($US M)
Base stations - included with WOR			
Locomotives (WOR-equipped)	274	28,916	8.0
Locomotives (not WOR-equipped)	886	42,524	37.7
Central system, software, etc. - included with second story costs			
Locomotive Health Monitoring Total	1,160		45.7

The costs for the second story are presented together. The appropriate split of the costs depends largely on the implementation steps chosen.

SECOND STORY	# Units	$US / unit	Total ($US M)
Remaining base stations	304	68,294	20.8
Locomotives (OBC, interrogator antenna, speed and direction indicators)	1,189	41,674	49.3
Transponders	16,035	387	6.2
Central office costs - see details below			46.8
WIUs (Wayside Interface Unit) - see below	1,209	30,702	44.9
Subtotal			168.0
TFDTs for track forces	2,198	21,687	47.6
Moving costs, separation costs, etc.			6.7
Voice radio upgrade			6.0
Subtotal			60.4
SECOND STORY Total			228.4

TOTAL ATCS COSTS	Total ($US M)
	311.1

Fully equipped locomotives have an MCP, OBC, OBT, display, keyboard, wire harness, power supply, interrogator antenna, locomotive sensors, speed indicator, direction indicator.

The central office costs include the building, communication, hardware and software. The functionality in the software is the central safety system, train handling assist, local tactical planner, train pacing and full train control.

The volume and unit price given for WIUs is only those for power switches, interlockings and slide fences. Spring switches will cost about $US 12,842. Electric locks and intermediate locations will cost about $US 3,147. The full amount (including the costs of dismantling current signal masts) is covered in the WIU total in the above table.

Data radio base stations include BCP, antenna, duplexer, feeder, installation or upgrade of DC plant, conditioning, installation, and the following where needed; antenna tower, building, land, civil engineering activities, AC power.

Different prices were used for data radio base stations in the WOR estimate and the second story estimate. There are a variety of reasons for this. If the power fails for an ATCS base station, it will cause more disruption than if a WOR base station fails, so a higher capacity battery for standby power was included in some of the base stations. WOR base stations are generally in more accessible locations. The additional costs to bring in power to remote locations or build a tower are included for some base stations and excluded for others. Lastly, the estimates were made by different firms. A supplier is more likely to produce a tight estimate to improve the chances of getting the work. Internal estimates are more likely to include contingencies; which increase the chance that the work will be done on budget.

6.1 - IMPLEMENTATION CONSIDERATIONS

ATCS is a large and relatively complex project for a railroad. Preparing a business case for full ATCS on the railroad is an important first step. It will provide specific answers to which components and functionality are worthwhile, what territory should be equipped, which classes of locomotives to equip, what resources are needed to implement it, what risks need to be minimized and what the payback will be.

Several larger issues would also need to be covered; the contribution ATCS makes to the railway's strategic direction and the immediacy of external pressures. This would include customer demands for service, legislative requirements for safety, economic needs for right sizing, physical needs of signal, communication, track and equipment replacement or expansion.

Once the business case analysis is complete, current decisions can be made with more confidence. For instance, assume there is a current project which needs to transmit data, but it is not decided whether ATCS-standard data radio should be used or not. When the ATCS business case is complete, it becomes clear that the ATCS standard is needed to avoid the pitfall of replacing or upgrading the data radio system later.

The sheer size of ATCS requires that risk reduction strategies need to be considered. Field testing is ongoing and prototyping of many components has already been done. Development and testing of key software before installing the hardware system wide is another way to reduce risk. The local tactical planner and the central safety system are prime candidates for this strategy.

Common development of the key software is another option. This could be done by the industry (say through the AAR), by joint agreement between railroads, in partnership with suppliers who wish to sell the developed software or in conjunction with legislative bodies, especially the central safety system which impacts safety.

Risk management would seem to require that any railroad install ATCS in limited geographic or functional stages. Geographic staging would allow integrated operation of ATCS, and would serve to confirm the expected benefits in advance of a commitment to equip an entire railroad. Either geographic or functional staging would permit time for training of users, and would also allow each part of the installation to be carefully evaluated before the next stage was undertaken.

Since ATCS is an information system and a management tool, "buy in" by management and operating staff is very important. Preliminary indications are that labour and management will respond favorably to the new technology. Presentations to operating unions on BN elicited a very positive response. UP reports that train crews are making extensive use of the work order display to query UP data systems on behalf of shippers.

Another risk reduction strategy is to implement in smaller, more manageable steps. This will reduce the demand for project management, people for implementing and training, and capital to more reasonable levels. This reasoning pushes towards a slower implementation. However, the following two points push towards a faster implementation. A trade off between the two extremes is needed.

Returning to the analogy of ATCS as a two story building, the first story is structurally complete and can stand on its own. However, if only one application from the first story was implemented, then the data radio infrastructure would not be used to its full potential. Payback is improved by the implementation of many applications. Additionally, once the data radio and the administrative functions of the first story are in place, large incremental benefits may still be realized through the addition of the second story; the central safety system, the local tactical planner and other parts of the train control function.

A phased approach can present challenges in equipping and dispatching the locomotives. If unequipped locomotives run on ATCS territory, then line capacity, run time and reliability benefits will be reduced. A study performed for Rockwell in 1990 indicated that there was almost no benefit in terms of running time improvement or increased line capacity until more than three-quarters of the trains were equipped.

The synergy between the ATCS features / benefits and the need to equip most locomotives / track force vehicles both push towards a faster implementation. However, the size of ATCS and the resources required calls for a slower migration path. Balancing these two forces is a key implementation issue. The next section describes some of the migration path options.

6.2 - MIGRATION PATH

ATCS need not be purchased as a single package. Work Order Reporting or Locomotive Health Monitoring may be implemented independently, for example. Alternatively, a part of the railroad (a region or division) might be equipped with a full ATCS package to test out the training, implementation, and benefits before implementing system wide.

If the railroad is planning capital replacement programs for code systems, vital relays, or communication infrastructure, then ATCS components can be used instead of the traditional hardware. Should there be a need for increased capacity, either for trackage or for equipment, then ATCS can be implemented instead of buying more equipment or laying more track.

ATCS could also be implemented geographically. The central systems would need to be developed for the first territory, but a reduced number of wayside devices and locomotives would need equipping. This would require that the equipped and unequipped locomotives be managed separately, which will reduce the locomotive utilization. However, this impact can be reduced by equipping more than the minimum number of locomotives for the territory but still less than the whole fleet.

Implementation of train control could be phased in by equipping the central office and locomotives first but keeping the existing signal plant in place as an interim step. While this strategy may delay realization of the full benefits associated with line capacity, run time and reliability, it spreads out the demand for capital and other resources.

ATCS can also be implemented in functional steps, data radio being the logical first piece because it enables so many other applications. The AAR ATCS project team has produced two possible migration paths for ATCS implementation: one for dark territory and one for routes already equipped with centralized traffic control. These two migration paths are shown in Figures 3 through 5.

6.1.1 - MIGRATION - BN

BN's conclusions regarding geographic staging were the same as CN's. BN found it virtually impossible to even consider trying to equip the entire railroad at one time. At the same time. so many of the identified benefits of ATCS required full functionality (100% of trains equipped, for example, in order to realize dispatching and line capacity benefits), that full implementation in a series of defined geographic areas was an obvious choice.

For BN, the definition of appropriate geographic areas was more difficult than for CN. BN is essentially three separate railroads which happen to share some common facilities: a coal hauling railroad, a carload freight railroad, and an intermodal railroad.

It is nearly impossible to find any part of BN on which all three services do not operate, and it will therefore be very difficult to maintain a captive locomotive fleet. Nevertheless, BN found that multi-stage implementation plans actually <u>increased</u> the net present value of ATCS. This is because BN recognized customer service benefits even from partial installation, and because of the generally high traffic density on BN (which produced immediate line capacity and running time improvements even in limited installations).

BN compared a two-stage implementation with two four-stage alternatives. The two-stage plan, which equipped the northern part of the railroad and the heavy coal routes first, followed by the southern half of the railroad (which is generally lighter density) produced an NPV of $403 million.

A four-stage plan beginning with the southern trackage, moving to the coal routes, and finally to the northern transcontinental lines, produced an NPV of $419 million. An alternate four-stage approach which equipped the northern lines first, then the coal routes, and finally the southern trackage, yielded an NPV of $451 million. This led BN to conclude, in its business case analysis, that ATCS might even be made self-financing, with the savings from each stage of the installation paying for the next stage. Managing such a complex, multi-stage project would, however, be very difficult.

The value of BN's investigation into staging is that it suggests that, while the total cost of an ATCS installation will be large for any railroad, a staged implementation can minimize financing problems.

ATCS MIGRATION PATH: Dark Territory (TWC or TI/TO)

Figure 3

	STEPS	RESULTS	OFFICE	LOCOMOTIVE	TRACK	FIELD	COMMERCIAL APPLICATIONS
1	Interface	Interface with MIS systems					
1	Computerize office with voice radio	Reduces errors in overlapping authorities	TWC with conflict checking (switch status optional)				
2	Data Link	Reduces radio traffic, more accurate information	CDC functions - set 2	OBC functions - set 2			Commercial product - set 1
3	OBC with display	Reduces errors in misreading, transcribing and confirming authorities	CDC functions - set 1	OBC functions - set 1			
3a	Location system	More efficient use of system, reliability & capacity improvement	CDC functions - set 3	OBC functions - set 3			Commercial product - set 2
3b	Enforcement	Train separation, protect track forces, reduce derailments	CDC functions - set 4	OBC functions - set 4			
3	Track Forces	Decreases transmission errors, more efficient use of track gangs	CDC functions - set 5		TFT functions - set 5		Commercial product - set 3
3	Field systems	Improve efficiency and safety of operation	CDC functions - set 6			WIU functions - set 6	Commercial product - set 4

See Figure 5 "ATCS Functions and Products List" for itemized elements.

ATCS MIGRATION PATH: CTC Territory

	STEPS	RESULTS	OFFICE	LOCOMOTIVE	TRACK	FIELD	COMMERCIAL APPLICATIONS
1	Interface	Interface with MIS systems					
1	Computerize office	Reduces errors in overlapping authorities	TWC with conflict checking (switch status optional)				
2	Data Link	Business applications, code line replacement					Commercial product - set 1
3	OBC with display, location system	More efficient use of system, reliability and capacity improvement	CDC functions - set 2 & 3 (only track_train without OBC)	OBC functions - set 2 & 3			Commercial product - set 2
3	Track Forces	Decreases transmission errors, more efficient use of track gangs	CDC functions - set 5		TFT functions - set 5		Commercial product - set 3
3	Field systems (if not done at 3)	Improve efficiency and safety of operation (vital link field to office)	CDC functions - set 6			WIU functions - set 6	Commercial product - set 4
3a	Issue authorities	Reduce transmission errors	CDC functions - set 1	OBC functions - set 1			
3b	Enforcement	Train separation, protect track forces, reduce derailments	CDC functions - set 4	OBC functions - set 4			

See Figure 5 "ATCS Functions and Products List" for itemized elements.

ATCS Functions and Products List

Figure 5

Train Control Functions

Set 1
- Track_train
- Init_train
- Issue_authority
- Release_authority
- Terminate_train
- Train_session_mgr
- Restrict_MA
- Rogue_handler
- Clear_track
- On_off
- Pace_train
- Emerg_stop

Set 2
- Load_route
- Mon_health
- Issue_TCN
- Release_TCN
- Oper_TCN

Set 3
- Change_op_level (may need to redefine meaning of level)
- Advisories
- Loco_fail
- Train_defect
- Mon_loco_health
- Distribute_time
- Historic_log
- Diagnostic_log

Set 4
- Enforcement

Set 5
- Track_gang
- Init_gang
- Terminate_gang
- Issue_lineup
- Gang_session_mgr
- Issue_TWP
- Release_TWP
- Oper_TWP
- Release_lineup

Set 6
- Set_route
- Oper_ctl_device
- Fiel_session_mgr
- Code_line_replacement
- Combine_train
- Split_train
- Stack
- Oper_non_ctl_device
- Oper_hwy_device
- Oper-TDD
- Control_signals

Commercial applications

Set 1
- Work order reporting
- Locomotive health
- Interface with "locomotive control system"

Set 2
- Tactical planner
- Strategic planner
- Interface terminal information management systems

Set 3
- Payroll reporting
- Track inspection
- Track work and maintenance reporting
- Material and production reporting

Set 4
- Intelligent interface to wayside

6.1.2 - MIGRATION - CN

In the CN business case, WOR and locomotive health monitoring looked sufficiently promising to pay their own way. However, they were not expected to provide the entire ATCS infrastructure. For instance, WOR was planned for the industrial areas as a first step. This means that less than one third of the locomotive fleet would be equipped with data radio and about one quarter of the data radio base stations would be installed.

Similarly, locomotive health monitoring would equip all the mainline fleet with data radio and locomotive sensors, but not the more expensive OBC needed for train control. As a first cut, no additional data radio base stations were added for locomotive health monitoring, just the data radio base stations put in place by WOR. This achieves several goals; most of the advantages of real time information about both car pick ups and set outs, most of the information about the locomotive fleet and a good start implementing the data radio communication system and equipping locomotives.

Of course, all the advantages from WOR and locomotive health monitoring will not be realized until the local tactical planner is implemented and the information gathered is used by the local tactical planner and other systems. However, benefits flow in from the WOR and locomotive health monitoring projects now and future ATCS benefits are closer because some of the infrastructure is in place.

Although not included in the business case, some CN track in the BC north is on the borderline for an upgrade in capacity due to the traffic load. An ATCS pilot is under development for this territory instead of the more conventional signal system.

The CN business case does not include large benefits for the pole line replacement nor the track forces terminals. Because of this, they would not be used to drive the implementation. However, should capital replacement become necessary, using ATCS components would be a strong option.

In the business case, two implementation scenarios were set out for train control. The first was to implement it as fast as possible to get the benefits quickly. The second was to phase it by geographic regions. The geographical staging reduced the return a little, but also seemed more practical in terms of manageability, financing and risk reduction. The business case only looked at broad implementation strategies; this area deserves more detailed study than it has received so far.

CN, being such a low density road, requires an additional step in the migration path. Network rationalization is being actively studied and the results will impact both the territory that requires field hardware such as WIUs and data radio and the number of locomotives that will need to be equipped.

7.1 - CONCLUSIONS

The ATCS technology has been tested. BN operated a pilot project on the Iron Range in northern Minnesota for four years. CN has been testing a prototype ATCS work order system in the Toronto area since 1990, and is equipping part of the BC North line with ATCS train control hardware and software.

None of the technology in ATCS is new. Digital radio has been in use for a number of years. Computers have functioned successfully in harsher environments than diesel locomotives. Train dispatching software has been developed and tested. The remaining ATCS development tasks will require time and money, but they are not in the same class as the Star Wars technology.

At the same time, ATCS offers the railroad industry a higher level of safety than can be achieved by any current train control system. Along with safety, ATCS also provides effective tools for controlling railroad assets and service quality. It appears, from the work done by both BN and CN, that major improvements in railroad service are possible. These service improvements should produce additional revenue and increased market share. The local tactical planner is key to several of the benefits of ATCS. If this software does not live up to expectations, the business decision will need to be reviewed.

The following table shows the NPV, internal rate of return and the capital cost calculated in the BN and CN business cases. BN calculations for ATCS were based on 1989 costs. CN's business case was completed in 1990. It seems reasonable to expect that the cost of most ATCS equipment will decline over time, since that has been the trend for electronic and computer equipment over many years. Therefore, the prices shown in section 5 are likely to overstate the cost of ATCS.

CAPITAL COST, INTERNAL RATE OF RETURN AND NET PRESENT VALUE
BN and CN ATCS Business Case Findings

Railroad	Capital Cost	IRR	NPV*
BN - Base Strategy	$ 350M	28%	$ 406M
CN - Risk Reduction Strategy	$ 311M	24%	$ 123M

*NPV based on discount rate of 9% (real) for BN and 15% for CN. The NPV calculation shows the difference between the costs of ATCS and the benefits of ATCS. Note that BN's discount rate is a real interest rate, net of inflation and taxes. This is yet another element of conservatism in the benefits analysis, since a real rate of return of 9% is very high (real long-term rates in spring 1993 are about 3.5%).

BN and CN both conducted sensitivity analyses on the prices of various components of the system and on the benefits. Since the benefits flowed from so many different areas, sensitivity analysis of specific benefit areas also produced only small changes in the return. BN's business case included a risk assessment, in which an attempt was made to define the probability of any expected return. The analysis found that the probability of a rate of return of less than 9% from an ATCS implementation was near zero.

Both BN and CN found, in their business cases, that the expected return from an investment in ATCS was between 20% and 30%. The range reflects different timing and implementation scenarios. What is striking about the two business cases is that, despite differences in methodology and differences between the two railroads in terms of traffic densities and traffic mixes, the rates of return were very similar. This is another indication of the "robustness" of the benefits of ATCS. The expected return does not vary a great deal when different costs or different implementation strategies are used.

Finally, there are many benefits of ATCS that have not been quantified. They include more predictable working hours for train crews, reduced job stress for train dispatchers, reduced wear on track and equipment, electronic blue flagging, on-board hot bearing detection, car environment monitoring, and Beltpack ™ for remote operation of locomotives. Previous projects have had similar problems. For example, dieselization benefits far exceeded what was predicted before its implementation.

The costs of electronics, communication equipment and computers continue to decline and an increasing number of benefits are not included in the business cases. Both these factors point to the return of ATCS being conservative at 20% to 30%.

ATCS is a technology with many potential applications in the railroad industry. It will improve safety, service reliability, and asset management. It will enable railroads to more easily share trackage with other users (foreign roads and passenger trains). It will increase line capacity, enabling several U.S. railroads to avoid potentially large capital investments. It will enable CN and Canadian Pacific (CP) to more easily combine facilities and reduce investment. The benefits are varied and robust. ATCS offers the railroad industry the chance to go beyond cost reductions and to focus also on improving service.

A major advantage of ATCS for railroads is that it has been developed as an open-architecture industry standard. Railroads are interdependent; most traffic moves on more that one railroad. The interoperability of ATCS-equipped locomotives will take the industry a step closer to offering "seamless transportation".

Interline Service Management (ISM), a new initiative by the AAR and several railroads, may add to the attractiveness of ATCS. While ATCS may not be essential to realize the goals of the ISM initiative, it will certainly help the process of improving railroads' ability to supply each other with accurate ETAs and service plans.

One challenge of ATCS, as with so many information technologies, is that it goes beyond simply automating the existing processes. It will create new processes and change the current method of operations. For example, the local tactical planner will provide good meets, regardless of the experience of the dispatcher. It will also significantly impact the job of a dispatcher. In turn, this will effect the on-time performance delivered to the customer and change the required skills and training needed by dispatchers.

ATCS also impacts several areas of operation, crossing over functional boundaries, which further adds to the challenge. Locomotive health monitoring, for example, impacts locomotive maintenance as well as power control. This increases the importance of making the high level decisions (eg. functionality chosen, territory covered), translating the concept into specific impacts in individual areas (eg. percentage reduction in locomotive failures) and then explaining why, how and when it is going to make a difference.

ATCS is real; the benefits of ATCS are real; the need to provide better service is real. The question may actually be when to implement ATCS, not whether to implement it or not.

APPENDICES

APPENDIX A.1 - BN Business Case

#14

ARES BENEFITS ANALYSIS

VOLUME 1
SUMMARY OF FINDINGS

Prepared by: ______________________
M. E. Smith

Approved by: ______________________
E. L. Butt

August 14, 1989

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LIST OF FIGURES AND TABLES

SECTION 1.0
INTRODUCTION

KEY POINTS

- *Ten Burlington Northern departments and seven consulting firms analyzed ARES' potential effects on:*
    - *line-haul and terminal operational efficiency*
    - *service*
    - *market penetration*
    - *locomotive use*
    - *loss and damage to lading*
    - *road train crew labor negotiations*
    - *equipment, track, and liability losses from accidents*
- *The team analyzed ARES' effects under three corporate strategies, "focused," "base," and "expansion."*
- *This study examined ARES' reductions in transit times to:*
    - *increase service and revenues,*
    - *decrease operating costs, or*
    - *avoid investments in right of way*
- *ARES' goals are to:*
    - *command and control the safe movement of trains on schedule*
    - *communicate among vehicles on the track and operations personnel*
    - *gather and distribute information about railroad operations*
- *ARES will be installed in three segments over seven years:*
    - *the Control Segment, which automates dispatching*
    - *the Data Segment, which enables communication among vehicles and operations personnel*
    - *the Vehicle Segment, which equips vehicles to communicate with ARES*
- *ARES offers the following benefits to BN:*
    - *increased safety*
    - *greater efficiency*
    - *improved service*
    - *greater productivity*
    - *higher capacity*
    - *improved business management*

1.1 BENEFITS ANALYSIS TEAM

For several years, Burlington Northern has been developing, testing, and evaluating ARES, the Advanced Railroad Electronics System. The goal of ARES is to improve safety, productivity, and service throughout Burlington Northern Railroad.

A team of Burlington Northern experts and external consultants recently analyzed the potential benefits of ARES. The team included:

Burlington Northern	External Consultants
Planning and Evaluation	John Morton Company
Transportation	Carl Martland (MIT)
System Engineering	A&L Associates
Information Systems Services	Harold Bongarten Associates
Labor Relations	University of Pennsylvania
Marketing	Strategic Decisions Group
Operations Services	Zeta-Tech Associates
Service Design	
Operations (St. Paul, Denver, Seattle)	
Research and Development	

1.2 TECHNICAL APPROACH

As shown in Figure 1-1, Burlington Northern and its contractors have spent considerable effort on the ARES benefits analysis. BN retained contractors to assist in answering questions in three critical areas:

1. To what extent will line-haul and terminal operational efficiency and service improve under ARES?
2. What will be the effect on BN's markets of the service improvements identified in (1)?
3. How will LARS affect the efficiency of locomotive utilization and servicing?

Burlington Northern personnel explored other areas of benefit:

1. To what extent will improved train handling reduce loss and damage to lading?
2. To what extent will improvements in line-haul efficiency and reliability improve BN's negotiating posture for road train crew labor?
3. By how much will the safety improvements of ARES reduce equipment, track, and liability losses from accidents?

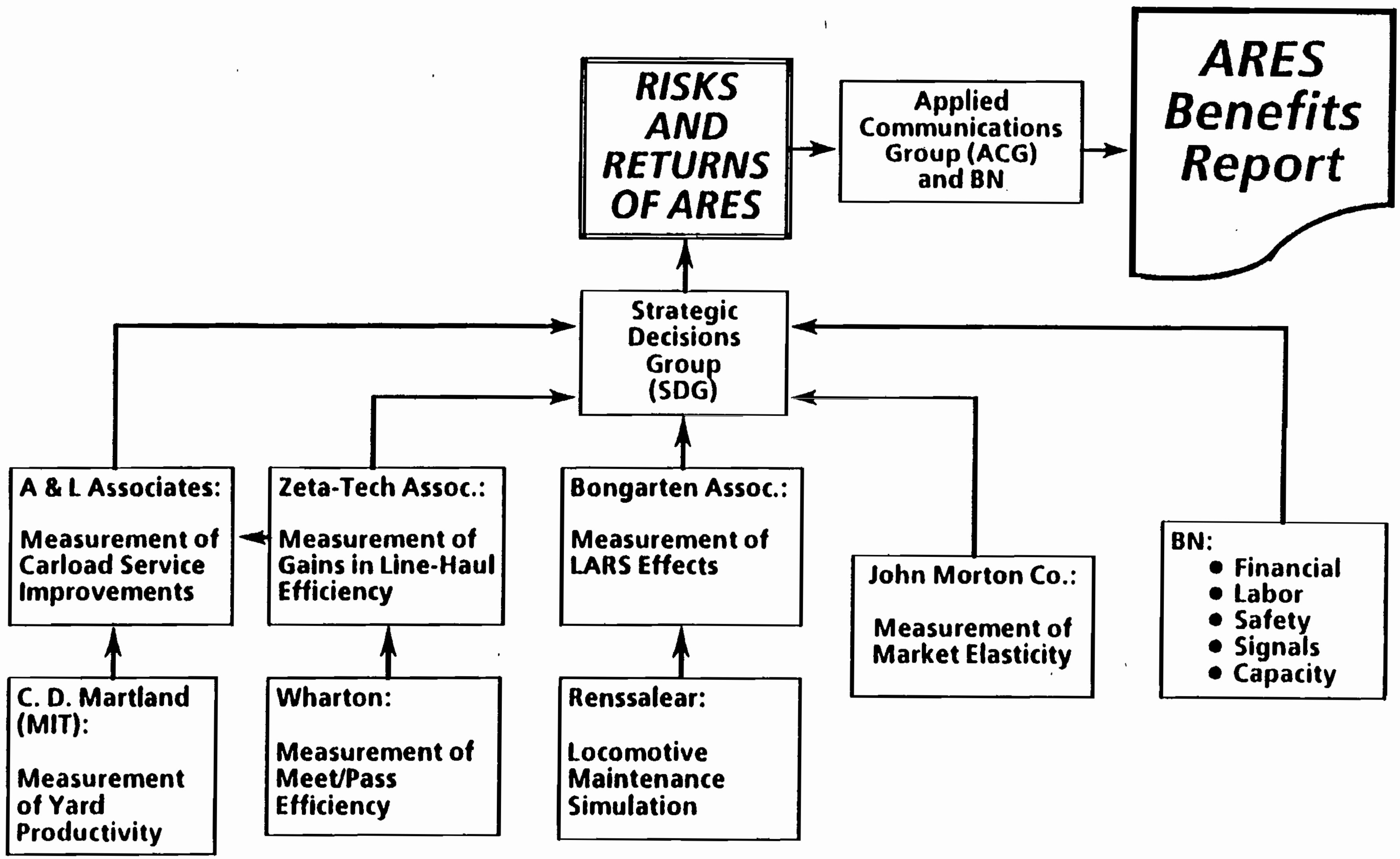


FIGURE 1-1 THE ARES BENEFITS ANALYSIS PROCESS

A difficult benefit to measure was the extent to which service would improve and the financial gain service improvement could make. The team began by exploring the gains in line-haul efficiency from ARES' precision position and speed indications and automated meet/pass planning tools.

Zeta-Tech measured line-haul efficiency gains by collecting data on all trains traversing sixteen representative Burlington Northern lanes (approximately 150 miles of track for each lane) for approximately twenty-four hours. A computer algorithm designed by Wharton analyzed the data to reflect the manner in which the ARES meet/pass planner will work. The results of this computer analysis were compared to the manner in which the trains were actually dispatched to determine gains in travel time available by train class.

Zeta-Tech also selected a representative set of trains for evaluating the Energy Management System (EMS) of ARES. They analyzed the event recorder tape on each train to determine how the engineer handled the train. They fed information to the EMS to determine how it would handle the train. Zeta-Tech then used a simulation model to compare fuel consumption of the train in the manner that it was actually handled to the way in which EMS recommended that it be handled.

At the same time, Mr. Carl Martland of the Massachusetts Institute of Technology visited BN yards to determine what effects ARES might have on terminal performance. Mr. Martland collected data on six yards over one month and spent a day at each yard studying its operation. He fed this data into a computer model of yard operations to duplicate BN's current yard operation. Mr. Martland then used computer simulation to model the way in which the yards would operate when ARES becomes available.

After the team determined possible line-haul and yard operational improvements, A&L Associates determined how these gains would affect service for carload commodities that need reclassification. They used a computer model to determine how connection reliability would improve under the ARES-equipped railroad. From this, they determined the degree to which customer reliability would improve for carload freight.

Meanwhile, John Morton Company investigated the extent to which improved customer reliability could yield financial gain. They did this by interviewing shippers to determine how much more they would pay for service that had greater reliability.

As these studies proceeded, Bongarten Associates developed methods to determine how much LARS could improve locomotive utilization and reduce maintenance costs. They developed a computer model to analyze what would happen if more data and more data processing capability were available to remotely monitor and diagnose locomotive systems. They used this model to analyze Burlington Northern locomotive failure data for the last six months of 1988.

These contractors fed their information to the Strategic Decisions Group (SDG). SDG augmented this information with internal Burlington Northern data on loss and damage, accidents, and labor to determine the total amount of benefits available from ARES. SDG then used judgments from BN managers to determine the likelihood of achieving these benefit levels.

The analysis examined benefits under three corporate strategies provided by BN's Planning and Evaluation group in Fort Worth. The first strategy assumes that

Burlington Northern retains all of its current coal and grain traffic (focused strategy). It retains auto, intermodal and merchandise traffic only if the traffic moves more than 800 miles or if it is an interline move. The second strategy assumes that BN continues to conduct business as it does today (base strategy). The third strategy expands service and enhances revenues (expansion strategy).

The analysis presents key uncertainties as probability distributions. It mathematically combines distributions to determine the uncertainty in the final estimates. This approach both quantifies the uncertainty of specific benefits and avoids "single-point" estimates.

The team made every effort to ensure the analysis was realistic. It avoided double counting of benefits, for example, expressing a benefit as a reduced cost or increased revenue but not both. It took no credit for programs already underway and added realistic time delays between implementation and realization of benefits. The analysis also anticipated that a significant number of locomotives would be out of service due to equipment installation during the implementation of ARES. The analysis includes the cost of leasing locomotives to cover the anticipated shortfall. The analysis also accounts for trains powered by foreign locomotives and needing to use a Burlington Northern ARES-equipped locomotive.

One of the expected benefits of ARES is reduced transit times. This benefit can be realized in three ways:

1) as an increase in service level and enhanced revenues,

2) as a decrease in operating costs, or

3) as an avoidance of future investments in right of way.

The analysis looked at each of these realizations separately and examined the tradeoffs among them to recommend the best strategy.

1.3 ARES, THE ADVANCED RAILROAD ELECTRONICS SYSTEM

ARES combines the technologies of high speed computing, digital communications, satellite positioning, and state-of-the-art electronics to:

- command and control the safe movement of trains on schedule,
- communicate among locomotives, MOW vehicles, wayside systems, dispatchers, and managers, and
- gather and distribute information about locomotives, trains, crews, consists, and track.

1.3.1 Feasibility

Work began in 1984 to explore the feasibility of ARES. BN concluded that ARES could be built and installed on the railroad, and so it began to develop a prototype with Rockwell International in 1986 to test ARES in a real operating environment. The prototype runs on 17 locomotives and three MOW vehicles over 230 miles of track on the Mesabi Iron range. Figure 1-2 shows the history of the ARES feasibility study and prototype development.

BN is using information from its testing to define the functions and forms of the production system.

1.3.2 Development and Installation

ARES will be built by Rockwell International and installed throughout the railroad in three segments. First, the Control Segment will equip dispatchers to monitor the positions and velocities of all vehicles in all types of territory to control traffic more effectively. ARES will produce a traffic plan, display activity at three levels of detail, and supply information about consists, crews, and work orders for any train in the territory. ARES will monitor activity to ensure that vehicles follow proper operating procedures and warn the dispatcher of violations to limits of speed and authority. ARES will produce authorities which it has checked for conflict. After the dispatcher reviews them, ARES will transmit them automatically to engineers.

In the ARES Data Segment, BN will install equipment to send data between radio base stations along BN track, locomotives, MOW vehicles, and track monitoring and control equipment. Data will travel in short messages called packets routed by a front-end processor, cluster controllers, and ground terminal controllers at radio base stations approximately 30 miles apart. Wayside Interface Units, or WIU's, control powered switches, monitor manual switches, and communicate switch and signal status through the network to the dispatcher.

In the ARES Vehicle Segment, BN will equip each locomotive with a receiver of Navstar satellite signals to calculate train position and speed. A display on board each locomotive will inform train crew members about movement authorities, the route ahead, work along the route, and the health of other locomotives in the power consist. The health monitoring system will monitor various aspects of locomotive performance to diagnose malfunctions early and schedule maintenance most cost-effectively. BN will equip each MOW vehicle with a satellite receiver to calculate its position and speed, a device to communicate to the dispatcher, and a printer to receive warrants, bulletins, and ETA's in the field. The Vehicle Segment will also equip ARES to apply a full-service brake to any train if its crew is disabled or violates a movement authority.

The relationship of these segments appears in Figure 1-3. Figure 1-4 shows the Development and Implementation schedules for the three segments of ARES. ARES is described in detail in the ARES Control Segment Systems Requirements Document produced by Burlington Northern in June, 1989. Volume 1 introduces its functions, capabilities, and benefits and defines its development activities. Volume 2 with appendices details the operation, functions, quantitative performance and capacity, and architecture of the ARES Control Segment.

ARES HISTORY
PHASE I and PHASE II

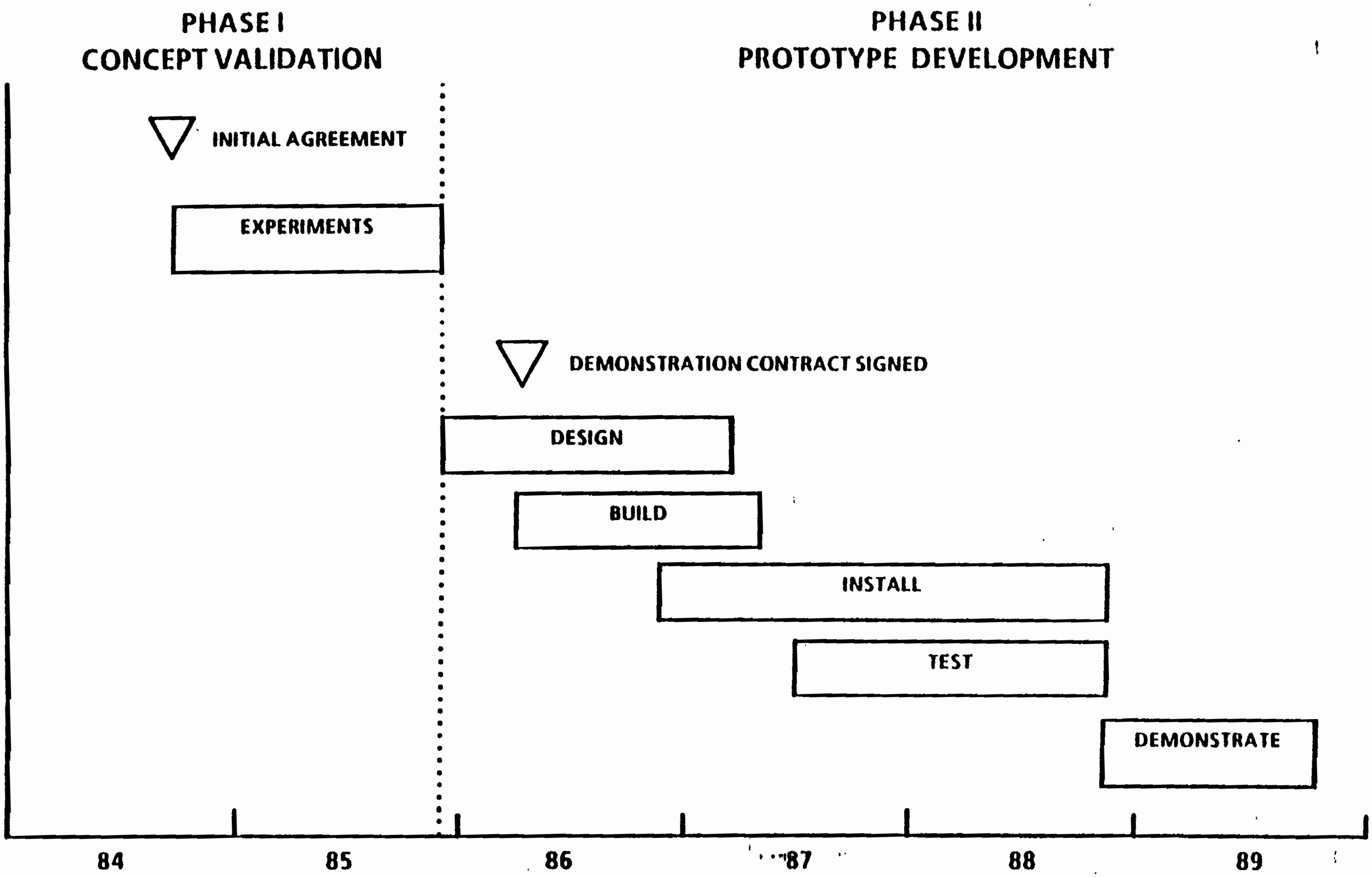


FIGURE 1-2

RELATIONSHIP AMONG ARES IMPLEMENTATION SEGMENTS

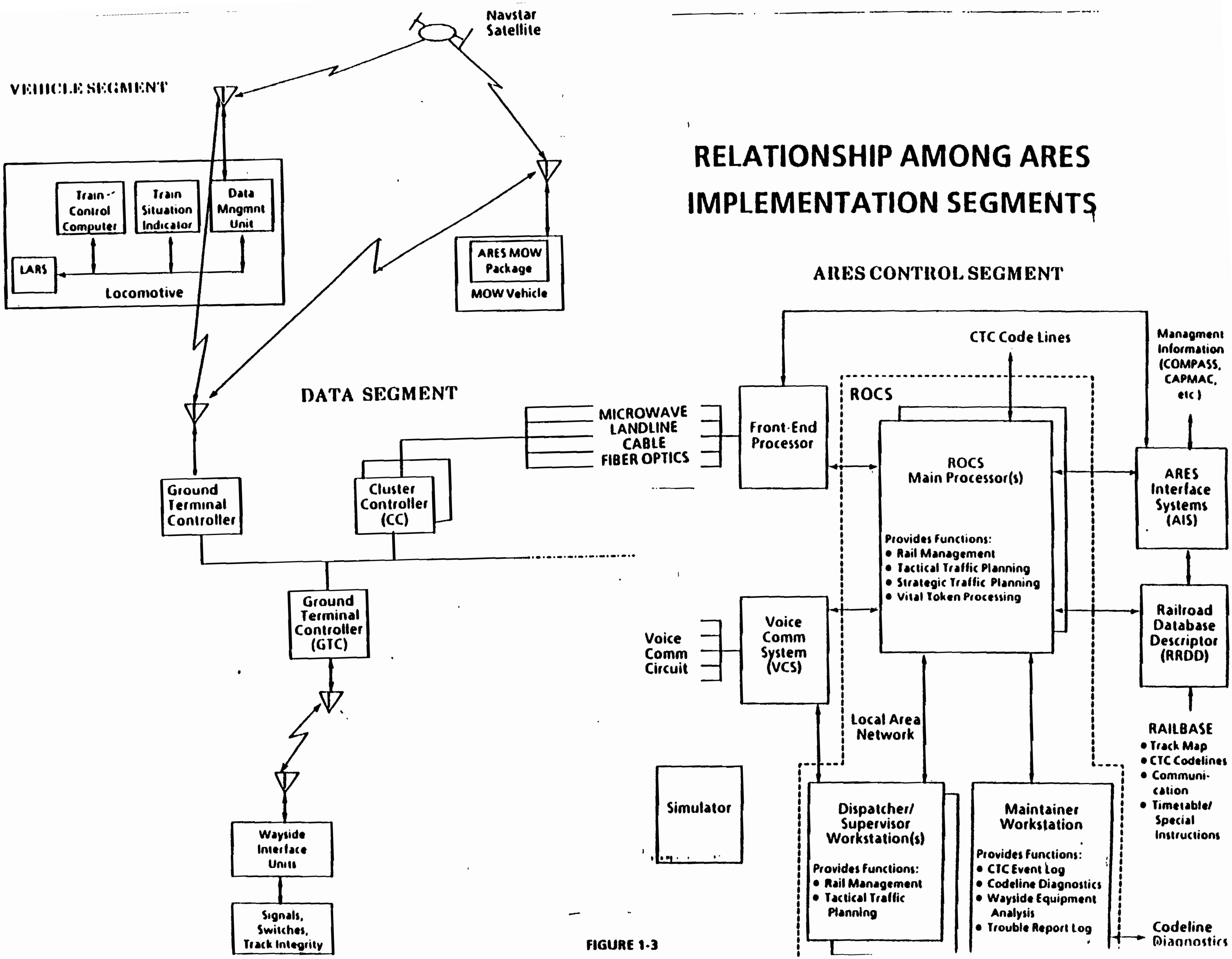


FIGURE 1-3

ARES IMPLEMENTATION PHASE III

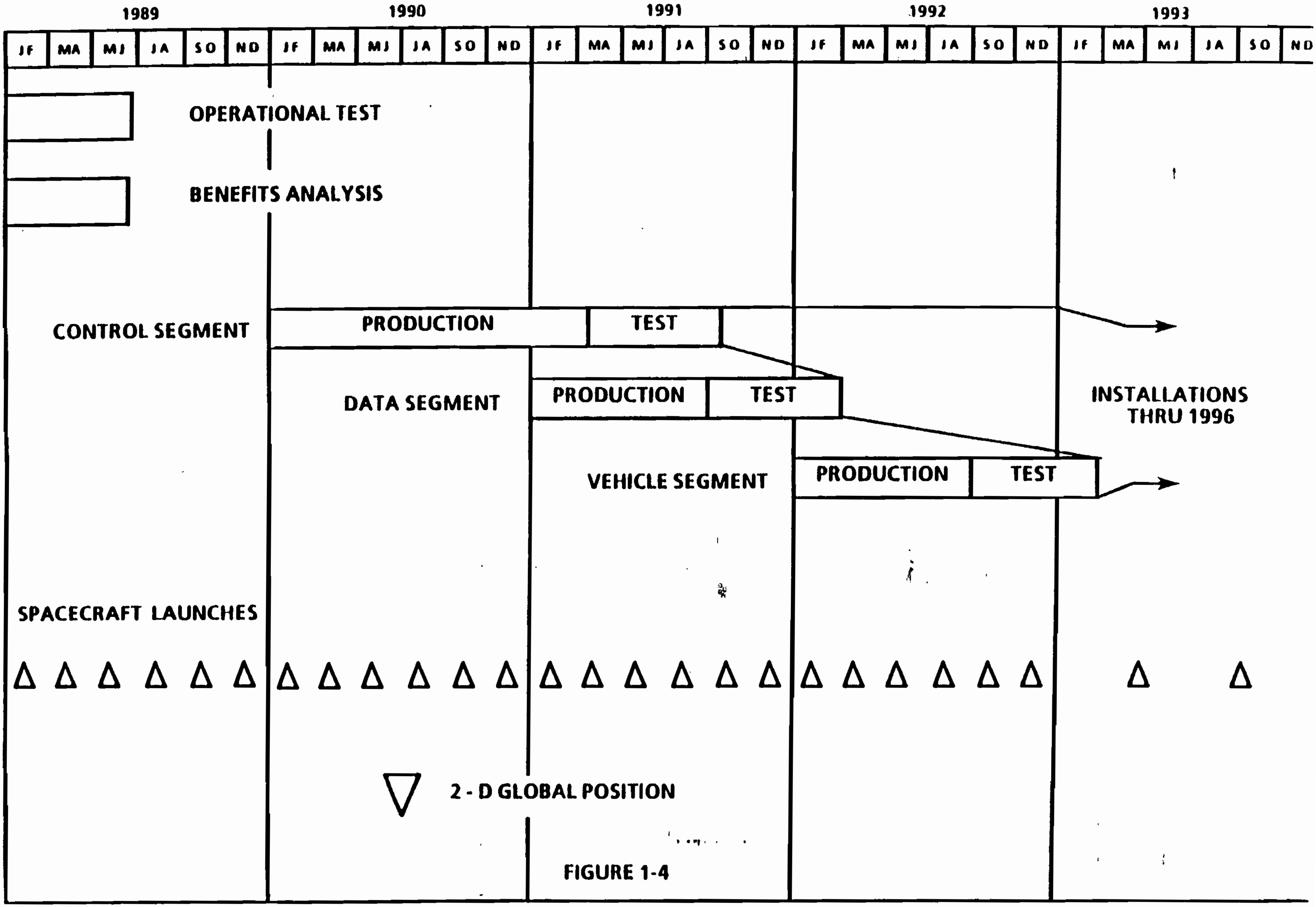


FIGURE 1-4

1.3.3 Benefits

ARES offers many benefits which enable BN to reach its goals of safe and profitable rail operations. Following is a summary of those benefits.

- **Increased rail operations safety** results from constant monitoring of wayside signal and detector equipment, train movement, and locomotive health.
- **Greater operating efficiency and improved customer service** come from operating trains to schedule and handling trains that deviate from schedule, the results of improved traffic planning.
- **Improved safety and increased customer service** come from real -time position, speed and ETA's for all trains computed continuously and automatically provided to MOW crews and other BN users through existing BN computer systems.
- **Improved dispatcher productivity** results from automating routine dispatching activities such as threat monitoring, warrant generation, traffic planning, and train sheet documentation.
- **Higher effective line capacity** is provided by accurate vehicle position information and automatic train movement authorization.
- **Improved MOW productivity** results from improved traffic planning.
- **Improved business management** is possible with accurate, current information about the status and performance of operations and equipment.

The following pages quantify and analyze these benefits under three strategies for BN's future growth.

SECTION 2.0
ARES AND CORPORATE STRATEGIES

KEY POINTS

- *The study examined ARES within three corporate strategies:*
  - *"focused," in which BN retains all coal and grain traffic but only auto, intermodal, or merchandise traffic if an interline move or a move greater than 800 miles on-line*
  - *"base," in which no changes occur in pricing, service level, traffic growth, or transportation industry cost structures*
  - *"expansion," in which service consistency improves 15% and traffic volumes generally increase 75%*
- *For each strategy, the study used projected growth rates lower than BN's actual growth rate from 1986 to 1988.*

2.1. CORPORATE STRATEGIES

The Planning and Evaluation department of Burlington Northern has developed three strategies to govern the direction of the railroad into the twenty first century. These are titled focused, base, and expansion. The following section defines and compares them.

2.1.1 FOCUSED STRATEGY

The focused strategy makes two primary assumptions:

- Burlington Northern retains all coal and grain traffic.
- Burlington Northern retains auto, intermodal, and merchandise only if that traffic is an interline move or is moving more than 800 miles on-line.

These assumptions are based on the proposition that future rail traffic will not be competitive with new long-haul trucks for non-bulk traffic at distances less than 800 miles.

2.1.2 BASE STRATEGY

The base strategy assumes that today's competitive situation does not change:

- There are no changes in pricing, level of service, or traffic growth rate.
- The cost structures of railroads, trucking lines, and barge companies remain as they are.

2.1.3 EXPANSION STRATEGY

The expansion strategy assumes increased service consistencies (the percent of time shipments arrive on schedule) and elasticities (here, changes in traffic volume due to improved service) for various commodity types:

- Service consistency improves 15%, from 70% to 85%.
- Overall, traffic volumes increase five percent for every percent of increase in service consistency.
- However, some commodities' volumes increase more or less due to improved service. For example, farm products' volumes increase another 75% when service improves, while coal's volumes do not increase any more. The following multipliers show how much improved service increases volumes for various commodities:

+ 75%	-	Farm Products, Canned Goods, Frozen Food, Sweeteners/Oils, Beverages,Grocery Products, Minerals, Government and Consumer Goods, Paper, Intermodal other than Expediter, Environmental Logistics.
+ 50%	-	Industrial Chemicals, Petroleum, Steel Products, Aluminum, Other Metals, Petrochemicals, Pulpwood, Plywood, Lumber, Particle Board, Woodpulp, Other Wood Products.
+ 25%	-	Automotive
+ 0%	-	Barley, Corn, Wheat, Other Grains, Oil Seeds, Feeds, Flour/Grain, Malt, Fertilizer, Industrial Sands, Clays/Barites, Iron/Ores, Coke, Coal.
+ 100%	-	Expediter intermodal

- All carriers are able to incorporate these improvements.

2.2 STRATEGY COMPARISONS

The strategies generate traffic volumes projected to the year 2005 and summarized in Table 2 - 1. Table 2 - 1 shows full carload trips in millions and compounded annual percentage growth rates.

The projected traffic flows of Table 2 - 1 are compared graphically in Figure 2 - 2.

Traffic Type	Current Flow	Traffic Flow in 2005 (full carload trips, millions/compound annual growth rate)		
		Focused Strategy	Base Strategy	Expansion Strategy
Intermodal	1085	1500/2.2%	1825/3.5%	2400/5.4%
Coal	1415	1475/0.3%	1475/0.3%	1475/0.3%
Grain	485	605/1.5%	610/1.5%	610/1.5%
Merchandise	1110	1190/0.5%	1770/3.2%	2580/5.8%
Total	4095	4770/1.0%	5680/2.2%	7065/3.7%

Table 2 - 1 TRAFFIC FLOW PROJECTIONS FOR 2005

2.3 PROJECTED GROWTH RATES

The annualized compound growth rates of total traffic for the focused, base, and expansion strategies are 1.0%, 2.2%, and 3.7% respectively. Comparing these growth rates to the actual and projected traffic levels shown in Figure 2 - 2 yields the following conclusions:

- The projected growth rate used in the ARES benefits analysis is not as high under any strategy as the actual growth rate was from 1986 through 1988.
- The growth rates projected to the year 1993 by the Planning and Evaluation department are significantly higher than those used in the benefits analysis.

The Addendum to this document presents a number of actual and projected measures of growth from 1986 to 1993. Note that traffic levels in Figure A - 4 are measured in revenue ton miles. The focused, base, and expansion strategies measure growth in full carload trips. Full car load trips will grow slower than revenue ton miles.

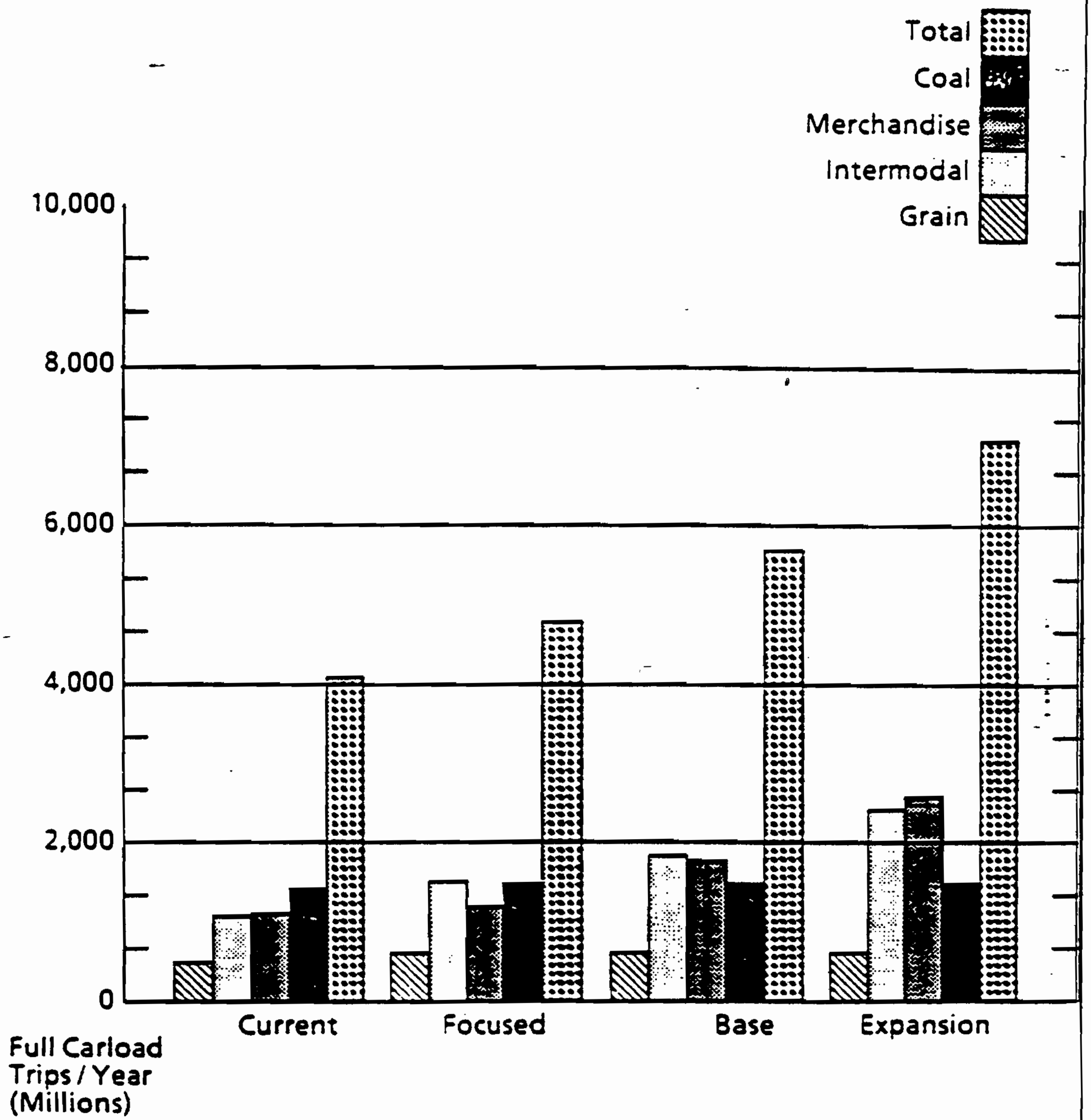


Figure 2 - 2 PROJECTED TRAFFIC VOLUME FOR 2005

SECTION 3.0
ARES BENEFITS

KEY POINTS

- *The study examined benefits in the following areas and estimates the present value of those benefits:*

• *fuel*	*$52 million*
• *equipment*	*$81 million*
• *labor*	*$190 million*
• *trackside equipment and damage prevention*	*$96 million*
• *enhanced revenues*	*$199 million*
TOTAL	*$618 million*

- *To account for uncertainty in these estimates, the study calculated ranges of values for them and probabilities of achieving values within the ranges.*
- *The factors with the largest potential for delivering benefits are also the most uncertain:*
    - *ARES' ability to improve transit time and*
    - *The amount customers are willing to pay for better service.*
- *Accounting for ranges and probabilities, ARES will make the following mean contribution to net present value for each corporate strategy:*

• *focused strategy*	*$360 million*
• *base strategy*	*$406 million*
• *expansion strategy*	*$576 million*

- *The probability of ARES earning less than 9% real after-tax rate of return is extremely small.*

3.1 BENEFIT CATEGORIES

ARES will provide benefit to Burlington Northern in the following areas:

- FUEL
- EQUIPMENT
- LABOR
- TRACKSIDE EQUIPMENT AND DAMAGE PREVENTION
- ENHANCED REVENUES

The following sections describe each benefit, discuss the methodology used to estimate it, and estimate its value in dollars to Burlington Northern.

3.1.1 FUEL

ARES will reduce fuel consumption through three mechanisms:

- Energy Management System
- Improved Meet/Pass Planning
- Increased Locomotive Efficiency From LARS

3.1.1.1 Energy Management System

The Energy Management System (EMS) is a part of ARES which provides the train engineer with optimal train handling control settings, or maneuvers, to minimize fuel use while maintaining schedule. For example, the cresting maneuver sets the locomotive throttle position back as the train approaches the top of a hill and maintains lower throttle positions over the crest, producing lower minimum speed, slower acceleration, and less fuel use.

The EMS study compared simulations of actual (baseline) trains to simulations of the same trains with EMS units. The simulations were performed on the American Railroad Train Energy Model (TEM), which can calculate fuel consumption, running time, and other costs of operating a defined consist over a defined route.

Locomotive event recorder tapes of fifty-five consists across sixteen line segments yielded baseline train handling information. These tapes record train speed and control settings. The study digitized the data to build a TEM command file consisting of a series of target speeds. By following these target speeds, the TEM simulator was able to match actual train operation, representing virtually the entire range of operating conditions, practices, and traffic densities on Burlington Northern main lines. Where possible, the study sampled one train in each of four broad categories -- loaded bulk (coal, grain, ore), empty bulk, mixed freight, and intermodal -- on each lane; in every case it sampled at least three trains in a lane.

Rockwell International then developed EMS train handling scripts for each of the fifty-five train consists. TEM command files similar to those for the baseline simulations were created from these scripts, again using target speeds rather than control settings. The EMS-modified speed profiles were simulated on the TEM model to produce new running times and fuel consumption numbers. The differences between these values and those for the baseline simulations indicated the benefit of the Energy Management System.

The EMS study appears in full in Appendix 1. It concludes that as much as 3% of fuel can be saved through the use of an EMS. However, these savings come at the expense of travel time. Since the EMS must get the train to its destination on time with a minimum of fuel consumption, the algorithms which produce its train-handling scripts need additional work. However, a report from Australia* suggests that this problem can be solved with fuel savings greater than 3% and no sacrifice of total travel time. Therefore, this

*I. P. Milry et al., "Freight Locomotive Fuel Conservation Project, Final Report" South Australian Institute of Technology, August, 1987.

analysis estimates that fuel savings from a properly designed EMS could range from 2% to 4%.

3.1.1.2 Meet/Pass Planner

ARES will provide improved information about the actual positions of trains and an improved, computer-based planner meets and passes. These two elements will save fuel because trains can be "paced" to arrive at designated meet/pass points on time rather than early or late. As a result, the "hurry up and wait" event at meets/passes will be eliminated. Trains will spend a greater amount of time moving than they now do, at a slower speed, but at the same or a higher average speed overall. This improved velocity profile will save fuel.

A University of Pennsylvania computer model which simulated Rockwell's meet/pass planner estimated the fuel savings from better meet/pass planning and pacing. It took data from all fifty-five trains used in the EMS benefit study on train size and weight and delays enroute. The simulator then suggested a more optimal set of meets and passes for the trains than the ones which actually took place and a new velocity profile for each train. The TEM simulator used the new velocity profiles to estimate fuel savings from the meet/pass planner.

The TEM results from the original University of Pennsylvania study, which are presented in full in Appendix 2, estimate a fuel savings of about 2.5%. A separate analysis by the University of Pennsylvania which added a more clever algorithm to the Rockwell meet/pass planner showed the potential for an additional 3.5% fuel savings. The second University of Pennsylvania study appears in Appendix 3. Combining the results of the two studies suggests that fuel savings from an ARES meet/pass planner could range from 2% to 6%.

3.1.1.3 LARS

LARS may increase the time that a locomotive is operating at peak output. However, locomotives operating at degraded levels usually burn proportionately less fuel. Therefore, the fuel savings from LARS appears to be negligible.

3.1.1.4 Combined Fuel Savings

Large fuel savings can not be projected by adding several mid-sized estimates together. For example, using two devices which each save 75% will not save 150%. But, small percentages can be added together without overestimating significantly.

However, when two ranges of estimates are added together, the low estimate for the total should not be the sum of the two lower estimates, but some number greater than that, for the probability of being at the extreme of either estimate is small, and the probability of being at the extreme of both estimates simultaneously is extremely small. Likewise, the high estimate of combined estimates should be smaller than the sum of the two high estimates.

So, the fuel savings from the combined use of the EMS and ARES meet/pass planner will probably range from 5.5% to 8.5% annually. The total fuel bill for Burlington Northern is approximately $260 million per year. The savings, then, will range from $14.3 million per year to $22.1 million per year.

3.2 EQUIPMENT

ARES will yield savings in four categories of equipment costs:

- Car ownership costs
- Locomotive ownership costs
- Locomotive maintenance costs
- Maintenance of way equipment ownership costs

ARES will save equipment costs primarily because is reduces train transit times through more efficient dispatching. Better dispatching reduces train delays by finding more efficient meets and passes than a dispatcher could find without computerized searches, closer headways, and more precise information about train location and speed.

Table 3-1 shows the type of delay for 896 trains on the Northern Region during one week in January, 1989. Nearly 80% of train delay was caused by meets and passes. If ARES can reduce this delay significantly, then ARES can make a significant improvement in the operational efficiency of the railroad.

Cause of Delay	No. of Incidents	Avg. Delay per Incident (Minutes)	Avg. Delay per Train (Minutes)	Percent of Total Delay
Meet and Pass	2,450	42	114	79.2
MOW Work	119	41	5	3.5
Signals	196	16	3	2.1
ROW Problem	95	46	5	3.5
Loco. Problem	127	39	6	4.2
Train Problem	214	46	11	7.6
TOTAL	3201	40	144	100.0

TABLE 3-1 CAUSES OF TRAIN DELAY FOR 896 TRAINS ON NORTHERN REGION DURING A ONE-WEEK PERIOD IN JANUARY, 1989

3.2.1 CAR OWNERSHIP COSTS

Car ownership costs decrease when a car carries more loads per year. It can do that if it spends less time carrying each load by traveling faster and waiting less to make connections. Some estimates of reduced travel times appear in the fuel efficiency simulations described earlier. The ARES meet/pass planner should also reduce line haul times as described below.

Three categories of traffic were considered in analyzing the changes in line-haul travel time. Each of these train types benefit from line-haul time improvements differently. The study considered:

- Carload freight (mixed freight)
- Dedicated intermodal
- Unit trains

3.2.1.1 Carload Freight

Carload freight generally must make connections from one train to another at terminals. So, spending less time on the line haul portion of the trip does not by itself guarantee improved carload service. If line-haul transit times were cut and trains arrived early in the yard, might the cars just wait longer there? Cars that had been running late and made up some of the time on the fast link would not wait extra time to make connections. In fact, some cars that might otherwise have missed connections might now make them. However, the fast link could cause a terminal to clog with trains that had been running ahead of schedule.

Because ARES keeps track of trains ahead of schedule and slows them down, pacing them to conserve fuel and arrive on time, it enables the benefit from line-haul time improvements. If ARES can reduce line-haul time, BN can revise schedules to take advantage of reduced running time without sacrificing reliability (the probability that a car will arrive on time). It could measure the benefit by multiplying the line-haul travel time savings by the percentage of time the car is on the line haul part of the trip. This reduction in car ownership cost would be translated into a capital savings in future years as fewer replacement cars would be needed.

Or, BN can estimate the benefit of ARES by assuming that schedules remain unchanged. Any improvement in line haul time would increase reliability as follows:

1. The amount of time required to travel from terminal to terminal would decrease.

2. Trains would arrive at terminals a little earlier or on schedule.

3. Cars would suffer fewer missed connections.

ARES' benefit need not be used completely to increase reliability at the expense of reduced travel time; using it to increase reliability sometimes reduces travel time as well. For example, a car that would have been a whole day late but arrives on time under ARES is likely to be turned faster, so both reliability and travel time improve.

However, in most cases, ARES will either increase reliability or reduce travel time. Because market research shows that increased reliability is more important to the customer than decreased travel time, this analysis assumes that BN will use the benefit of ARES to improve reliability. However, this study also calculates the benefit of reduced travel time.

The report in Appendix 4 shows a daily savings of $11,000 in car hire from faster link times and greater reliability. This study covered approximately 50% of BN carload traffic. So, the total savings would be $22,000 per day, or about $8 million annually. However, the car time savings included the savings accruing to cars that arrive at the final yard only a few hours early. Only about one-sixth of the savings is attributable to cars arriving a day or more sooner. Therefore, if BN pursues better reliability, the savings in car hire are about $1.5 million per year. On the other hand, if schedules were tightened at the expense of reliability, the full $8 million annual savings would be available.

3.2.1.2 Unit Trains

Unit train traffic does not require reclassification. Therefore, improvements in travel time reduce the number of cars required. In order to analyze the effect on unit train cars, coal and grain trains must be considered separately.

Coal trains are comprised primarily of shipper-owned cars. If their transit times are decreased, the shipper would need to own fewer car sets to deliver the same amount of coal. This gain to the shipper can be shared with BN through rate negotiation. BN management has estimated that between 25% and 75% of the value of this gain can be recovered in the rate. This gain is summarized in Table 3-2.

Element	Amount
Utility-owned coal fleet size	15,000 cars
Percent of time on BN road	63%
Transit time improvement	10% - 25%
Cars saved	950 - 2,400
Annual lease cost	$4,800
Fraction recoverable by BN	$5 million - $11 million
Annual gain to BN	$1 million - $8 million

Table 3-2 GAIN FROM REDUCTION IN TRAVEL TIME FOR UTILITY-OWNED COAL CARS

As shown in Table 3-2, there are approximately 15,000 utility-owned coal cars running on the Burlington Northern railroad. They spend about 63% of the time on line. Saving 10 to 25 percent of this time would reduce fleet size requirements by 6.3% to 15.8%, or 950 to 2400 cars. These cars cost approximately $4,800 in annual lease payments, so the total annual benefit is $5 million to $11 million. If ARES captures 25% to 75% of this amount, the benefits to BN will range from about $1 million to $8 million annually.

Table 3-3 shows the gains available from travel time savings for BN-owned coal cars and for grain cars.

Element	Amount -- Grain	Amount -- Coal
Number of BN cars	14,000	4,300
Percent of time in transit	55%	63%
Percent of transit time saved	10% - 25%	10% - 25%
Cars saved	770 - 1,900	270 - 680
Cost per car	$44,000	$55,000
Percent savings to BN	100%	25% - 75%
BN capital savings	$34 million - $84 million	$4 million - $28 million

TABLE 3-3 GAIN FROM REDUCTION IN TRAVEL TIME FOR GRAIN CARS AND BN-OWNED COAL CARS USED IN UNIT TRAIN SERVICE

As shown in Table 3-3, BN owns approximately 4,300 coal cars. These cars spend about 63% of their time on line. Reducing transit times by 10% to 25% will result in saving 270 to 680 of these cars. The resulting savings are $15 million to $37 million in capital expense. Due to the regulation of captive traffic, however, BN may have to cede some of these savings to the shipper. BN management has estimated that BN could keep approximately 25% to 75% of this saving, or $4 to $28 million in capital expense.

Grain trains are comprised primarily of 14,000 Burlington Northern-owned cars. They spend approximately 55% of the time in transit on Burlington Northern lines. Transit time analyses indicate that between 10% and 25% of this time can be saved with the installation of ARES. (See Appendix 5.) Thus, between 5.5% and 13.8% fewer cars should be needed to move the same amount of grain. As a result, the purchase of 770 to 1900 grain cars can be forestalled over the next several years. Each grain car costs approximately $44,000. Thus, the total savings are between $34 and $84 million in capital expense.

3.2.1.3 Dedicated Intermodal Trains

This analysis did not calculate equipment gains for intermodal trains because it assumed that BN would prefer to improve reliability.

3.2.2 LOCOMOTIVE OWNERSHIP COSTS

ARES' reductions in line-haul travel time will bring locomotives into the yard sooner. They can therefore be dispatched sooner onto other trains. As a result, BN will need fewer locomotives. The analysis team discussed this effect with experts at Burlington Northern and used their judgment to estimate how many locomotives might be saved. The team assumed that BN would use this saving to reduce capital expense.

The estimated savings appear in Table 3 - 4.

Category	Number of Locomo -tives	Time on Road	Decrease in Transit Time		Locomotives Saved		Capital Savings (millions)	
			Low	High	Low	High	Low	High
Intermdl.	360	52%	5%	10%	9	19	$12	$24
Carload	710	52%	5%	17%	18	63	$24	$82
Unit	805	52%	10%	25%	42	105	$54	$131

TABLE 3 - 4 LOCOMOTIVE SAVINGS FROM TRANSIT TIME IMPROVEMENTS

To estimate these savings, the team divided the Burlington Northern locomotive fleet into three categories depending on the type of freight hauled, intermodal, carload, or unit. It assumed that all locomotives spend 52% time on the road. For each type of freight hauled, the team assigned a lower and an upper bound to the expected decrease in transit time. (The lower bound is a 10% chance that the decrease will actually be smaller than this number; the upper bound is a 90% chance that the decrease will actually be smaller than this number.) It then calculated the number of locomotives saved by multiplying the number of locomotives in each class by the percent of time on the road, multiplying that result by the expected decrease in transit time, and rounding the result to the nearest whole number. For example, the following calculation yields the lower estimate of the number of intermodal locomotives saved:

number of locomotives saved = 360 x 0.52 x 0.05 = 9.36 (rounded to 9)

The number of locomotives saved was multiplied by $1.33 million to yield capital savings.

The team estimated low decreases in transit time for intermodal trains because they enjoy high priority with dispatchers and generally do not spend as much time on sidings as carload freight and unit trains. Intermodal trains will therefore not benefit as much from improved meet/pass planning as will the other two categories.

In contrast, current dispatching practices assign low priority to unit trains, shunting them to sidings to resolve meet/pass conflicts and keeping them there longer to prevent delaying higher priority traffic. ARES' improved meet/pass planning would allow unit trains to remain in the general traffic flow. Unit trains will probably profit the most from ARES' implementation.

As with combined fuel savings, three estimates are being added together. The probability of the extreme of any of the estimates (low or high) occurring is small and the probability of the sum of extremes occurring is extremely small. As a result, the low estimate of the total number of locomotives saved should not be the sum of the three lower estimates, but should be greater than that. Likewise, the high estimate of the number of locomotives saved should be smaller than the sum of the three high estimates.

3.2.3 LOCOMOTIVE MAINTENANCE COSTS

ARES may reduce locomotive maintenance costs through LARS. LARS' monitoring of major locomotive functions almost continuously will provide better information to make decisions about locomotive maintenance and reduce its cost.

Locomotive maintenance was analyzed by Harold Bongarten Associates. That analysis estimated the amount of possible savings from LARS. The model used actual Burlington Northern data to analyze the causes of locomotive failures and the amount of time spent for repair and maintenance. Simulations were made both with and without LARS information being available and the results compared to yield estimates of the reduced labor required to repair locomotives and the reduction in time a locomotive would be out of operation for servicing. The Harold Bongarten Associates study appears in Appendix 7. The results of that study appear in Table 3 - 5:

Item	LARS Savings (hours)	Value ($ / hour)	LARS Savings (thous-ands)
Trains	1,537	200	$307
Locomotives	123,288	15	$1,849
Bays	118,935	30	$3,568
Labor	144,449	26	$3,756
TOTAL			$9,480

TABLE 3 - 5 LARS SAVINGS IN ANNUAL LOCOMOTIVE MAINTENANCE COSTS

second is to realize the benefit in improved yard productivity. There are trade-offs between these two extremes. Burlington Northern could, for example, take some of the benefit in yard productivity and some in labor reductions. However, yard productivity is an important element in overall service reliability. Since numerous market surveys indicate service reliability is highly valued by customers, it is more appropriate to measure yard improvements in gains to yard productivity. If Burlington Northern management actually takes some of the ARES benefit in reducing labor, they would do so because labor reductions are worth more than improvement in service. If that is the case, ARES' benefits would be higher than estimated here.

3.3.3 TRAINMASTERS AND ROAD FOREMEN

ARES will increase trainmaster and road foremen productivity by automating field efficiency testing. Trainmasters and road foremen can monitor speed efficiency tests in the office instead of the field because ARES provides continuous information about train speed and location. For the few places that still have signals, such as interlockings, trainmasters and road foremen could monitor trains' responses to signals in the office. They would not have to observe whether crews drop fuses or torpedoes when appropriate. Trainmasters and road foremen would make only a few field efficiency tests such as inspecting trains after stops. The increase in trainmaster efficiency would provide time for other tasks.

3.3.4 CLERICAL EMPLOYEES

ARES will improve the efficiency of clerical employees by making certain COMPASS data entries unnecessary, reducing the amount of data required for manual entry to determine crew payroll, and allowing for more automation in the delivery of work orders. This benefit has been analyzed for three labor groups: (1) Train Order Operators, (2) Clerical Personnel Responsible for Work Orders, and (3) Road Crew Timekeeping Personnel. BN spends less than $1 million per year on these functions for train order operators and road crew timekeeping personnel. Because it is so small the amount of potential gain was not determined. The processing of work orders, however, was found to cost BN approximately $40 million per year. Interviews with BN personnel reveal that ARES automation could decrease this amount by 2% to 50%, thus saving BN $1 million to $20 million per year.

3.3.5 TRAIN OPERATING CREWS

ARES can increase train crew productivity in several ways. The largest gain is likely to result from increasing the number of miles in a crew's basic daily pay.

Burlington Northern labor experts have confirmed that if trains can be moved over the line more efficiently, they will be able to translate that into a direct increase in the number of miles that make up a basic day's pay. For example, if ARES allows trains to run 10% more miles in an eight hour day, they will be able to achieve a 10% higher figure for the number of miles in a basic day's pay.

The total bill for road train crew labor on the Burlington Northern is $533 million. Of this amount, approximately 75%, or $400 million, is directly or indirectly related to basic mileage pay or to the time required to traverse the line. (For example, initial terminal delay would be reduced in trains arrived closer to

3.2.4 MAINTENANCE OF WAY EQUIPMENT OWNERSHIP COSTS

The original ARES benefit analysis methodology included analysis of MOW equipment ownership costs. However, subsequent study shows that ARES delivers little reduction in these costs and so it does not appear in this report.

3.3 LABOR

With more timely and accurate information from ARES, railroad managers can make better use of all resources, including labor. Some assume that labor agreements will prevent BN from realizing increases in labor productivity. However, increased productivity will yield time to perform other tasks, even if no positions are eliminated. For example, clerks protected by labor agreements could use additional time to trace railroad cars. In addition, past experience has shown that gradual changes in contract agreements and attrition accomplish the same result. As competitive constraints increase, ARES' existence can be expected to cause change more quickly in the bargaining process.

This analysis identified the following categories of labor where ARES could improve productivity:

- Dispatchers
- Yard and Terminal Employees
- Trainmasters
- Clerical Employees
- Train Operating Crews
- Maintenance of Way Gangs

3.3.1 DISPATCHERS

ARES can improve dispatcher productivity. Dispatchers will be relieved of many clerical tasks and will not be required to spend time transmitting track warrants by voice. This productivity gain can be translated into increased dispatcher effectiveness or fewer dispatchers. As traffic volumes increase, BN may choose to hire fewer new dispatchers, a benefit calculated as "avoided wages."

Burlington Northern managers estimated that automating clerical tasks and warrant transmission will improve dispatcher productivity by 25% to 50%. Dispatcher labor costs are approximately $19 million per year. Thus, ARES will save $4 million to $9 million per year in dispatcher productivity.

Time and motion studies could be used to make a closer estimate of this benefit. However, because its size is relatively small, this analysis used managers' estimates.

3.3.2 YARD AND TERMINAL EMPLOYEES

ARES will provide terminal managers with yard positions of switch engines and better estimates of the time of arrival for through freights. This information will allow terminals to operate more efficiently because crews will be called only when needed and should be able to spend more of their time productively.

There are two ways improvements in terminal operations can be translated into benefits for Burlington Northern. The first is as a reduction in labor costs. The expectation.) To provide a range of estimates, this analysis calculated the gains of affecting as little as 25% or as much as 75% of crew compensation. Transit time reductions, then, could have as much benefit as $60 million per year or as little benefit as $6.7 million per year.

In addition, when trains run more nearly on schedule, a greater proportion of crews can be assigned to a single train run. As a result, fewer crews will be needed to staff trains that run at unpredictable times. Reducing the size of the board will not save wages; the same number of trains need staffing in any case. However, savings will accrue in fringe benefit costs estimated at $1 million to $2 million annually.

3.3.6 MAINTENANCE OF WAY GANGS

It was originally thought that Maintenance of Way (MOW) productivity increases would occur because the meet/pass planner would allow scheduling larger MOW time periods. However, larger MOW time periods reduce flexibility in train movement and so will probably not occur.

ARES still benefits Maintenance of Way in two ways:

- Knowing trains' locations before performing routine maintenance.
- Reducing the time to obtain track warrants for MOW activities.

MOW experts at Burlington Northern believe that these benefits will improve MOW productivity by 2.5% to 21%. Since BN spends approximately $183 million per year on road maintenance labor, this savings amounts to $4.5 to $38.5 million per year.

3.4 DAMAGE PREVENTION AND TRACKSIDE EQUIPMENT

3.4.1 ACCIDENT PREVENTION

Many accidents that have occurred on the railroad could have been prevented had ARES been in place. Such accidents are caused by:

- Buffing or slack
- Lateral drawbar force
- Rules violation
- Impaired employees
- Signal failure
- Overspeed
- Improper use of automatic, dynamic, or independent brakes

These categories are those used by the Federal Railroad Administration (FRA). The FRA classification does not include a specific category for human error. Accidents caused by human error would be included under one of the rules violations, impaired employees, overspeed, or improper braking categories of the FRA classification system.

To estimate the benefit of preventing these accidents, this analysis reviewed damage costs reported to the Federal Railroad Administration (FRA) and corresponding personal injury costs from BN files for accidents during the past five years. Only about 25% of personal injury costs could be identified. So, this analysis multiplied the amount identified by four to estimate the total personal injury costs of accidents which ARES could prevent. The total estimate for this benefit is $18 million.

3.4.2 PREVENTION OF LOSS AND DAMAGE TO LADING

Burlington Northern's Assets Protection department has found that most of the loss and damage to lading occurs in the line haul portion of the trip. Therefore, train handling accounts for the majority of this cost, and ARES can assist in reducing it.

Burlington Northern files indicate that $14 million is spent per year to pay claims for damaged lading. ARES can eliminate some portion of this cost. The exact amount is unknown, but the size of the benefit does not significantly affect this analysis. The nominal estimate is a saving of $5 million a year.

3.4.3 TRACKSIDE EQUIPMENT CREDIT

Under ARES, BN will eliminate polelines and add radio data links. Radios compatible with ARES will reduce the cost of ARES and so are considered as a credit against the costs of implementing ARES. Overlap between the physical elements of the two systems and the timing of poleline elimination yield present value of the offset of $6 million.

3.5 REVENUE ENHANCEMENTS

Burlington Northern will probably choose to use ARES' improvements in travel time to improve reliability and increase its prices or market shares. It will achieve gains in reliability by allowing more time for connections at yards, thus increasing the probability that connections are made.

Mr. Carl Martland of Massachusetts Institute of Technology (MIT) studied yard performance under ARES to evaluate its benefit. Mr. Martland used a model to simulate the operation of six major Burlington Northern yards -- Cherokee Yard, Murray Yard, Northtown Yard, Spokane, Pasco, and Seattle. The model determined that the probability of making a connection in BN's yards would increase under ARES even if line haul time did not improve.

The yard performance estimates made by Mr. Martland and the line haul performance improvements forecast by Zeta-Tech were combined in a model called the Service Planning Model (SPM). The SPM can determine changes in service reliability given changes in line haul and yard performance. However, reliability improvements, when known, must still be translated into net revenue for Burlington Northern.

The John Morton Company was retained to estimate revenue changes resulting from improved reliability. The company interviewed shippers and estimated how demand might change if reliability improved for five market groups -- plastics, pet food, aluminum, tires, and paper. The company also estimated price increases that could result from improved reliability. These changes are referred to as "demand elasticity" and "price elasticity."

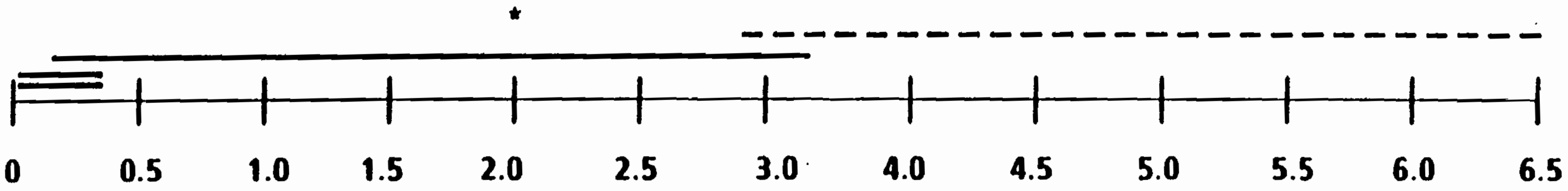
The SPM model and this analysis only consider interchange freight. Unit trains would probably not be as affected by reliability because shippers are not as sensitive to service. Improved reliability could significantly affect dedicated intermodal service. However, BN does not have a model of that service; also, it is a smaller market and likely represents a smaller gain.

The John Morton Company estimated price/service reliability cross elasticity to be approximately 4.0. This means that for each percent improvement in service reliability, Burlington Northern could expect a gain of 4% in price.

Many in the Marketing Department viewed these results as optimistic. BN's market managers in Fort Worth indicated that even large increases in service reliability would produce neither significant gains in price nor share except in food and consumer products, where they estimated a price/service reliability cross elasticity of 0.3. Their response implies that BN should retreat from carload markets and concentrate on being a bulk carrier.

A study conducted at Kansas State University provides a third estimate of elasticity from surveys of actual shipper sentiments on the value of improved service. The three estimates appear in Figure 3 - 6. Figure 3 - 6 highlights the service elasticity value of 2.0, which was selected as the nominal value for this analysis. This analysis also uses a range of 0.2 to 4.0, end points which vary by a factor of 20. Further study should narrow this range to estimate benefits more precisely.

At a more fundamental level, however, BN managers must know the value of good service to make strategic decisions about the future of the railroad. Resolving the uncertainty in estimating this value warrants substantial effort.



Percent Price Gain from a One Percent Improvement in Service Reliability

Legend:

═══════ BN Market Mangers' Perception of Customer Response

——————— Customer Response As Measured By Kansas State Study of Actual Choices

- - - - - - - What the Customers Told John Morton Company That They Will Pay for Service

* Nominal Value Used for ARES Analysis

FIGURE 3 - 6 PRICE GAIN VERSUS INCREASED SERVICE RELIABILITY

3.6 CAPACITY BENEFITS

ARES could significantly reduce future investments in right of way. However, ARES benefits can not be taken both to avoid all future capital outlay and to improve transit times fully. If some of the benefit of ARES is taken to improve capacity, Burlington Northern may realize the following savings:

	Present Value of Savings	
	Before Tax	After Tax
Focused Strategy	$112 Million	$82 Million
Base Strategy	$134 Million	$98 Million
Expansion Strategy	$332 Million	$243 Million

These estimates were complied from a thorough analysis by personnel in the Strategy Decisions Group and the Operations Analysis department of Burlington Northern. Their analysis appears in Appendix 8.

Since these savings accrue from avoiding investments on only some lines, BN can take a portion of the benefits in improved service or reduced cost at the same time. However, the service and cost benefits would be offset by some amount not determined in this analysis.

3.7 BENEFITS SUMMARY

Figure 3 - 7 shows a summary of ARES benefits. The categories have been ranked by order of contribution:

- Enhanced revenues from mixed freight and unit coal trains
- Labor productivity improvements
- Equipment savings
- Reduced fuel usage
- Savings on loss, damage and signals

Figure 3 - 7 provides a single estimate for each category of benefit, while the benefits estimated earlier in this section are expressed in ranges. Figure 3 - 7 simply shows the benefits in each category for the most likely point in each range. A further discussion regarding the full range of each estimate follows.

Each estimate shown in Figure 3 - 7 is expressed as a present value. Each present value is calculated as a discounted sum of all future cash flows that the listed benefits will generate. All cash flows calculated for input to the present value calculation have been netted of taxes. All cash flows used here are forecasted in constant dollars. Therefore, a discount rate net of taxes and inflation has been selected to perform the present value calculation. This discount rate is 9%, as provided by the Planning and Evaluation Department. Readers who are interested in further detail regarding the mechanics of present value calculation may find in it numerous texts (e.g., *Engineering Economics*, Grant and Ireson).

When the cost cash flows are translated into a present value and subtracted from the present value of the benefits, the result is a net present value. In order to account for uncertainty in estimates, this analysis defers the calculation of net present value

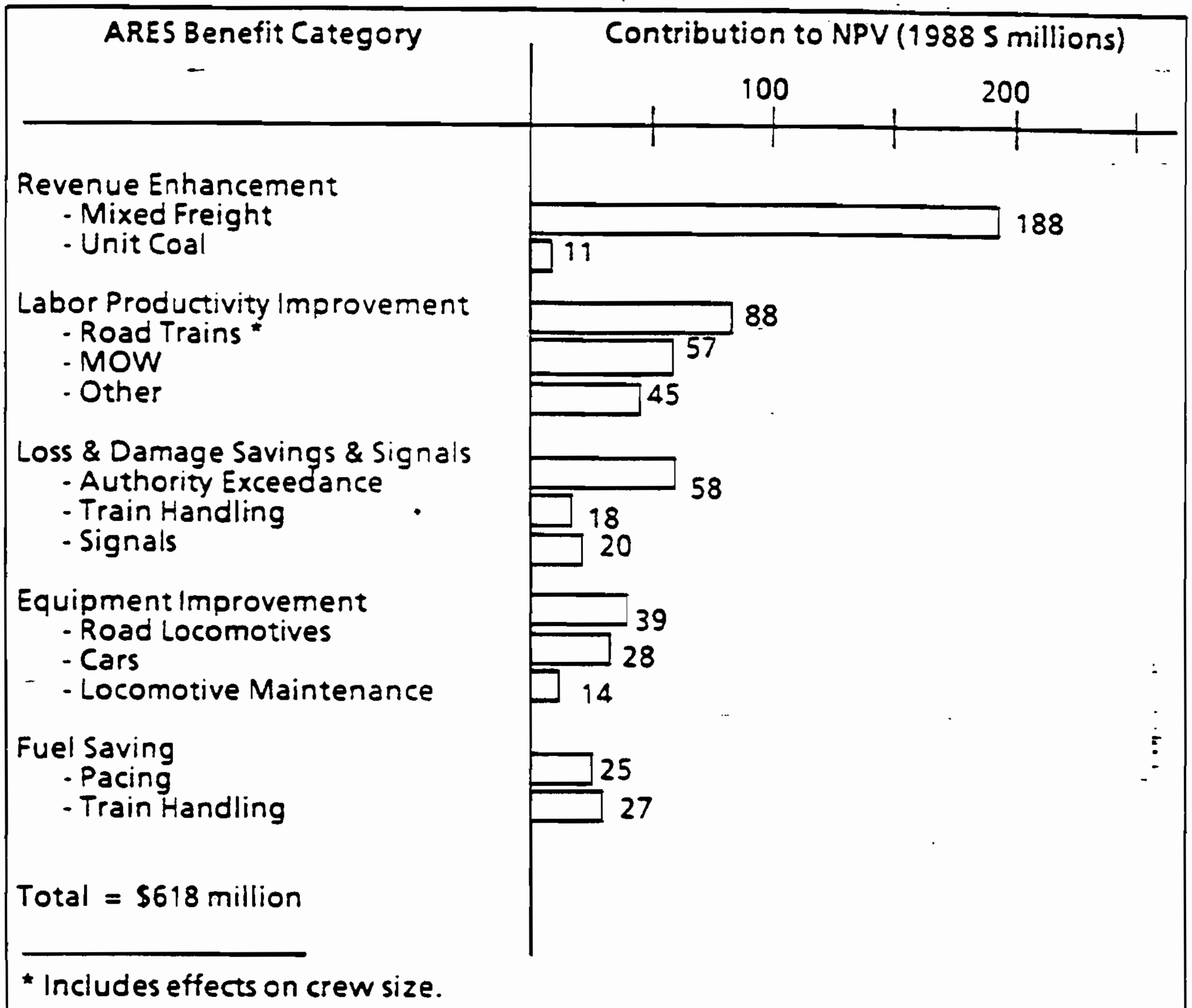


FIGURE 3 - 7 ARES BENEFITS BY SAVINGS AND REVENUE

until later and looks now at the cash flow requirements of ARES.

ARES is a long-term commitment. Most likely, nine years will elapse before it produces a positive cash flow. ARES' dispatching software will yield some early benefits. But most benefits accrue only after the communications system is operating and most locomotives are ARES-equipped. Then, however -- two years after ARES is fully implemented -- the cash flow turns positive.

Figure 3 - 8 shows the net after-tax cash flow expected from ARES. Figure 3 - 8 also shows the cumulative effect of yearly cash flow increments to the year 2000.

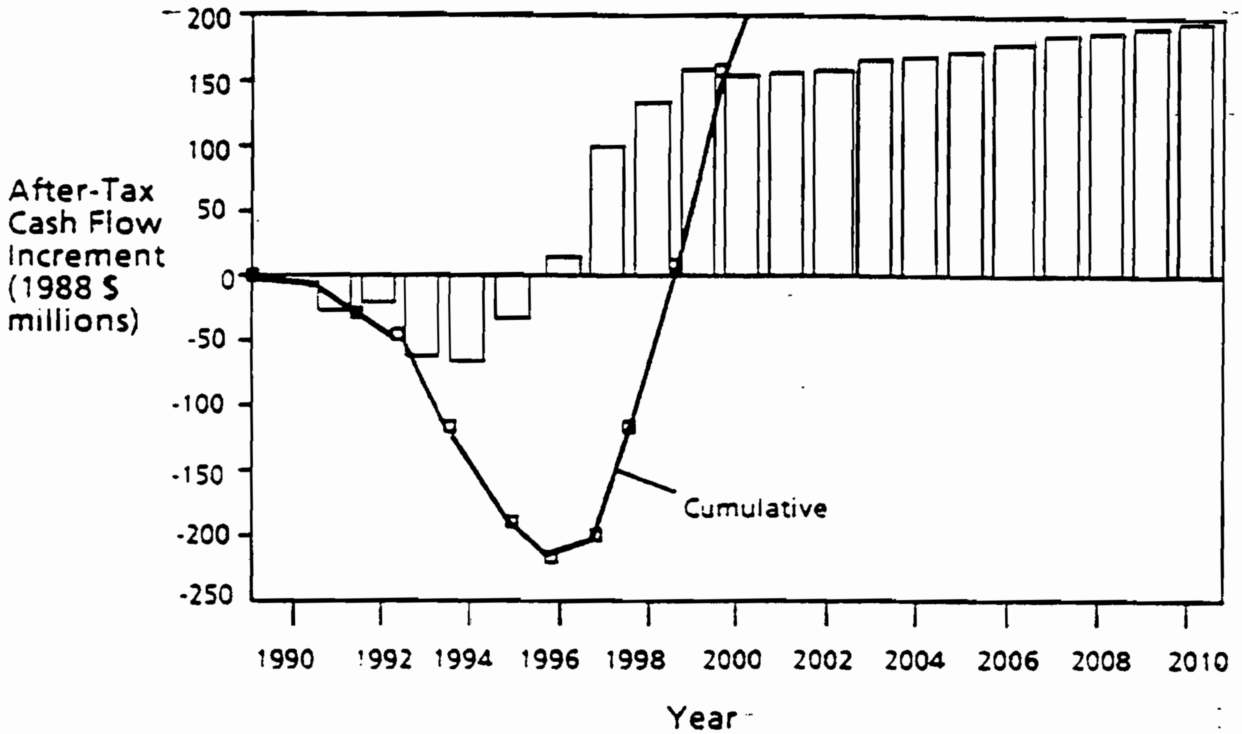


FIGURE 3 - 8 ARES CASH FLOW

3.8 EXPLANATION OF UNCERTAINTY

None of the estimates from observation, simulation, or expert judgment is certain. There are also probably many benefits that cannot be foreseen or quantified. For example, ARES will improve the quality of the corporate data base, yielding better strategic decisions of profound benefit to the organization. Uncertain and unforeseen benefits for ARES increase the risks in deciding to implement it. An intelligent decision requires that BN understands those risks.

A simple example illustrates the analysis of uncertainty or risk. Imagine gambling on a coin toss which paid $1000 if heads came up and nothing for tails. What is it worth to enter the game? Almost certainly, less than $500, because the risk of loss is high. On the other hand, a game which pays $550 for heads and $450 for tails offers less risk, and the worth of entering it is closer to $500. The average payoff of both games, however, is the same.

Similar uncertainties exist with ARES. Will the line-haul transit time improvements be on the order of 15%, as the simulator indicated? Or will they be less, due to factors that computers cannot take into account? Can BN get 2% to 5% increase in prices for every percent improvement in reliability, as the customer surveys indicate? Or will it, in fact, get nearly nothing?

This analysis accounts for uncertainty through *distributions* of results for uncertain values. These distributions reflect the collective judgments of BN officers and consultants. Multiplying these distributions yields a distribution of benefits for ARES under each corporate strategy, a range more useful in making decisions than a single-point estimate.

It is also useful to look at each uncertainty separately. For example, ARES may reduce accident costs from about $2 million to about $21 million per year. How much impact would $2 million have instead of $21 million? Or, analysis of transit time improvements estimates improvement of 5% to 15%. How much impact does the low estimate have compared to a high estimate?

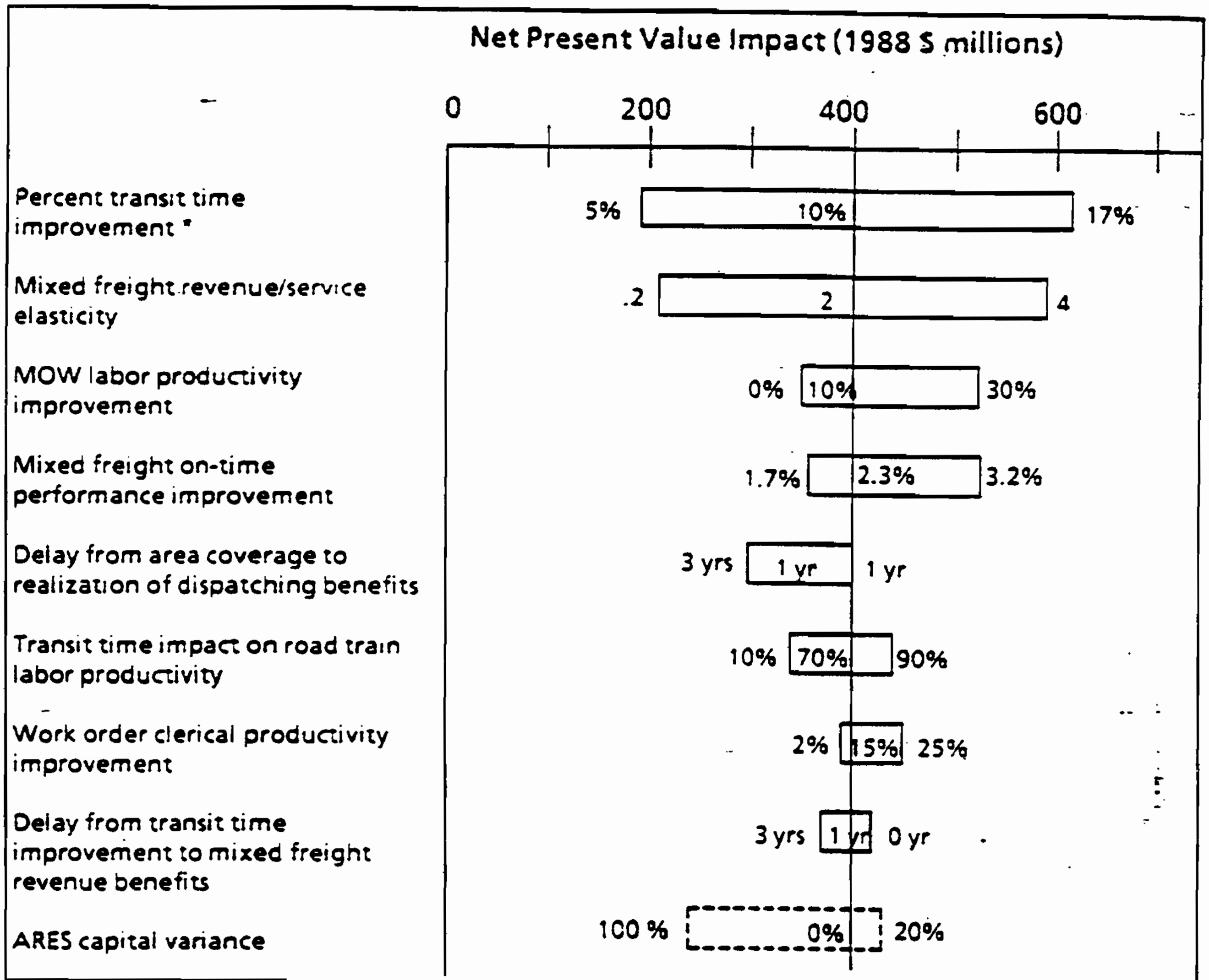
Examining uncertainties separately also shows how important each one is. One which slightly affects the total warrants less precise definition than one whose impact is significant.

Benefits and their uncertainties appear in Figure 3 - 9. The benefits which contribute the most to overall uncertainty appear at the top of the diagram. Items at the bottom, because they are small or accurately known, contribute little to the uncertainty in the estimates of net present value.

The numbers along and within the horizontal bars of the figure represent the low, nominal, and high estimates for each of the categories of benefits affecting estimates of net present value. For example, the low estimate of mixed freight revenue/service elasticity was set at 0.2, the nominal value was set at 2.0, and the high estimate was 4.0.

If BN is to make more certain estimates of the size of ARES' benefits, the figure reveals that it should study train transit time improvement and revenue/service elasticity further.

The dashed bar at the bottom of the figure shows the effect of varying the capital cost of ARES around the estimates provided by the ARES project group from 20% less to two times ARES' estimated cost. Uncertainties in ARES' implementation costs have not been estimated and are not the subject of this report. However, the range adds perspective to analyzing ARES' benefits.



Note: Other uncertainties are relatively insignificant.

* Shows transit time improvement for mixed freight and assumes a full correlation to other traffic types. Also assumes that reliability gains and transit time improvement are highly correlated.

FIGURE 3 - 9 SOURCES OF UNCERTAINTY

3.9 GENERATION OF NET PRESENT VALUE PROBABILITY DISTRIBUTIONS

In the following discussions, random events to which probabilities are ascribed are represented by a small circle. The following items were used to compute net present value probability distributions:

- The impact of shorter transit times on road train labor crew productivity.
- The price elasticity of improved service for mixed freight.
- The improved productivity of MOW labor gangs.
- The delays between implementation of ARES and the beginning of precision dispatching.
- Mixed freight on-time performance improvement under ARES.
- Transit time improvements for intermodal, mixed freight, unit grain, and unit coal trains.

3.9.1 ROAD TRAIN LABOR PRODUCTIVITY

The contribution of shorter transit times to road train labor productivity and the impact of that improved productivity on net present value is illustrated in Figure 3 - 10. Figure 3 - 10 represents the best judgment of Burlington Northern experts on the amount of road train labor productivity resulting from shorter transit times which can be recovered in labor negotiations. To illustrate, if the impact of transit time on road train labor productivity is 90%, a 10% improvement in transit time will lead to a 9% productivity improvement for road train labor. Most likely, the probability of the transit time impact being 10% is 0.30 and the probability of the transit time impact being 90% is 0.70.

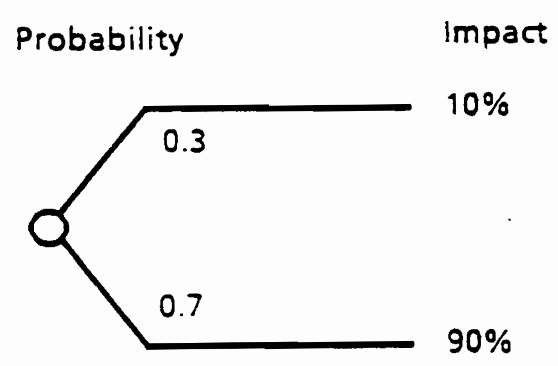


FIGURE 3 - 10 TRAIN LABOR IMPACT

3.9.2 MIXED FREIGHT PRICE/SERVICE ELASTICITY

The value of mixed freight price/service elasticity is key to estimating the overall range of ARES' benefits. The values of elasticity for mixed freight and the probabilities for those values are shown in Figure 3 - 11. The probability that mixed freight price/service elasticity is actually 0.7 was set to 0.25. Likewise, the probabilities that mixed freight price/service elasticity is actually 1.9 or 2.7 were set at 0.50 and 0.25 respectively.

The elasticities and probabilities that appear in Figure 3 - 11 were gathered from Burlington Northern marketing experts and from the market study conducted by the John Morton Company. The John Morton Company study appears in Appendix 5.

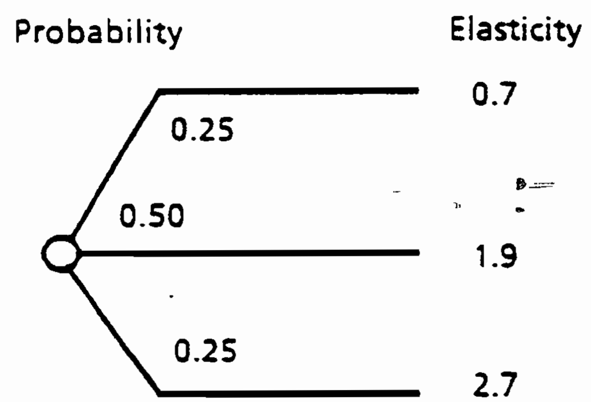


FIGURE 3 - 11 PRICE/SERVICE ELASTICITY*

* A Volume/Price Elasticity of 1.4 is assumed

3.9.3 MOW LABOR PRODUCTIVITY IMPROVEMENT

MOW labor productivity improvements to be expected under ARES were estimated from interviews with Burlington Northern experts. The probabilities assigned by these experts to different values of improvement in MOW labor are illustrated in Figure 3 - 12.

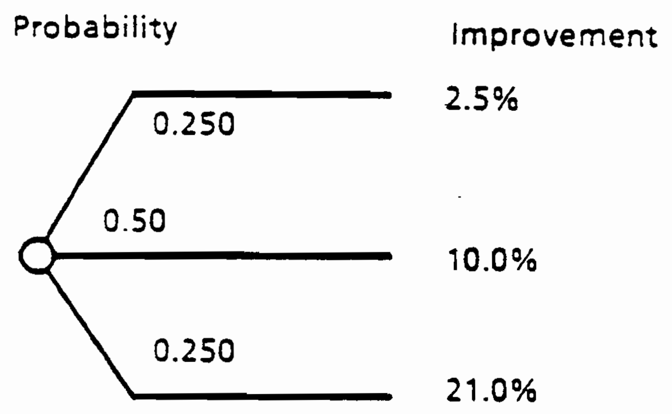


FIGURE 3 - 12 PERCENT IMPROVEMENT IN MOW LABOR PRODUCTIVITY

3.9.4 DISPATCHING BENEFITS DELAY

The delay between area coverage and realization of benefits from precision dispatching was estimated from interviews with BN managers. The delays used in the benefits analysis and the probabilities assigned to those delays are shown in Figure 3 - 13.

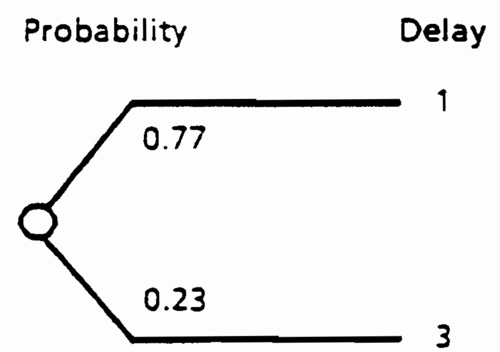


FIGURE 3 - 13 DELAY IN YEARS BETWEEN INSTALLATION AND BENEFIT REALIZATION*

* From Area Coverage to Realization

3.9.5 TRANSIT TIME IMPROVEMENTS FOR INTERMODAL, MIXED FREIGHT, UNIT GRAIN, AND UNIT COAL TRAINS

The transit time improvements used in the benefits analysis were supplied by studies done by Zeta-Tech and the University of Pennsylvania. Results of the two studies are summarized in Figure 3 - 14. The uncertainty in transit time improvements was approximated by five discrete levels and is shown as the first column in Figure 3 - 14. The remaining four columns represent the amount of gain associated with that probability. For example, a transit time improvement of 3.7% for intermodal traffic was assigned a probability of 0.1; a 7.2% improvement in transit time for intermodal traffic was assigned a probability of 0.4.

Probability	Intermodal (%)	Mixed Freight (%)	Unit Grain (%)	Unit Coal (%)
0.1	3.7	3.7	7.7	7.7
0.2	5.8	6.5	13.1	13.1
0.4	7.2	10.1	19.5	19.5
0.2	8.8	14.3	24.0	24.0
0.1	12.0	19.5	26.0	26.0

FIGURE 3 - 14 UNCERTAINTY* IN TRANSIT TIME IMPROVEMENTS FOR DIFFERENT TYPES OF TRAFFIC

(*Uncertainty assumed to be fully correlated)

3.9.6 Mixed Freight On-Time Performance Improvements

The mixed-freight on-time performance improvements were approximated by three discrete levels, all of which depended on transit time improvements. The uncertainties in transit time improvements are shown in Figure 3 - 15. The first column of Figure 3 - 15 represents the uncertainty in transit time improvements and are identical to the first column of Figure 3 - 14. The second column of Figure 3 - 15 represents the three discrete levels into which the uncertainty of mixed freight was quantified. The third column represents the amount of on-time improvement in mixed freight to be expected from the corresponding transit time improvement and mixed freight probability. The data in column three was taken from studies done by A&L Associates and Carl Martland. The fourth column is the joint probability of the transit time improvement and the mixed freight improvement uncertainty.

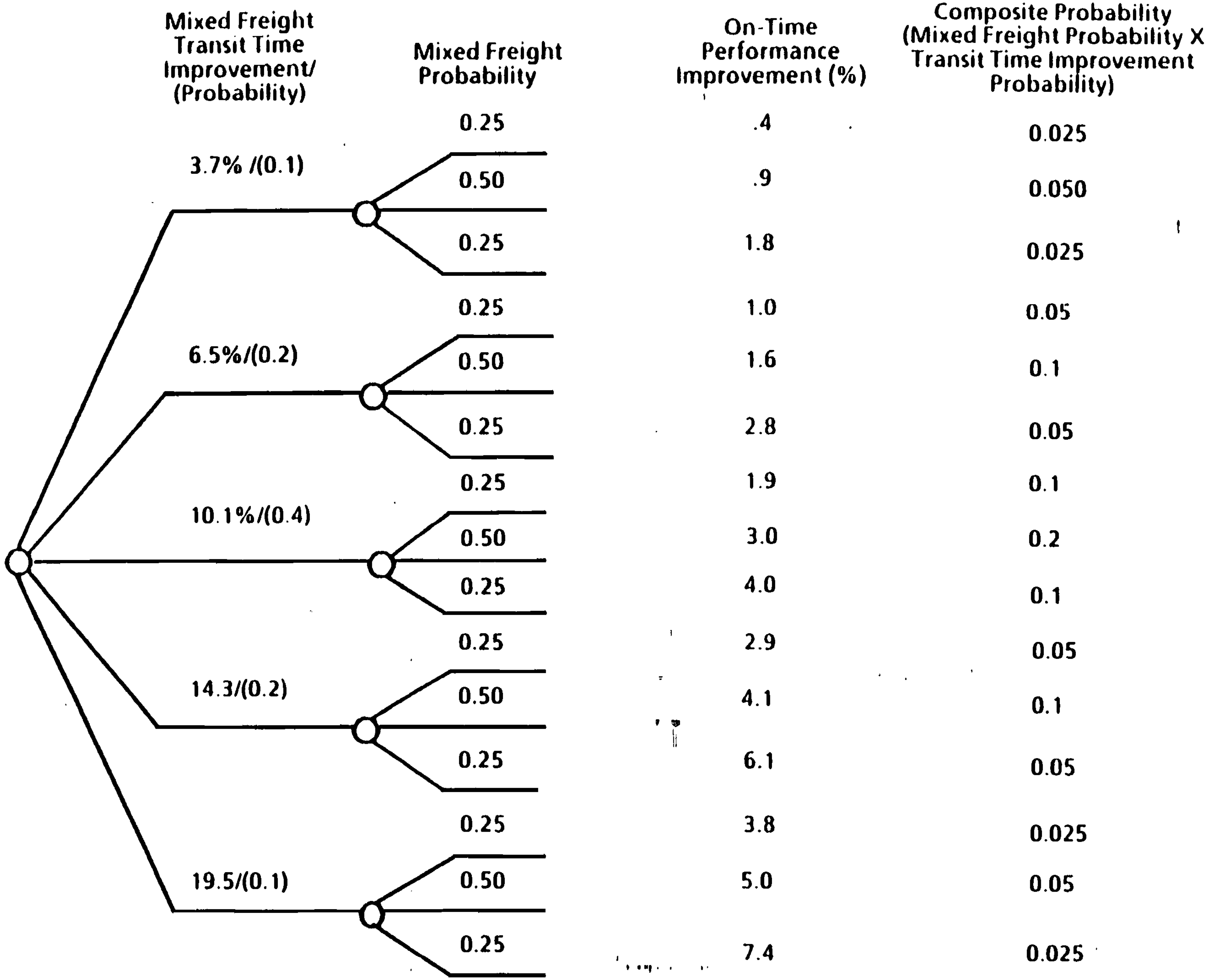


FIGURE 3-15 COMPOSITE PROBABILITY (MIXED FREIGHT PROBABILITY X TRANSIT TIME IMPROVEMENT PROBABILITY)

3.9.7 COMBINED DECISION TREES

Combining Figures 3 - 10 through 3 - 15 produces a complete decision tree which encompasses all allowed possibilities of assigning values to the factors which influence net present value. Figure 3 - 16 shows a single branch of this decision tree. The complete decision tree has 540 separate paths.

The net present value distributions were constructed from the decision tree in the following way:

1. Each path was traversed and the probability at each decision point was multiplied to arrive at a composite probability for that path.

2. A net present value was calculated for the series of assumptions represented in the decision tree. This value was calculated from the Cost-Benefit model.

3. If different paths yielded the same value, their composite probabilities were added.

4. A bell-shaped distribution of probability versus net present value was constructed from the results of step 3.

5. A plot of cumulative probability versus net present value was constructed from the results of step 4 and appears in Figure 3 - 17.

The entire range of net present value estimates appears on the horizontal axis of Figure 3 - 17. The vertical axis shows the probability that the actual net present value contributed by ARES will be equal to or less than a number selected on the horizontal axis.

To use Figure 3 - 17, select a number for net present value from the horizontal axis and read the probability from the curve directly above this number. The probability read from the curve represents the chance that the actual net present value contributed by ARES will be less than or equal to the value selected.

Figure 3 - 17 also shows the probability that actual net present value from ARES is greater than or equal to some particular estimate. To determine this probability, select a number on the horizontal axis and read the probability from the curve directly above this value. Subtract the probability thus derived from the numerical value 1. The result represents the probability of the actual net present value being equal to or greater than the number selected on the horizontal axis.

Figure 3 - 17 immediately reveals that the probability of ARES earning less than 9% real rate of return (net present value equals zero or less) is extremely small.

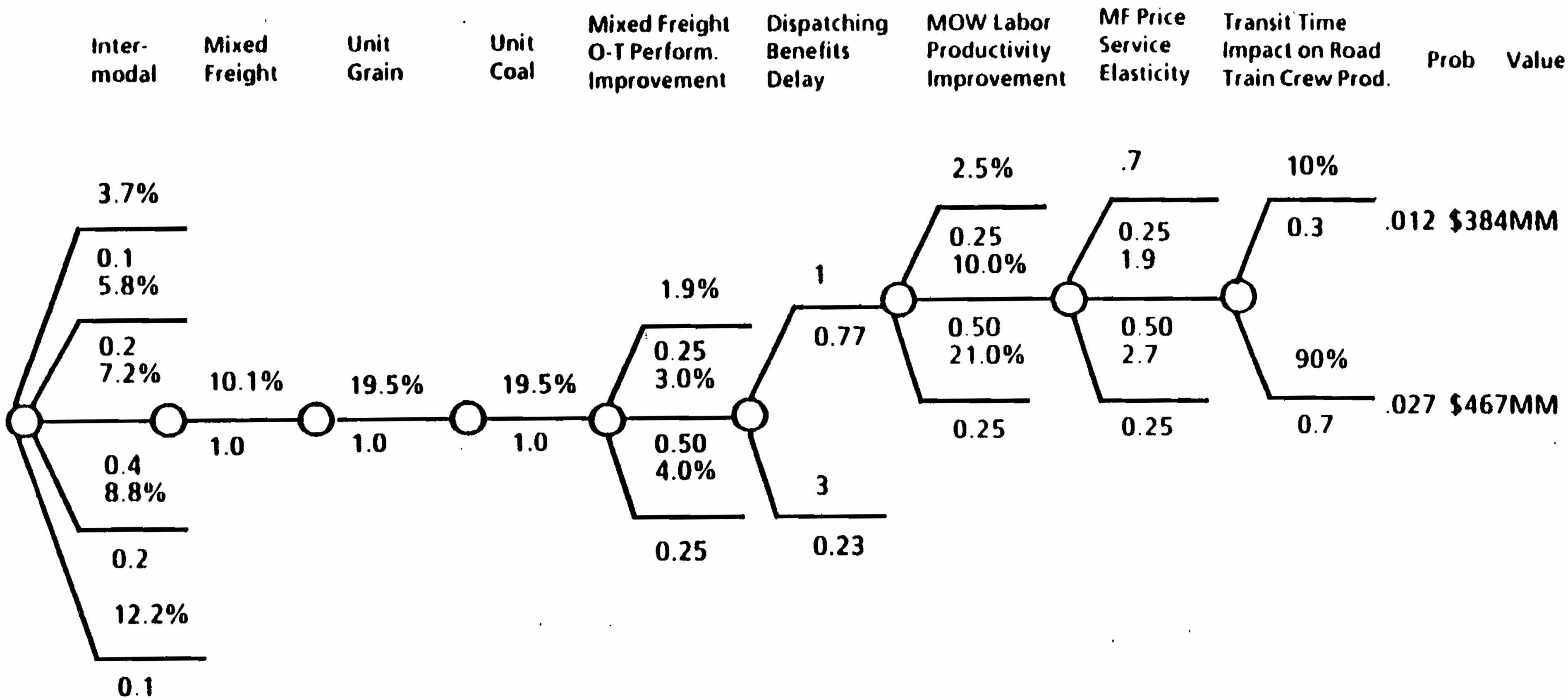
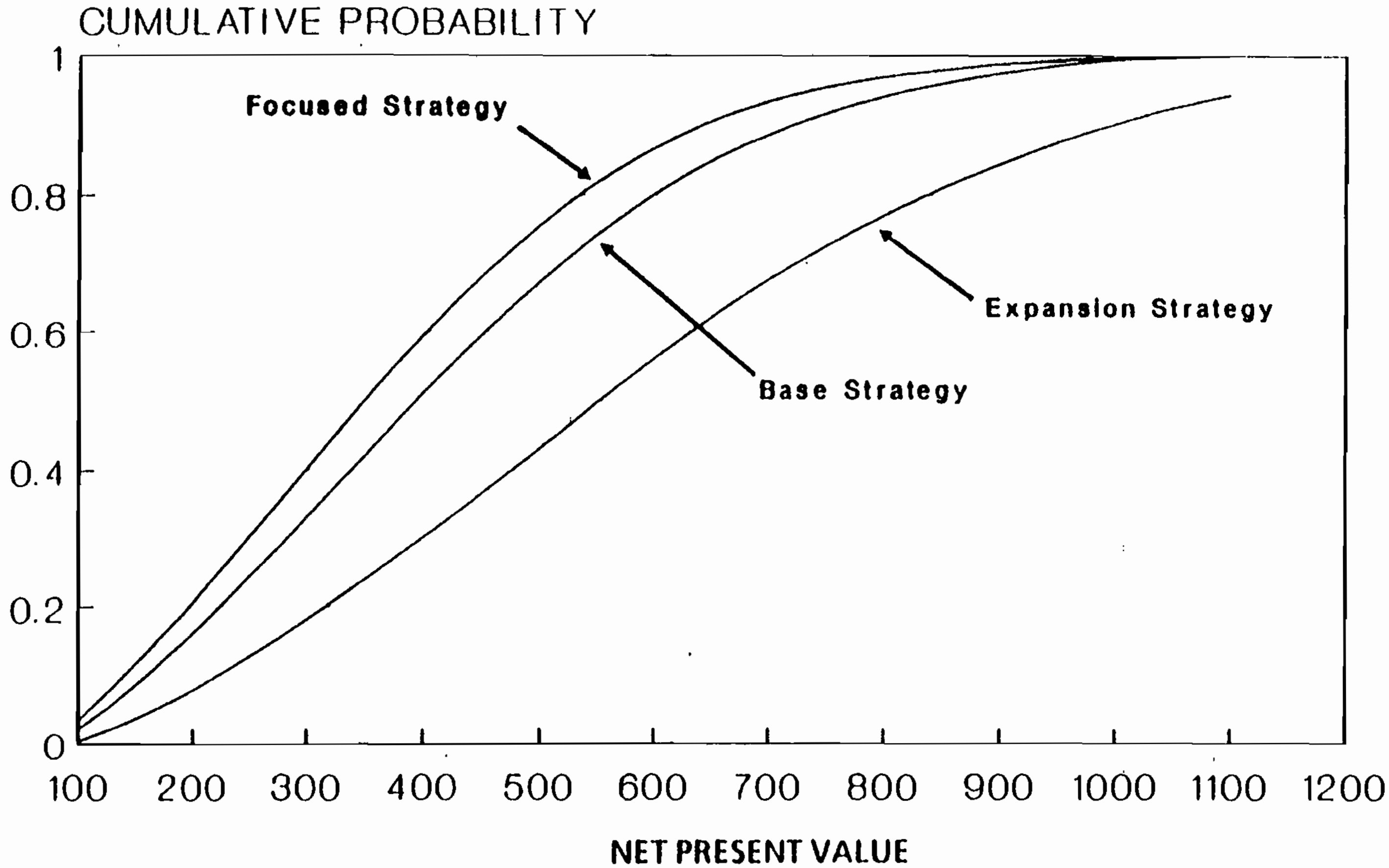


FIGURE 3-16 NET PRESENT VALUE DECISION TREE (ONE PATH ILLUSTRATED)



Base (Status Quo) Strategy Mean = $406 Million
Focused Strategy Mean = $360 Million
Expansion Strategy Mean = $576 Million

Figure 3-17 ARES Net Present Value Probability Distributions (Focused, Base, and Expansion Strategy)

SECTION 4.0
IMPLEMENTATION OPTIONS

KEY POINTS

- *Three features offer 88% of ARES' benefits:*

	Contribution to net present value
• *precision dispatching*	*$422 million*
• *on-board signaling and authorization*	*$78 million*
• *train control*	*$45 million*

- *Functions that deliver precision dispatching and on-board signaling and authorization cost $54,000 per unit.*

- *Locomotive monitoring and analysis makes only a small contribution to precision dispatching and costs $16,000 per unit.*

- *Functions which deliver train control, the feature which enables ARES to stop a train with a disabled crew or authority violation, cost $12,000 per unit.*

- *ARES must be fully implemented to deliver its significant benefits. To prevent disrupting operations, ARES must be implemented in phases. The following plans deliver varying contributions to net present value:*

• *two phases*	*$403 million*
• *four phases*	*$419 to $451 million or more*

- *A larger number of smaller phases may deliver even more contribution to net present value and, because each phase accrues value quickly, may even allow ARES to finance itself. However, such plans require:*
    - *longer total implementation time*
    - *higher total cost due to inflation, the need for more equipment, and closer and more difficult management of implementation*

4.1 THE ELEMENTS OF ARES

The features of ARES offer varying amounts of benefit. Figure 4 - 1 shows that more than two-thirds of the benefit of ARES, or $422 million, comes from precision dispatching. On-board signaling and authorization contribute another $78 million. Train control contributes another $45 million. These three features offer 88% of the benefit of the system as shown in the following graph:

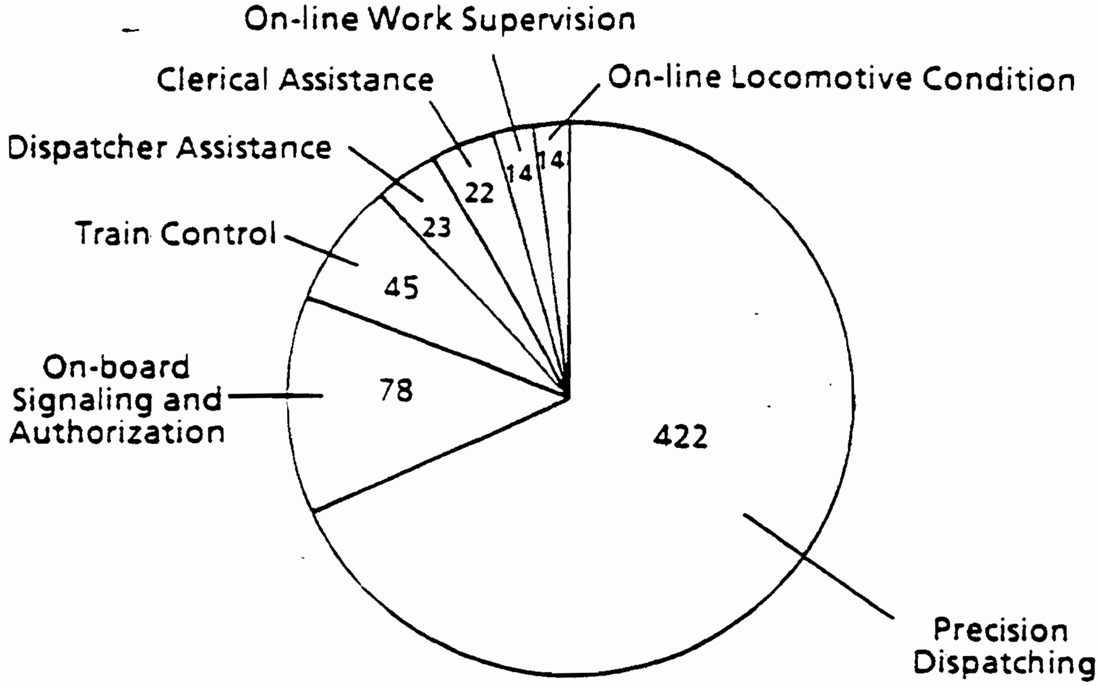


FIGURE 4 - 1 TOTAL BENEFIT CONTRIBUTION TO NPV (1988 $MILLIONS)

The following table shows the functions which deliver the features of precision dispatching, on-board signaling and authorization, and train control.

	Precision Dispatching	On-board Signaling and Authorization	Train Control
Data Link to Locomotives	X	X	X
Precision Positioning and Speed Indications	X	X	X
Traffic Planning and Computer-aided Dispatching	X		
Locomotive Monitoring and Analysis	0		
Computer-aided Train Handling			X

X = Significant Contribution
0 = Less Significant Contribution

TABLE 4 - 2 FUNCTIONS DELIVERING ARES' BENEFITS

Because precision dispatching offers the greatest benefit, the functions which enable it are of highest priority, particularly when they also enable other significant benefits. The data link to locomotives and precision positioning and speed indications are essential for ARES to deliver all of its most significant benefits. Locomotive monitoring and analysis contribute relatively little to precision dispatching. Computer-aided dispatching contributes only to precision dispatching, but the benefit of precision dispatching is nearly ten times the benefit of train control, which requires computer-aided train handling. Sorting functions in view of these priorities yields the following list of functions in order of potential benefit:

- Data link to locomotives
- Precision positioning and speed indications
- Traffic Planning and Computer-aided dispatching
- Locomotive monitoring and analysis
- Computer-aided train handling

These priorities help to determine the on-board equipment that BN should include in ARES. Table 4 - 3 shows the equipment components and their costs required for each function.

SAFETY:

Safety Improvement Because of:

- Enforcement.
- Train Handling.
- Route Integrity.
- All ATCS Features.

SAFETY:

Safety Benefits Come From 3 Sources:

☐ Reduce Direct Costs of Accidents (Lading, Equipment, Track).	$ 2.1 M
☐ Avoid Future Legislation:	
▭ Operating Costs.	$ 3.0 M
▭ Capital Costs.	$ 4.4 M
☐ TOTAL SAFETY BENEFITS:	$ 9.5 M

☐ Additional Benefits:

- ▭ Avoid 220 Injuries and 23 Fatalities.

FUNCTION	COMPONENT	COST*
Data link to locomotives	Basic hardware**	$14
	Simple input/output	$04***
Precision positioning and speed indications	Geopositioning receiver	$05
	Wheel tachometer	$02
Computer-aided dispatching	Sophisticated input/ output	$12
	MOW input/output	$02
	Train control computer	$19
Locomotive monitoring and analysis	LARS package	$16
Computer-aided train handling	LIM/RIM package	$12

* per unit, 1988 thousands
** rack, power supply, data radio, filters, and cable set
*** if installed, reduces the cost of sophisticated input/output to $08

TABLE 4 - 3 ARES FUNCTIONS COMPONENTS AND COSTS

The first three functions, the data link to locomotives, precision positioning and speed indications, and computer-aided dispatching, deliver the benefits of precision dispatching and on-board signaling and authorization for $54,000 total per unit. Locomotive monitoring and analysis, which makes a small contribution to precision dispatching, costs $16,000 per unit. Computer-aided train handling costs $12,000 per unit and delivers only the benefit of train control.

These estimates argue for:

- investing in equipment which enables precision dispatching and on-board signaling and authorization and
- evaluating the costs and benefits of locomotive monitoring and analysis and computer-aided train handling separately, possibly deferring investment in them at this time.

However, while the benefits of precision dispatching and on-board signaling and authorization are far greater, they are also far more uncertain than the benefits of locomotive monitoring and analysis and computer-aided train handling. In addition, computer-aided train handling allows the dispatcher to brake the train from the Control Center if the crew becomes disabled or violates an authority. The ability to save lives through remote intervention can not be expressed in dollars and cents. Therefore, BN may wish to consider investing not only in equipment which enables precision dispatching and on-board signaling and authorization for its potential payback but also in equipment which enables computer-aided train handling for its contribution to safety.

4.2 TIMING AND GEOGRAPHICAL STAGING

More than two-thirds of the benefits of ARES come from precision dispatching, which requires that virtually all trains in an area be equipped to communicate with ARES. It is not practical to fit locomotives throughout the railroad with ARES equipment at once. However, staging -- equipping locomotives in stages, limiting equipped locomotives to geographical areas, and adding "buffer" locomotives to power trains between those areas -- delivers the benefit of precision dispatching at least to significant portions of the railroad at a time. It also gives BN the ability to implement ARES in manageable phases.

4.2.1 THE TWO-STAGE PLAN

One implementation plan, to be completed in two stages, appears in Figure 4-4. The first stage, in 1993 - 4, includes the Northern Region track, from Seattle in the west to Chicago in the east, from Haver in the north to Kansas City in the south. The second stage, in 1995 - 6, includes the Southern Region track, from Denver in the west to Galena in the east and north and to Houston in the south.

This two-stage plan delivers $403 million in net present value, as detailed in Table 4 - 5.

4.2.2 FOUR-STAGE PLANS

Four stages appear to yield even greater net present value. One plan, judged feasible by BN's Transportation Department, begins in 1993 with the Denver and Tulsa - Houston track. In 1994, BN adds track bounded by Tulsa, Kansas City, Galena, and Birmingham. It adds a central section of track in 1995. It adds the north-most lines in 1996 as shown in Figure 4 - 6.

This plan delivers $419 million in net present value and might, through optimization, deliver even more. It yields almost 4% more than the two-stage plan, as detailed in Table 4 - 7.

BN might review other four-stage plans which deliver even more net present value. For example, one begins in the northwest, adds north-central track, adds central track, and ends with southern track as shown in Figure 4 - 8.

This plan yields $451 million net present value, 12% more than the two-stage plan, as detailed in Table 4 - 9.

4.2.3 PLANS WITH MORE THAN FOUR STAGES

In fact, a greater number of smaller stages delivers value even more quickly so that ARES might be implemented to finance itself. A stage accrues value as soon as it is implemented, and a small stage can be implemented relatively quickly. So, its contribution to net present value could be used to finance the next stage, which would accrue value to be used to finance the next stage, and so on until the entire railroad operates under ARES.

The disadvantages to this approach include longer total implementation time so that BN realizes ARES' total benefit later. Inflation may cause BN to pay a higher price for the system. A greater number of smaller stages will also require more locomotives to buffer implemented from unimplemented areas. Managing a longer implementation made up of smaller steps may be more difficult and frustrating. All of these considerations will affect final implementation plans. Nonetheless, implementation options provide BN some flexibility in financing ARES.

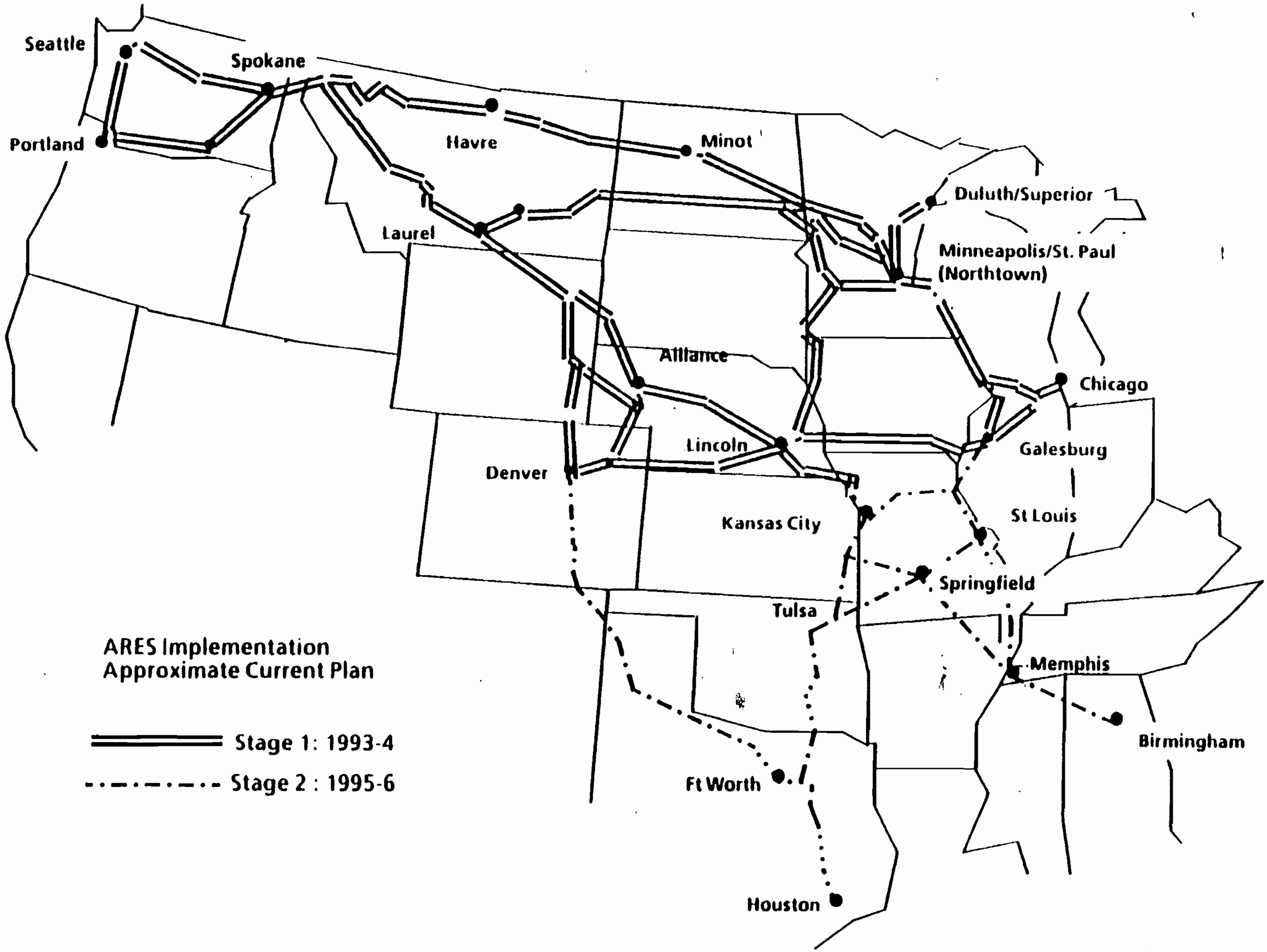


FIGURE 4.4 TWO-STAGE ARES IMPLEMENTATION

TCS Implementation Schedule	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Central Dispatch Center	0%	34%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Wayside Communications	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%	100%
On-board Equipment	0%	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%
ROW Survey	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%
Development effort	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%
TCS Benefits Realization Schedule												
Transit Time												
Intermodal	0%	0%	0%	0%	4%	9%	16%	34%	56%	76%	94%	100%
Mixed Freight	0%	0%	0%	0%	4%	9%	18%	37%	59%	78%	95%	100%
Unit Grain	0%	0%	0%	0%	4%	8%	11%	29%	50%	71%	93%	100%
Unit Coal	0%	0%	0%	0%	4%	8%	14%	32%	53%	74%	93%	100%
On-board Equipment	0%	0%	0%	0%	0%	9%	28%	53%	78%	94%	100%	100%
Signal Maintenance	0%	0%	0%	0%	0%	0%	4%	11%	36%	61%	82%	100%
Central Dispatching	0%	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Miscellaneous	0%	0%	0%	0%	4%	9%	14%	33%	54%	75%	94%	100%

Other Effects Schedule	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ROW Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Signal Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
TCS Road Locomotive Buffer	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Base Road Train Crew Size Factors	100.0%	100.0%	95.0%	89.7%	84.6%	79.6%	74.3%	69.3%	69.1%	68.8%	68.7%	68.4%
Road Train Crew Size Impact Factors	0.0%	0.0%	2.5%	5.4%	8.5%	12.1%	16.1%	20.8%	19.5%	17.8%	16.4%	14.7%

TABLE 4 - 5 TWO-STAGE PLAN CONTRIBUTION TO NVP

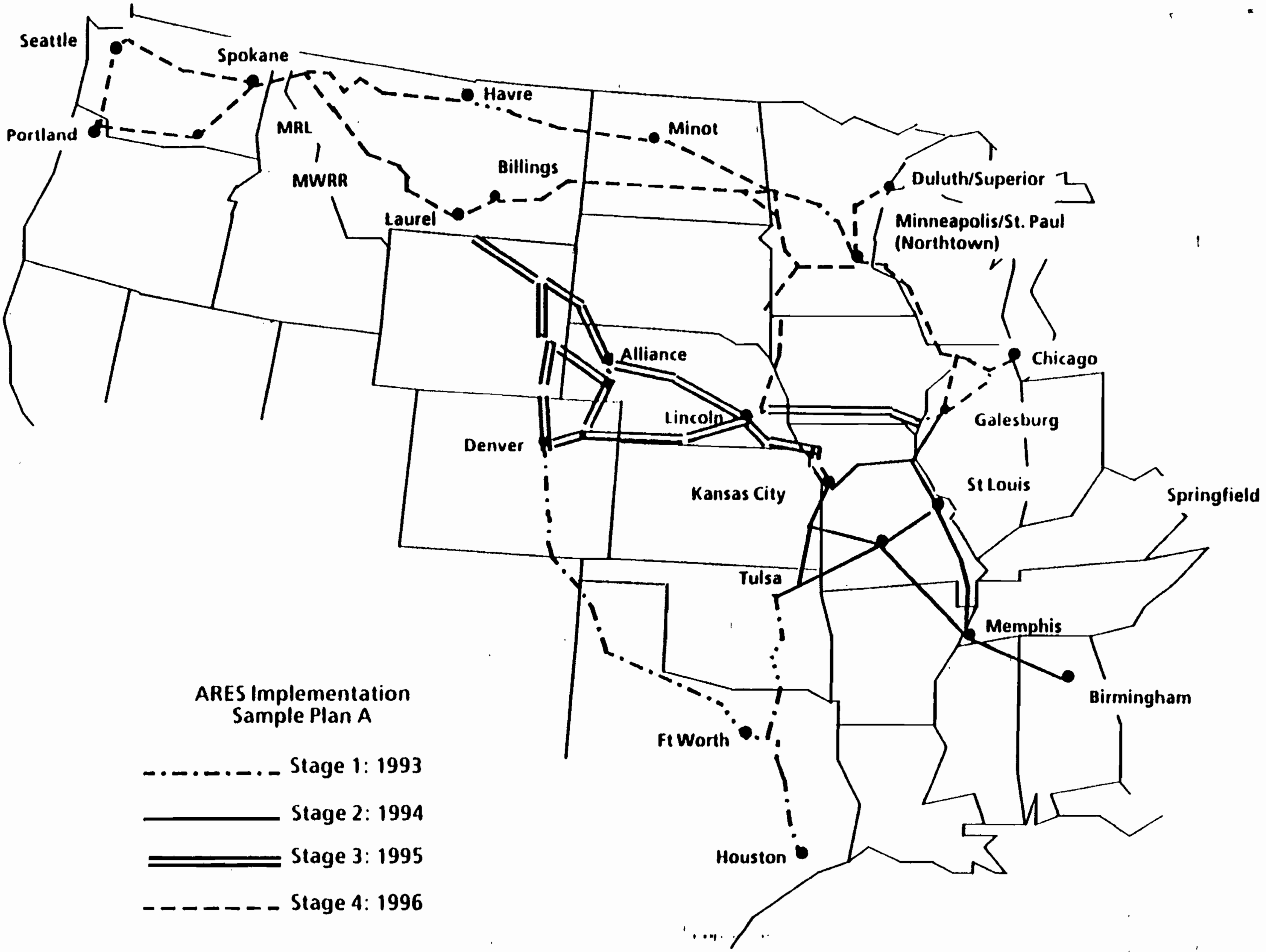


FIGURE 4 - 6 FOUR-STAGE ARES IMPLEMENTATION - ONE APPROACH

TCS Implementation Schedule	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Central Dispatch Center	0%	34%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Wayside Communications	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%
On-board Equipment	0%	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%
ROW Survey	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Development effort	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%
TCS Benefits Realization Schedule												
Transit Time												
Intermodal	0%	0%	0%	0%	4%	9%	18%	38%	59%	79%	95%	100%
Mixed Freight	0%	0%	0%	0%	4%	10%	21%	41%	62%	81%	96%	100%
Unit Grain	0%	0%	0%	0%	4%	8%	13%	31%	53%	73%	93%	100%
Unit Coal	0%	0%	0%	0%	4%	9%	22%	45%	66%	87%	98%	100%
On-board Equipment	0%	0%	0%	0%	0%	9%	28%	53%	78%	94%	100%	100%
Signal Maintenance	0%	0%	0%	0%	0%	0%	5%	19%	44%	69%	88%	100%
Central Dispatching	0%	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Miscellaneous	0%	0%	0%	0%	4%	9%	18%	47%	60%	83%	96%	100%
Other Effects Schedule	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
ROW Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Signal Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
TCS Road Locomotive Buffer	0%	0%	0%	0%	3.0%	5.0%	4.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Base Road Train Crew Size Factors	100.0%	100.0%	95.0%	89.7%	84.6%	79.6%	74.3%	69.3%	69.1%	68.8%	68.7%	68.4%
Road Train Crew Size Impact Factors	0.0%	0.0%	2.5%	5.4%	8.5%	12.1%	16.1%	20.8%	19.5%	17.8%	16.4%	14.7%

TABLE 4 - 7 FOUR-STAGE ARES IMPLEMENTATION - ONE APPROACH

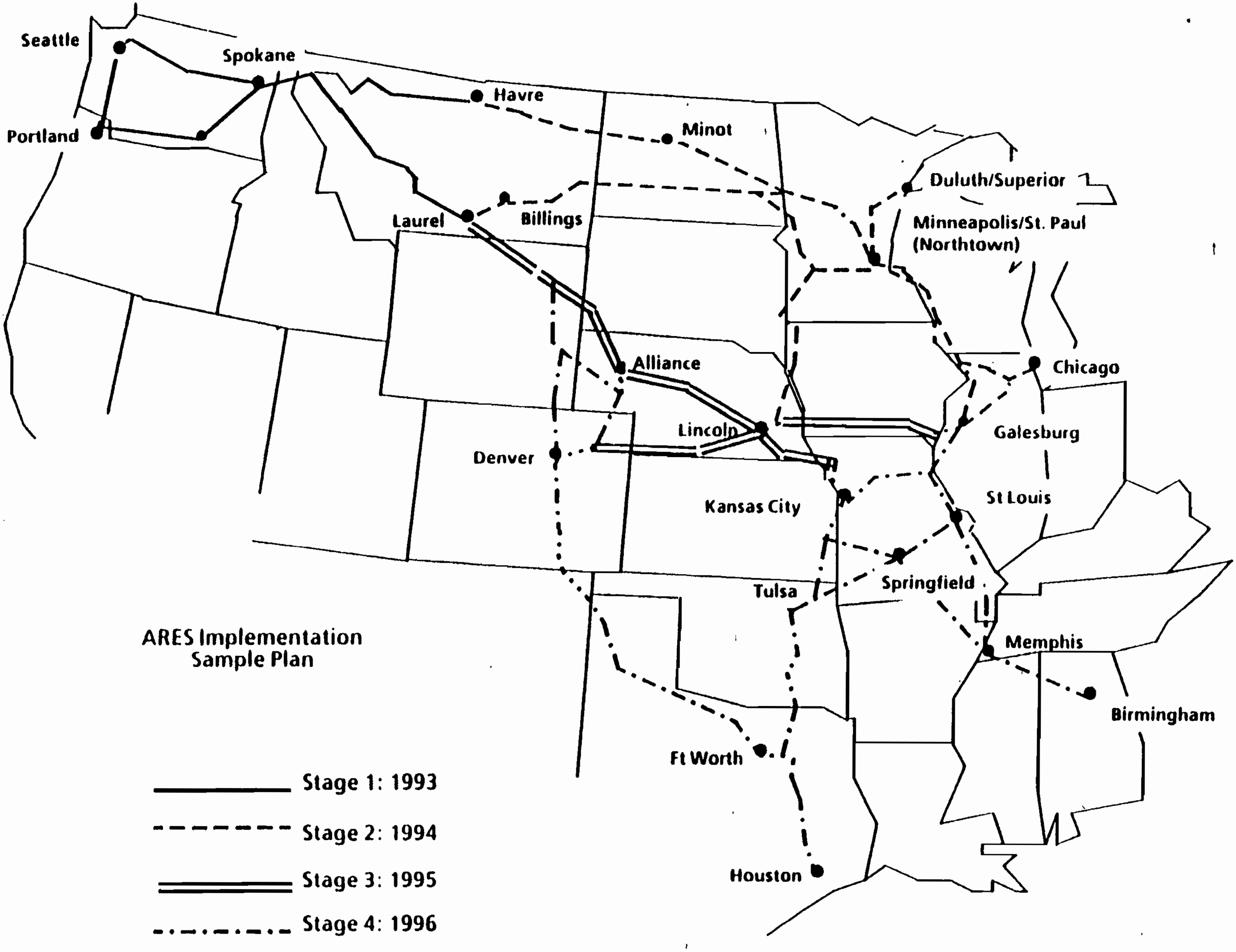


FIGURE 4 - 8 FOUR-STAGE ARES IMPLEMENTATION - A SECOND APPROACH

TCS Implementation Schedule	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Central Dispatch Center	0%	34%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Wayside Communications	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%
On-board Equipment	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
ROW Survey	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Development effort	0%	25%	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%
TCS Benefits Realization Schedule												
Transit Time												
Intermodal	0%	0%	0%	0%	4%	14%	33%	57%	78%	92%	99%	100%
Mixed Freight	0%	0%	0%	0%	4%	13%	29%	53%	74%	90%	98%	100%
Unit Grain	0%	0%	0%	0%	4%	16%	39%	63%	85%	97%	100%	100%
Unit Coal	0%	0%	0%	0%	4%	10%	23%	45%	66%	85%	97%	100%
On-board Equipment	0%	0%	0%	0%	0%	9%	28%	53%	78%	94%	100%	100%
Signal Maintenance	0%	0%	0%	0%	0%	0%	8%	25%	50%	75%	92%	100%
Central Dispatching	0%	0%	0%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Miscellaneous	0%	0%	0%	0%	4%	12%	31%	54%	78%	91%	99%	100%

Other Effects Schedule	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ROW Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Signal Investment Offsets (1988$M)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
TCS Road Locomotive Buffer	0.0%	0.0%	0.0%	0.0%	4.0%	5.0%	4.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Base Road Train Crew Size Factors	100.0%	100.0%	95.0%	89.7%	84.6%	79.6%	74.3%	69.3%	69.1%	68.8%	68.7%	68.4%
Road Train Crew Size Impact Factors	0.0%	0.0%	2.5%	5.4%	8.5%	12.1%	16.1%	20.8%	19.5%	17.8%	16.4%	14.7%

TABLE 4 - 9 FOUR-STAGE ARES IMPLEMENTATION - A SECOND APPROACH

SECTION 5.0
VALIDATION

KEY POINTS

- *The factors with the largest potential for delivering ARES ' benefits are also the most uncertain and require additional validation:*
    - *ARES' ability to improve transit time, being studied by Operations Research, and*
    - *The amount customers are willing to pay for better service, being studied by Marketing Services.*

The benefits analysis revealed two areas of considerable difference of opinion within Burlington Northern. Each has a large effect on the final estimates. The areas of controversy are:

- The amount and effect of transit time improvements expected with ARES deployment.
- The demand elasticity of improved service reliability.

Operations Research and Marketing Services are validating estimates of these two key elements.

5.1 TRANSIT TIME IMPROVEMENT

Operations Research will develop independent estimates of transit time improvements under ARES. These estimates may narrow the range of transit time savings for each traffic class.

5.2 DEMAND ELASTICITY

Marketing Services is considering other methods for estimating the demand elasticity of service. Possible methods include examining information on the reward/penalty structure of Burlington Northern contracts, running the Ship-Smart freight handling/price model, and interviewing market managers more rigorously.

Earlier, this report noted the strategic importance of Burlington Northern understanding the value of service. The estimates used in this study range by a factor of 20. Such a range allows BN to reach a decision about ARES, but many other strategically important questions require a more certain measure. Therefore, estimating demand elasticity more precisely is an important goal which should be pursued apart from the ARES decision.

SECTION 6.0
SUMMARY AND CONCLUSIONS

KEY POINTS

- *Because ARES can improve service and decrease investments to expand capacity, it can cost-effectively enable BN's pursuit of both base and expansion strategies.*

- *ARES' large contribution to BN's net present value regardless of strategy increases shareholder value and supports the prime goal of the corporation.*

- *ARES is a long term commitment, with a payback of only two years after implementation but with an implementation period of seven years.*

- *ARES' expected internal rate of return is 28% and virtually guaranteed to exceed 9% adjusted for inflation.*

- *ARES is significantly cheaper to install ($24,000 per mile) than CTC ($80,000 per mile).*

- *ARES qualifies in three of four categories of capital projects listed in BN's 1990 Capital Expenditure Program Guidelines:*

  - *items related to safety or service*
  - *items dealing with critical capacity matters*
  - *productivity items with high returns*

  Should the FRA mandate Automatic Train Control, ARES will offer the most economical compliance and qualify for the fourth category, projects required by law or regulation.

- *ARES will not cause terminals to clog; rather, its benefits will help BN manage terminal resources more effectively.*

- *ARES' benefits warrant highest priority on elements which achieve precision dispatching; an ARES control center should precede other capital expenditures.*

- *Decisions to develop locomotive monitoring and analysis systems should follow the 100-locomotive test of such capabilities.*

- *Successful implementation is critical to ARES' success. Implementation options offer some flexibility in financing ARES but present disadvantages as well and must be considered with care.*

6.1 ARES AND BURLINGTON NORTHERN'S CORPORATE STRATEGIES

This study has noted that investing in ARES appears to benefit any of three long-term business strategies. ARES benefits a more expansive, high-service strategy most because ARES provides a cost-effective method for substantially improving service.

The service improvements needed in an expansive strategy require very large investments in right-of-way and signaling. ARES can improve service without such large investments, however. Thus, the decision to implement ARES could influence the corporate direction of Burlington Northern.

As shown in the addendum at the end of this volume, even the base strategy requires capital investments to support a significant increase in volume. Many BN managers and staff are concerned that these investments may not yield enough return; therefore, much thought is being given to pursuing the focused strategy and foregoing the investments.

Since ARES can provide better service and decrease investment in capacity, there may not be a need to ignore markets as required by the focused strategy. ARES could be the impetus behind a strategy both to improve service and expand markets, and to reduce capital investments.

6.2 CONCLUSIONS

As shown in Figure 3 - 17, ARES provides a large net present value to the railroad regardless of the railroad's corporate strategy. This entire net present value, discounted for perceived risk, translates directly into shareholder value. As ARES is implemented and its benefits become obvious, investors will begin to find investment in Burlington Northern far more enticing. ARES therefore supports and is compatible with the prime goal of the corporation.

6.2.1 PAYBACK

Much scrutiny has been given recently to the concept of "payback." A project's payback is the number of years before the benefit stream pays back the original investment. Payback is often used to allocate resources because of a perception that capital is quite scarce and it is often used to allocate scarce capital by designating a very short payback period, say one or two years, as the maximum allowed to any funded project. Usually however, requiring short payback periods allows for investment only in very-high-risk short-term ventures (such as options trading) or in capital projects that become essential due to collapsing infrastructure. Solid investments that have a return significantly greater than the cost of capital can then be overlooked. In short, payback analysis with short payback period criteria can result in short-term capital savings at the risk of the long-term survival of the enterprise.

ARES' payback is either two years or nine years, depending on how one defines payback. Once the investment is completed, the benefits stream will exceed the cost in two years. However, since it will take seven years to implement the system fully, the turn to positive cash flow does not occur until the ninth year. Thus, in spite of having a payback of only two years, ARES is a long term commitment.

6.2.2 INTERNAL RATE OF RETURN

The internal rate of return is another measure of a project's attractiveness. If the internal rate of return is greater than the cost of capital, then capital can be raised to finance it and the payments to that capital will be exceeded by the benefits of the investment. However, if the project involves substantial risk, then the benefit flows may not be sufficient to service the investment. Therefore, internal rate of return requires an analysis of risk as well.

ARES' expected internal rate of return is 28%. However, the investment is risky because BN is unsure of the true internal rate of return. However, the net present value curves in Figure 3 - 15 provide a way to evaluate that risk. According to the figure, there is virtually no probability that the net present value will fall below zero. That means that the internal rate of return is virtually guaranteed to exceed an inflation-adjusted 9%. Therefore, ARES benefits are virtually assured of being large enough to service the investments they require.

6.2.3 PHASING

This analysis has presented a number of phasing plans. In general, plans with four phases or more seem to exceed the value of plans with only two phases because benefits from smaller completed phases can start accruing sooner. It is possible that more than four phases can be employed; however, the cost of isolating locomotives would then begin to rise. A balance between the number of phases and the cost of isolating locomotives will yield a phasing plan with the best return.

6.2.4 CONTRIBUTION TO BURLINGTON NORTHERN CAPITAL INVESTMENT GOALS

One of the first statements in the 1990 Capital Expenditure Program Guidelines for Burlington Northern is that priority will be given to "...capital expenditures which will best serve the *long term* needs of the Company" [emphasis added]. As the control system of the future, ARES is indeed a technology that best serves the long term needs of Burlington Northern.

A number of railroad officers have commented that ARES, or something like it, would be the chosen control system were a new railroad to be built from scratch. If for no other reason, this choice would be made because ARES is significantly cheaper than CTC. The cost of installing centralized traffic control (CTC) in unsignalled territory is approximately $80,000 per mile. The cost of ARES is approximately $24,000 per mile. (See SDG report, Appendix 8, page 31.) The concern is often raised, however, that BN has too much invested in its current control system to make a change.

One of the best examples of the results of similar logic comes from the United States steel industry, which rejected new electric arc furnaces because of investment in existing technology. Rejection of ARES could lead the railroad down a similar path.

The 1990 Capital Expenditure Program Guidelines list four categories of capital projects, in order of priority:

1. Projects required by law or regulation.

2. Items related to safety or service.

3. Items dealing with critical capacity matters.

4. Productivity items with high returns.

ARES is not currently required by any law or regulation (although an FRA mandate of Automatic Train Control could change that). However, ARES clearly contributes significantly to the other three categories listed.

6.2.5 INCREMENTAL ANALYSIS OF LARS AND TRAIN CONTROL

The projected net present value of LARS makes it appear a rather marginal investment. However,there are significant uncertainties in the analysis. A test of LARS on 100 locomotives is currently under way. That test will yield better estimates of LARS' effect railroad operation.

This analysis found train control to be a clear winner; however, it does not contribute nearly as large a benefit as precision dispatching. On the other hand, train control contributes significantly to safety. After ARES is installed, major accidents due to impaired crews or violation of authority will be virtually impossible. This gain is difficult to measure in dollars and cents. And, if FRA mandates Automatic Train Control, ARES will be the cheapest way to comply.

6.3 OTHER FINDINGS

The analysis team made a number of ancillary but significant findings about ARES' benefits. Their observations can not always be quantified, but they are nonetheless important:

- Improvement in transit time will not clog terminals. Rather, it will increase time to make connections in yards so that fewer cars will miss connections. Fewer cars with missed connections means there will be fewer cars to clog the terminal while waiting for the next train.

  Other benefits of ARES will also prevent clogging of terminals. Yardmasters will have better estimates of train arrival times. ARES will provide better information about the location of terminal equipment so that BN can manage terminal resources more effectively.

- While ARES will increase the effective capacity of the railroad, it will not solve certain capacity problems and bottlenecks such as the Cascade tunnel. ARES will also not eliminate the need to lay double track in some areas or to modernize and expand some terminals.

6.4 OBSERVATIONS

The analysis ~~of~~ ARES' benefits yields the following observations:

- Because precision dispatching is the most important benefit of ARES, the ARES team should place greatest priority and scrutiny on development of those ARES elements which help achieve precision dispatching. More specifically, construction of an ARES control center should precede other capital expenditures. Additionally, a greater emphasis on meet/pass planning and dynamic scheduling capabilities is justified.

- Since LARS does not have as high a rate of return as other ARES elements, a strong commitment to LARS should be deferred until the 100-locomotive test is completed. The test will yield information to lower the risk of the decision.

- Since the total net present value of ARES can be highly dependent on the ARES implementation scheme, significant effort should be placed in determining which scheme is best.

Burlington Northern retains all of its current coal and grain traffic (focused strategy). It retains auto, intermodal and merchandise traffic only if the traffic moves more than 800 miles or if it is an interline move. The second strategy assumes that BN continues to conduct business as it does today (base strategy). The third strategy expands service and enhances revenues (expansion strategy).

The analysis presents key uncertainties as probability distributions. It mathematically combines distributions to determine the uncertainty in the final estimates. This approach both quantifies the uncertainty of specific benefits and avoids "single-point" estimates.

The team made every effort to ensure the analysis was realistic. It avoided double counting of benefits, for example, expressing a benefit as a reduced cost or increased revenue but not both. It took no credit for programs already underway and added realistic time delays between implementation and realization of benefits. The analysis also anticipated that a significant number of locomotives would be out of service due to equipment installation during the implementation of ARES. The analysis includes the cost of leasing locomotives to cover the anticipated shortfall. The analysis also accounts for trains powered by foreign locomotives and needing to use a Burlington Northern ARES-equipped locomotive.

One of the expected benefits of ARES is reduced transit times. This benefit can be realized in three ways:

1) as an increase in service level and enhanced revenues,

2) as a decrease in operating costs, or

3) as an avoidance of future investments in right of way.

The analysis looked at each of these realizations separately and examined the tradeoffs among them to recommend the best strategy.

1.3 ARES, THE ADVANCED RAILROAD ELECTRONICS SYSTEM

ARES combines the technologies of high speed computing, digital communications, satellite positioning, and state-of-the-art electronics to:

- command and control the safe movement of trains on schedule,
- communicate among locomotives, MOW vehicles, wayside systems, dispatchers, and managers, and
- gather and distribute information about locomotives, trains, crews, consists, and track.

1.3.1 Feasibility

Work began in 1984 to explore the feasibility of ARES. BN concluded that ARES could be built and installed on the railroad, and so it began to develop a prototype with Rockwell International in 1986 to test ARES in a real operating environment. The prototype runs on 17 locomotives and three MOW vehicles over 230 miles of track on the Mesabi Iron range. Figure 1-2 shows the history of the ARES feasibility study and prototype development.

BN is using information from its testing to define the functions and forms of the production system.

1.3.2 Development and Installation

ARES will be built by Rockwell International and installed throughout the railroad in three segments. First, the Control Segment will equip dispatchers to monitor the positions and velocities of all vehicles in all types of territory to control traffic more effectively. ARES will produce a traffic plan, display activity at three levels of detail, and supply information about consists, crews, and work orders for any train in the territory. ARES will monitor activity to ensure that vehicles follow proper operating procedures and warn the dispatcher of violations to limits of speed and authority. ARES will produce authorities which it has checked for conflict. After the dispatcher reviews them, ARES will transmit them automatically to engineers.

In the ARES Data Segment, BN will install equipment to send data between radio base stations along BN track, locomotives, MOW vehicles, and track monitoring and control equipment. Data will travel in short messages called packets routed by a front-end processor, cluster controllers, and ground terminal controllers at radio base stations approximately 30 miles apart. Wayside Interface Units, or WIU's, control powered switches, monitor manual switches, and communicate switch and signal status through the network to the dispatcher.

In the ARES Vehicle Segment, BN will equip each locomotive with a receiver of Navstar satellite signals to calculate train position and speed. A display on board each locomotive will inform train crew members about movement authorities, the route ahead, work along the route, and the health of other locomotives in the power consist. The health monitoring system will monitor various aspects of locomotive performance to diagnose malfunctions early and schedule maintenance most cost-effectively. BN will equip each MOW vehicle with a satellite receiver to calculate its position and speed, a device to communicate to the dispatcher, and a printer to receive warrants, bulletins, and ETA's in the field. The Vehicle Segment will also equip ARES to apply a full-service brake to any train if its crew is disabled or violates a movement authority.

The relationship of these segments appears in Figure 1-3. Figure 1-4 shows the Development and Implementation schedules for the three segments of ARES. ARES is described in detail in the ARES Control Segment Systems Requirements Document produced by Burlington Northern in June, 1989. Volume 1 introduces its functions, capabilities, and benefits and defines its development activities. Volume 2 with appendices details the operation, functions, quantitative performance and capacity, and architecture of the ARES Control Segment.

ARES HISTORY
PHASE I and PHASE II

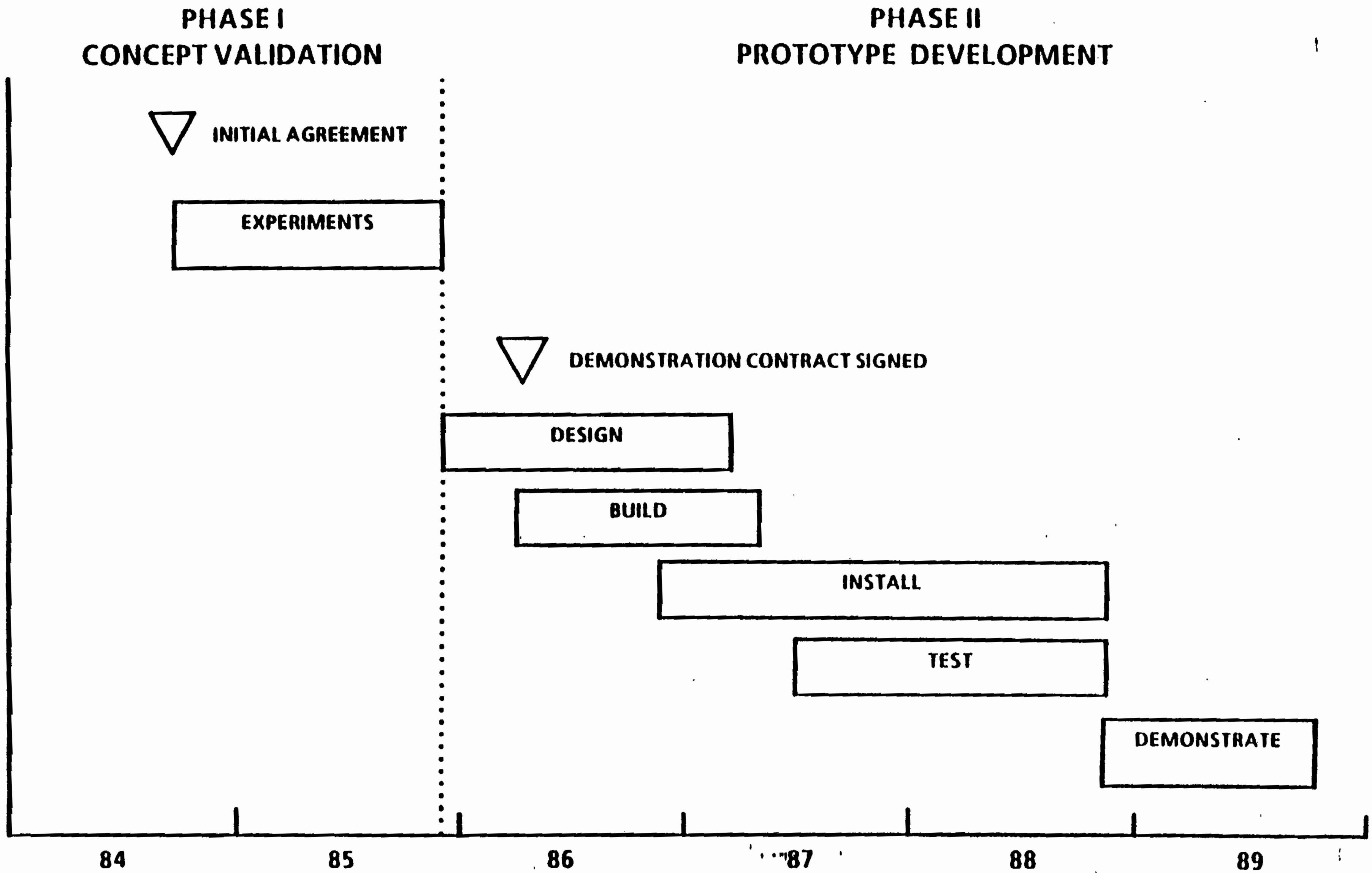


FIGURE 1-2

RELATIONSHIP AMONG ARES IMPLEMENTATION SEGMENTS

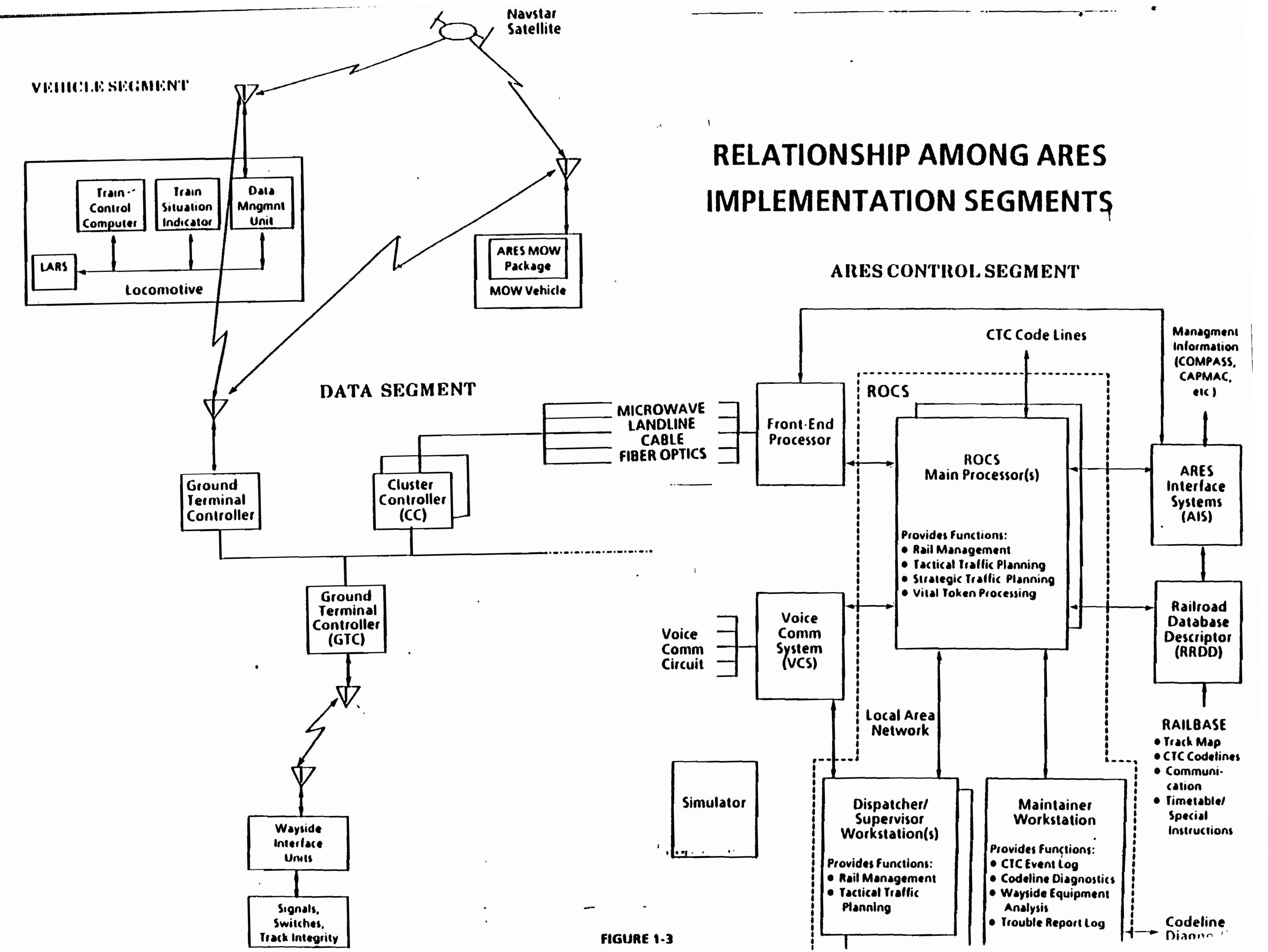


FIGURE 1-3

ARES IMPLEMENTATION PHASE III

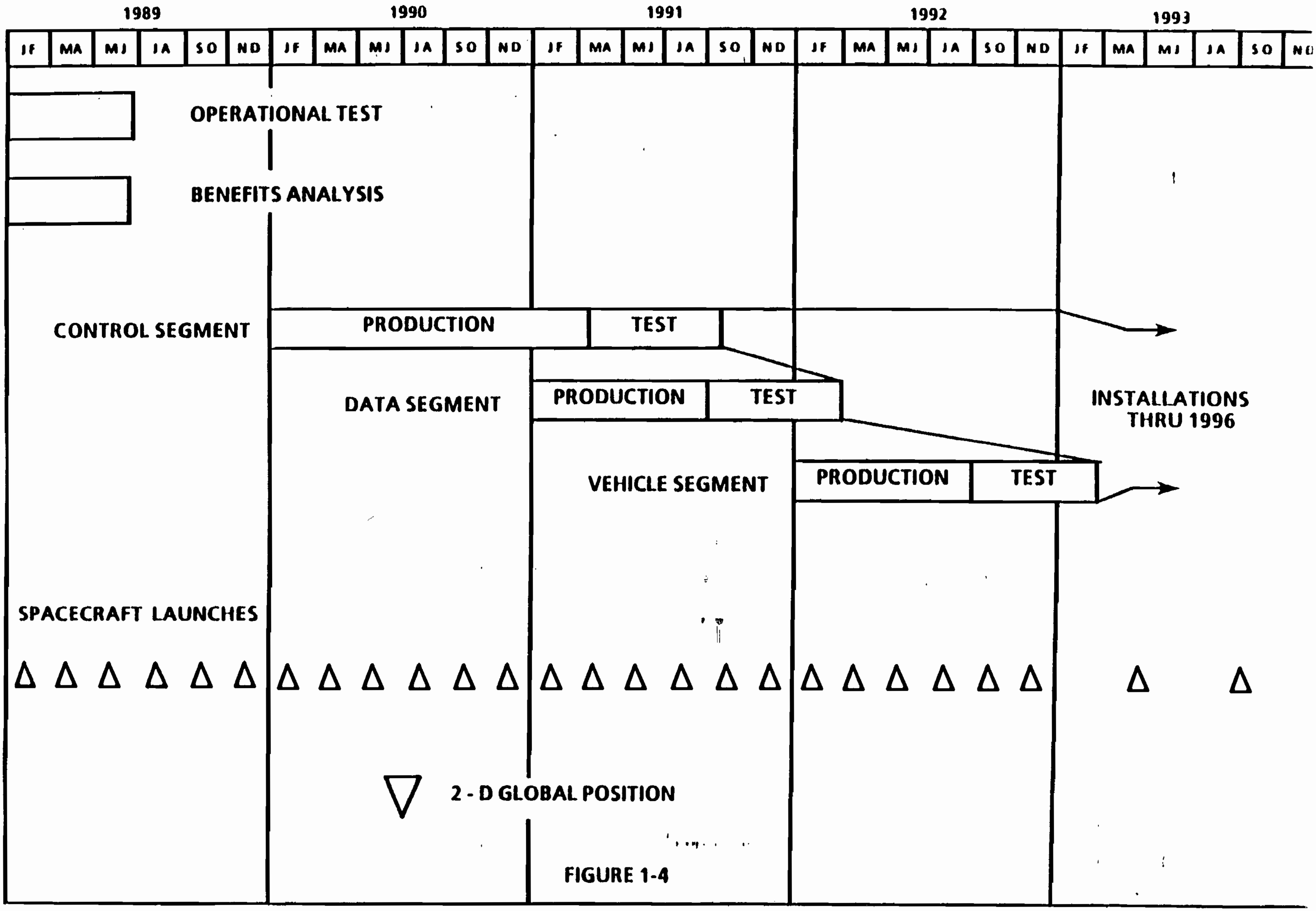


FIGURE 1-4

1.3.3 Benefits

ARES offers many benefits which enable BN to reach its goals of safe and profitable rail operations. Following is a summary of those benefits.

- **Increased rail operations safety** results from constant monitoring of wayside signal and detector equipment, train movement, and locomotive health.
- **Greater operating efficiency and improved customer service** come from operating trains to schedule and handling trains that deviate from schedule, the results of improved traffic planning.
- **Improved safety and increased customer service** come from real -time position, speed and ETA's for all trains computed continuously and automatically provided to MOW crews and other BN users through existing BN computer systems.
- **Improved dispatcher productivity** results from automating routine dispatching activities such as threat monitoring, warrant generation, traffic planning, and train sheet documentation.
- **Higher effective** line capacity is provided by accurate vehicle position information and automatic train movement authorization.
- **Improved MOW** productivity results from improved traffic planning.
- **Improved business management** is possible with accurate, current information about the status and performance of operations and equipment.

The following pages quantify and analyze these benefits under three strategies for BN's future growth.

SECTION 2.0
ARES AND CORPORATE STRATEGIES

KEY POINTS

- *The study examined ARES within three corporate strategies:*
    - *"focused," in which BN retains all coal and grain traffic but only auto, intermodal, or merchandise traffic if an interline move or a move greater than 800 miles on-line*
    - *"base," in which no changes occur in pricing, service level, traffic growth, or transportation industry cost structures*
    - *"expansion," in which service consistency improves 15% and traffic volumes generally increase 75%*
- *For each strategy, the study used projected growth rates lower than BN's actual growth rate from 1986 to 1988.*

2.1. CORPORATE STRATEGIES

The Planning and Evaluation department of Burlington Northern has developed three strategies to govern the direction of the railroad into the twenty first century. These are titled focused, base, and expansion. The following section defines and compares them.

2.1.1 FOCUSED STRATEGY

The focused strategy makes two primary assumptions:

- Burlington Northern retains all coal and grain traffic.
- Burlington Northern retains auto, intermodal, and merchandise only if that traffic is an interline move or is moving more than 800 miles on-line.

These assumptions are based on the proposition that future rail traffic will not be competitive with new long-haul trucks for non-bulk traffic at distances less than 800 miles.

2.1.2 BASE STRATEGY

The base strategy assumes that today's competitive situation does not change:

- There are no changes in pricing, level of service, or traffic growth rate.
- The cost structures of railroads, trucking lines, and barge companies remain as they are.

2.1.3 EXPANSION STRATEGY

The expansion strategy assumes increased service consistencies (the percent of time shipments arrive on schedule) and elasticities (here, changes in traffic volume due to improved service) for various commodity types:

- Service consistency improves 15%, from 70% to 85%.
- Overall, traffic volumes increase five percent for every percent of increase in service consistency.
- However, some commodities' volumes increase more or less due to improved service. For example, farm products' volumes increase another 75% when service improves, while coal's volumes do not increase any more. The following multipliers show how much improved service increases volumes for various commodities:

+ 75%	-	Farm Products, Canned Goods, Frozen Food, Sweeteners/Oils, Beverages,Grocery Products, Minerals, Government and Consumer Goods, Paper, Intermodal other than Expediter, Environmental Logistics.
+ 50%	-	Industrial Chemicals, Petroleum, Steel Products, Aluminum, Other Metals, Petrochemicals, Pulpwood, Plywood, Lumber, Particle Board, Woodpulp, Other Wood Products.
+ 25%	-	Automotive
+ 0%	-	Barley, Corn, Wheat, Other Grains, Oil Seeds, Feeds, Flour/Grain, Malt, Fertilizer, Industrial Sands, Clays/Barites, Iron/Ores, Coke, Coal.
+ 100%	-	Expediter intermodal

- All carriers are able to incorporate these improvements.

2.2 STRATEGY COMPARISONS

The strategies generate traffic volumes projected to the year 2005 and summarized in Table 2 - 1. Table 2 - 1 shows full carload trips in millions and compounded annual percentage growth rates.

The projected traffic flows of Table 2 - 1 are compared graphically in Figure 2 - 2.

Traffic Type	Current Flow	Traffic Flow in 2005 (full carload trips, millions/compound annual growth rate)		
		Focused Strategy	Base Strategy	Expansion Strategy
Intermodal	1085	1500/2.2%	1825/3.5%	2400/5.4%
Coal	1415	1475/0.3%	1475/0.3%	1475/0.3%
Grain	485	605/1.5%	610/1.5%	610/1.5%
Merchandise	1110	1190/0.5%	1770/3.2%	2580/5.8%
Total	4095	4770/1.0%	5680/2.2%	7065/3.7%

Table 2 - 1 TRAFFIC FLOW PROJECTIONS FOR 2005

2.3 PROJECTED GROWTH RATES

The annualized compound growth rates of total traffic for the focused, base, and expansion strategies are 1.0%, 2.2%, and 3.7% respectively. Comparing these growth rates to the actual and projected traffic levels shown in Figure 2 - 2 yields the following conclusions:

- The projected growth rate used in the ARES benefits analysis is not as high under any strategy as the actual growth rate was from 1986 through 1988.
- The growth rates projected to the year 1993 by the Planning and Evaluation department are significantly higher than those used in the benefits analysis.

The Addendum to this document presents a number of actual and projected measures of growth from 1986 to 1993. Note that traffic levels in Figure A - 4 are measured in revenue ton miles. The focused, base, and expansion strategies measure growth in full carload trips. Full car load trips will grow slower than revenue ton miles.

APPENDIX A.2: FACTS ABOUT BURLINGTON NORTHERN RAILROAD

1. Plant and Equipment

Route miles operated:	23,088
Route miles owned:	21,800
Track miles operated.	34,063
Track miles owned:	30.202
Freight cars:	58,210
Locomotives:	2,340

2. Traffic

Carloads originated:	3,548,891
Tons originated:	266,863,119
Ton-miles	232,441,300,000

Traffic mix:

1. Products of mines	39.4%
2. Manufactured/misc.	26.0%
3. Agricultural products	22.5%
4. Forest products	12.1%

3. Employment

Total compensation (1991)	$1,319,442,000
Average # of employees:	31,760

4. Sources of Expense

Employee compensation and benefits:	40.5%
Purchased services:	13.2%
Depreciation and amortization	8.7%
Material	8.5%
Equipment rents	8.0%
Fuel	7.2%
Other railroad expenses	10.1%
Other	3.8%

5. Financial

Operating Revenue (1991)	$4,558,650,000
Operating Expenses	$4,797,479,000
Net Railway Operating Income	($110,900,000)
Total Capital Expenditures	$367,587,000

Sources: Yearbook of Railroad Facts (Washington: AAR, 1992)
Transport Statistics in the United States, (Washington: Interstate Commerce Commission. 1991)

CN ATCS Business Case Presentation

All the figures in the CN Business Case Presentation are in Canadian Dollars. This spreadsheet gives the $US for each $C figure in the presentation based on a 4-year average rate of 0.85048

Page #	Item	Canadian $M	American $M
20	Increase in Profit	78.1	66.4
21	Reliability Increase in Revenues & Profits	48.5	41.2
21	Customer Service Benefits	78.1	66.4
24	Benefits from Consolidation	2.0	1.7
24	Benefits from Productivity Tools	6.8	5.8
24	Total Dispatch Office Benefits	8.8	7.5
26	Reduce Direct Costs of Accidents	2.1	1.8
26	Operating Costs	3.0	2.6
26	Capital Costs	4.4	3.7
26	Total Safety Benefits	9.5	8.1
27	Benefit Value	7.1	6.0
29	Locomotive Diagnostic Benefits	13.7	11.7
30	Meet/Pass Planner	2.9	2.5
30	Other Delay Reductions	3.3	2.8
30	Reduced Maintenance	0.5	0.4
30	Total Benefit Value	6.7	5.7
31	Total Savings	6.9	5.9
33	Crew Savings	7.0	6.0
33	Crew Savings (including more miles)	13.9	11.8
34	Value	21.6	18.4

Page #	Item	Canadian $M	American $M
36	WOR Customer Service Increases Profit	14.6	12.4
37	Loco Diag	13.7	11.7
37	Equip	6.7	5.7
37	Dispatch	8.8	7.5
37	Safety	9.5	8.1
37	Eng	7.1	6.0
37	Cust Service	78.1	66.4
37	Fuel	6.9	5.9
37	Crews	7.0	6.0
37	WOR	36.2	30.8
37	Total Mature Year Benefits	174.0	148.0
39	Total Capital Costs	365.8	311.1
39	Annual Incremental Operating Costs	23.6	20.1
44	Biggest Bang for the Buck		
44	NPV	275.8	234.6
44	Capital Cost	365.6	310.9
44	Risk Reduction		
44	NPV	144.9	123.2
44	Capital Cost	365.6	310.9
44	Reduce Costs		
44	NPV	179.8	152.9
44	Capital Cost	329.1	279.9
44	Inc Cust. Serv.		
44	NPV	222.2	189.0
44	Capital Cost	365.6	310.9
44	Dec Cust. Serv.		
44	NPV	67.5	57.4
44	Capital Cost	365.6	310.9

ATCS BUSINESS CASE

Appendix B.1

OUTLINE:

- Objectives.
- Cost / Benefit Model - Assumptions.
- Run Time and Reliability Improvements.
- Benefit Categories.
- Cost Categories.
- Implementation Scenarios.
- General Conclusions.

OBJECTIVES:

1. To Determine if ATCS Technology Offers Sufficient Long Term Value to Become CN's Technical Standard in the Purchase of New Train Control Equipment.

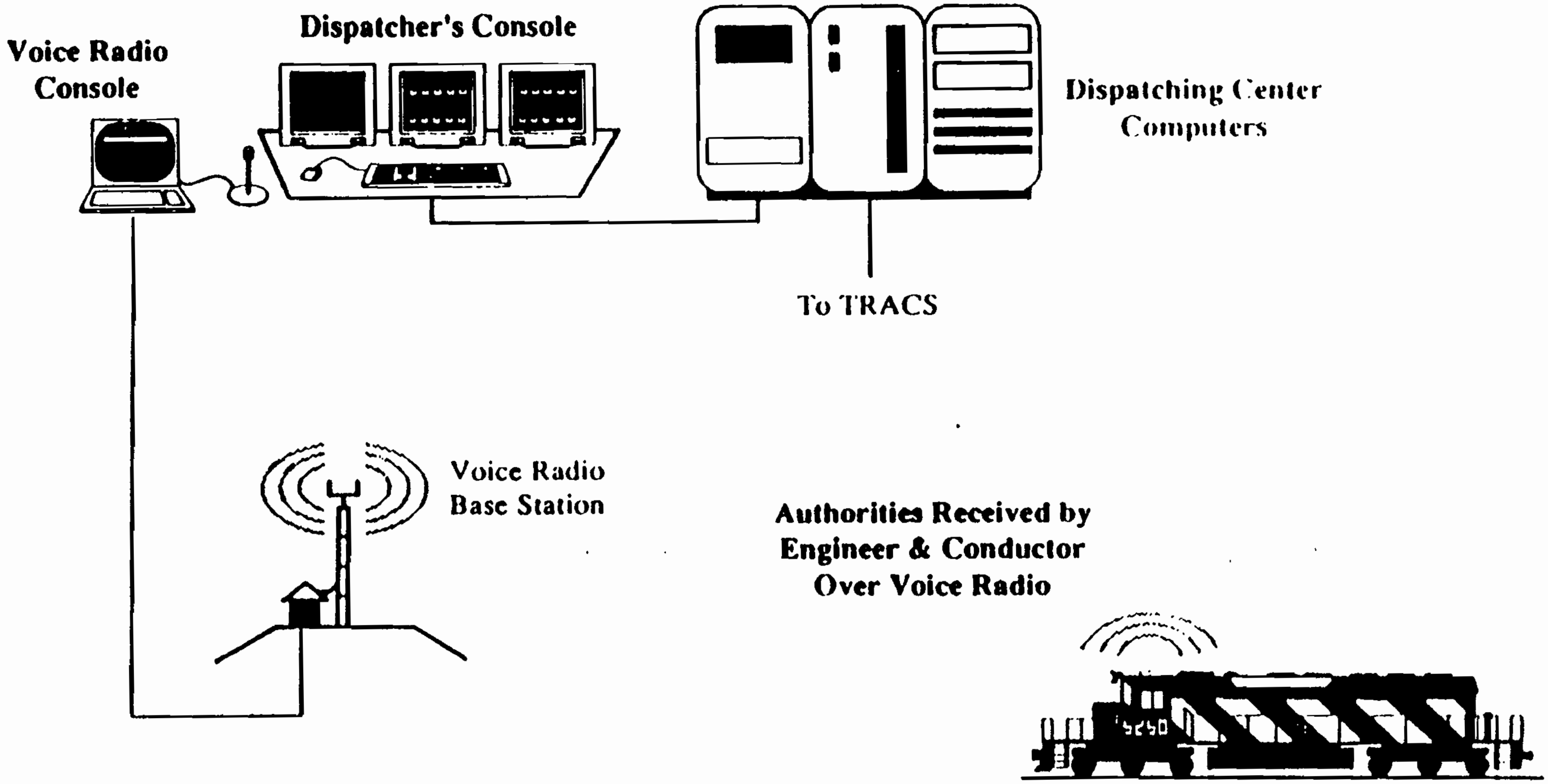
2. To Identify ATCS Components or Subsystems Which Should be Implemented in the Short Term.

3. To Identify Risk Areas Associated with ATCS Implementation and Identify Steps that Could be Taken to Reduce These Risks.

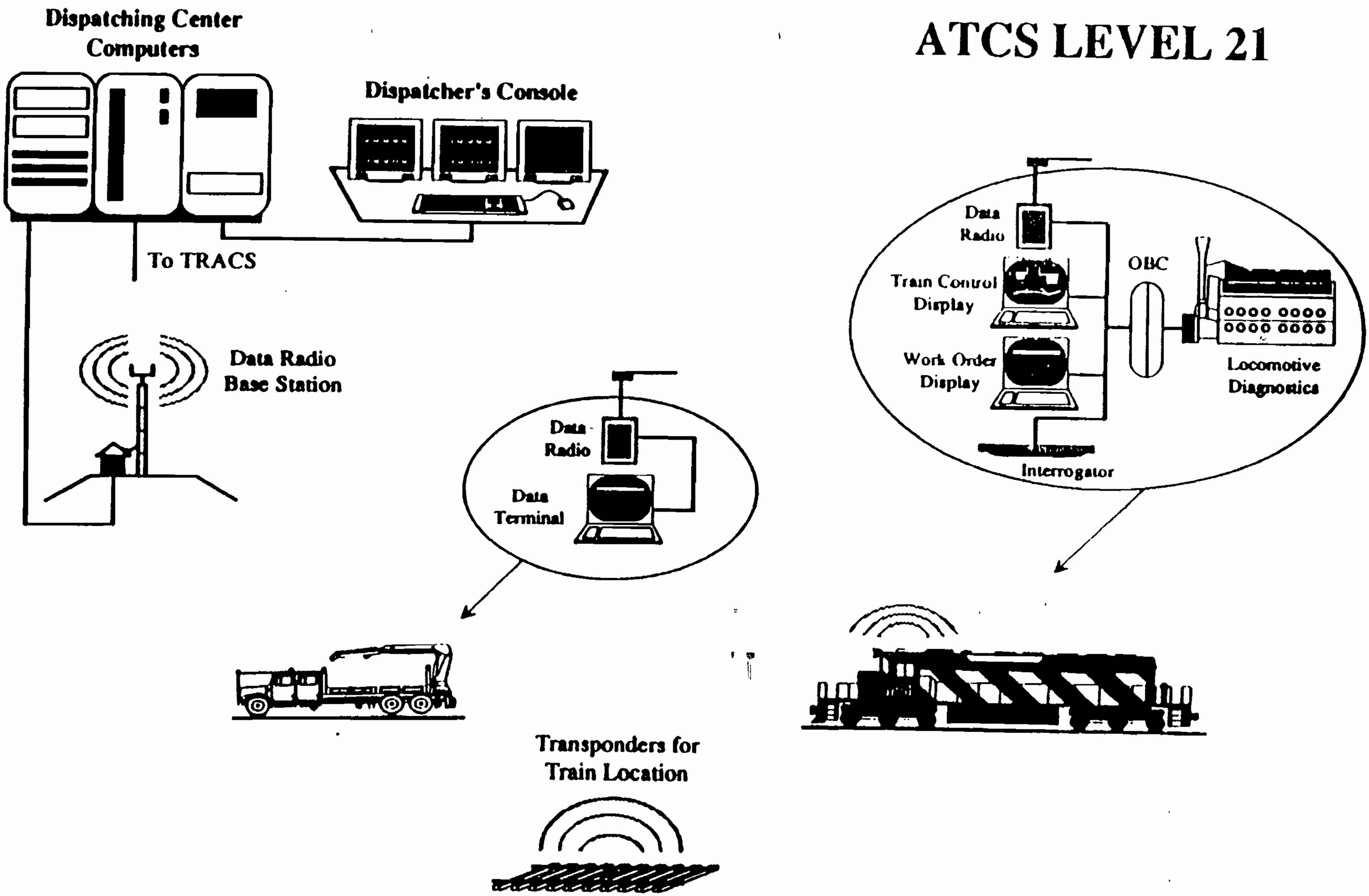
COST / BENEFIT MODEL:

- Key Assumptions:
  - ATCS Levels.
  - Locomotive Fleet Size.
  - Territories Covered.
  - Foreign Traffic.
  - Local Tactical Planner.

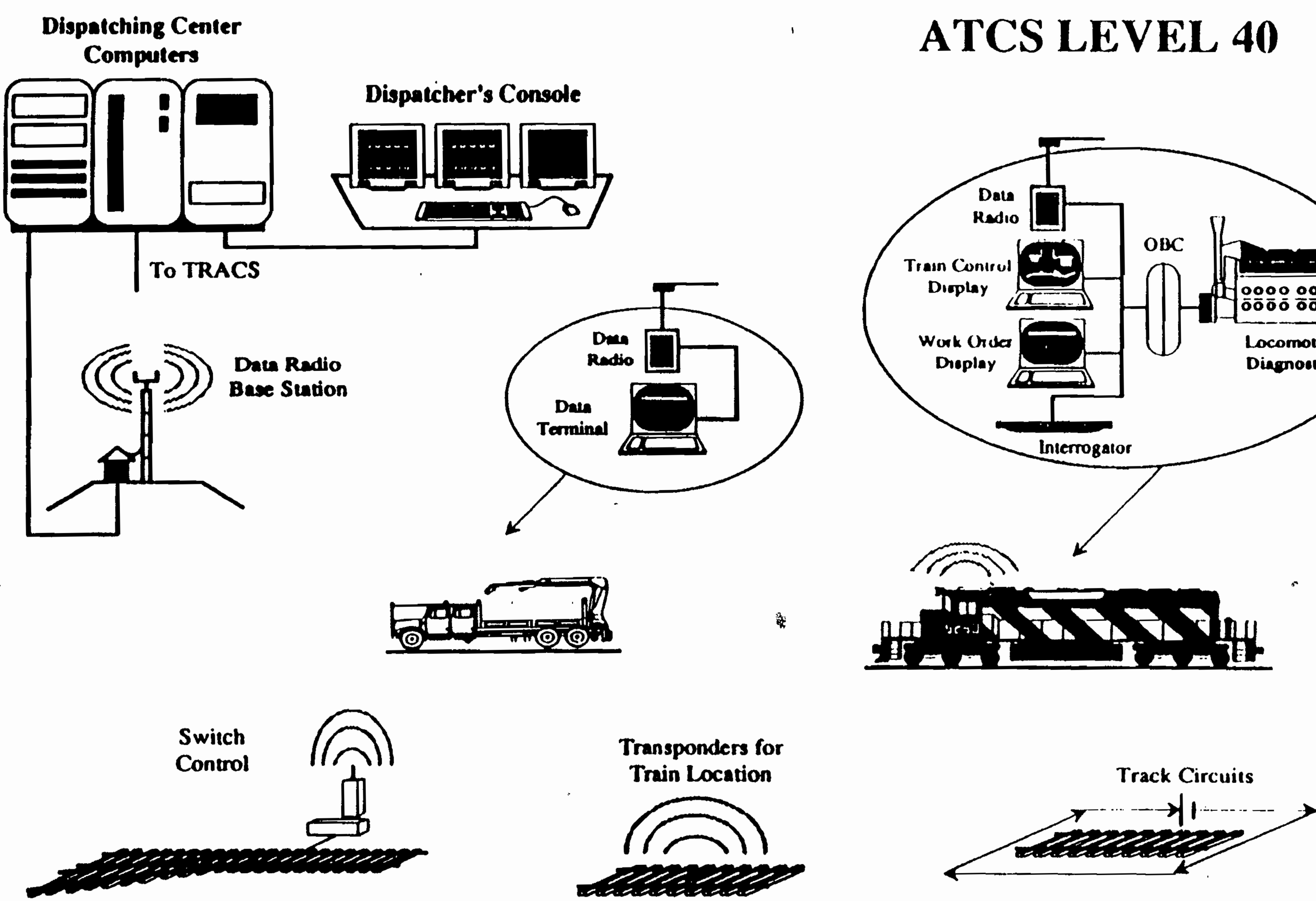
ATCS LEVEL 10



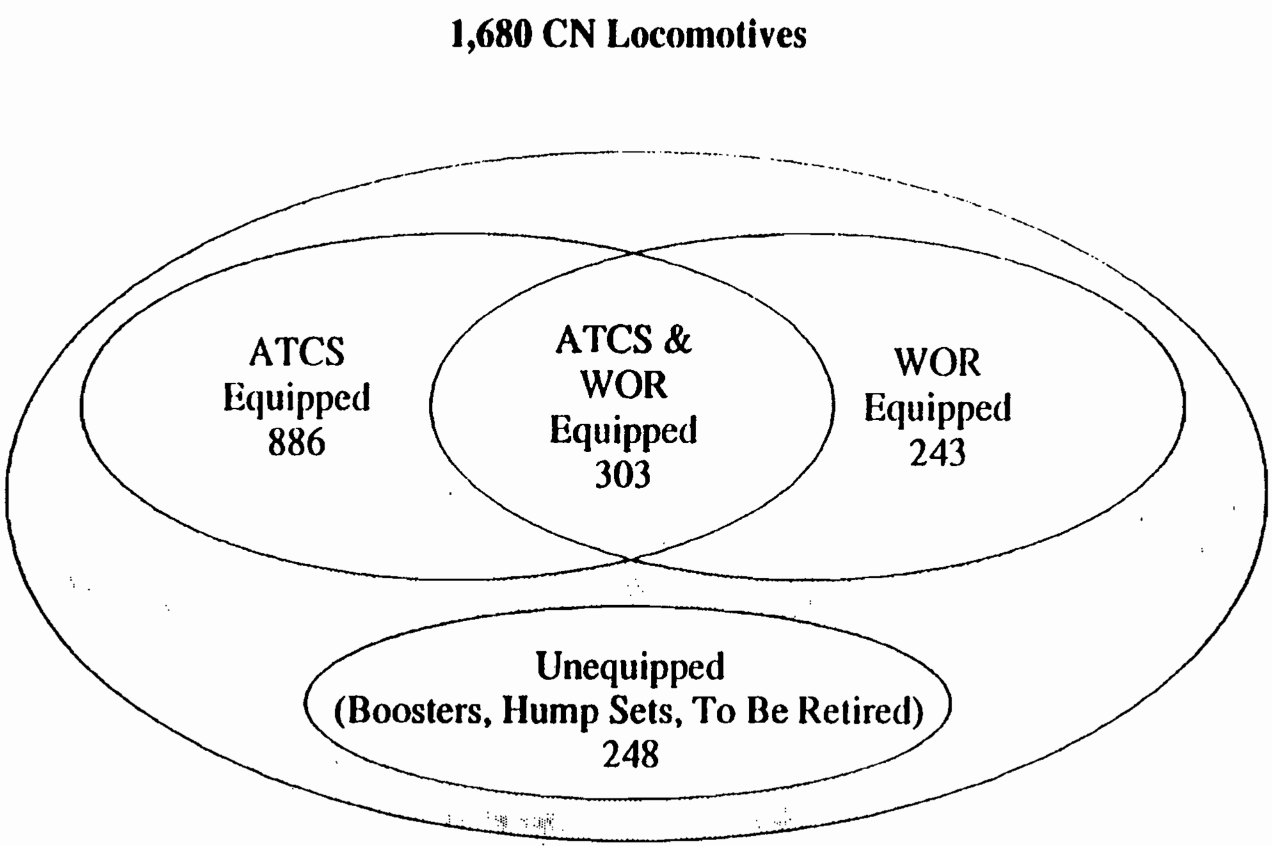
ATCS LEVEL 21



ATCS LEVEL 40



LOCOMOTIVE FLEET SIZE:



TERRITORIES COVERED:

- Mainline Track - Level 40.
- Major Branch Lines - Level 21.
- Other Lines - Level 10.
- ATCS Free Zones.

FOREIGN TRAFFIC:

- Costs Do Not Include Equipping VIA or GO.
- Assumed No Capital Contribution.
- Costs Do Not Include Equipping CSX, BN, NS, ... on Our Territory.

LOCAL TACTICAL PLANNER:

- Basis for Run Time and Reliability Improvements:
  - RT & R Important for Most Benefit Categories.

- Qualities:
  - Integrated with "Network Tactical" Planner.
  - Accurate Prediction of Train Performance - Real Time.
  - Automated Engineering Interface:
    - TOPs, Information Line-Ups.
  - Dynamic Headway.

RUN TIME & RELIABILITY

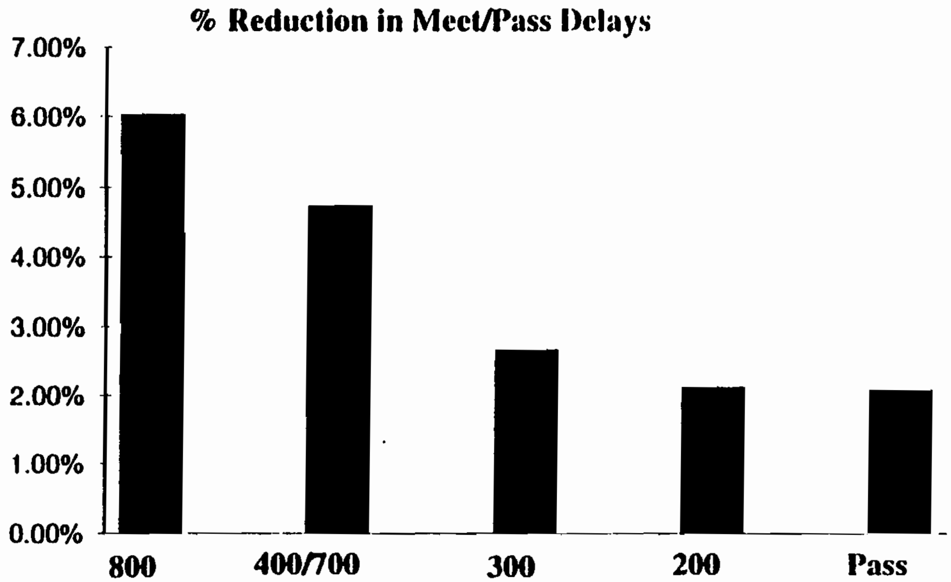
RUN TIME & RELIABILITY:

CIGGT Shows Run Time Reduces and Reliability Increases Simultaneously:

- Optimal Dispatch Decisions - Local Tactical Planner:
  - Meet/Pass Delay Reduction.
  - Other Delay Reduction.
- Dynamic Headway:
  - Fleeting of Trains.
  - Closer Headways.

RUN TIME & RELIABILITY:

Run Time Savings:



Weighted Average Meet/Pass Delay Reduction = 3.1%

RUN TIME & RELIABILITY:

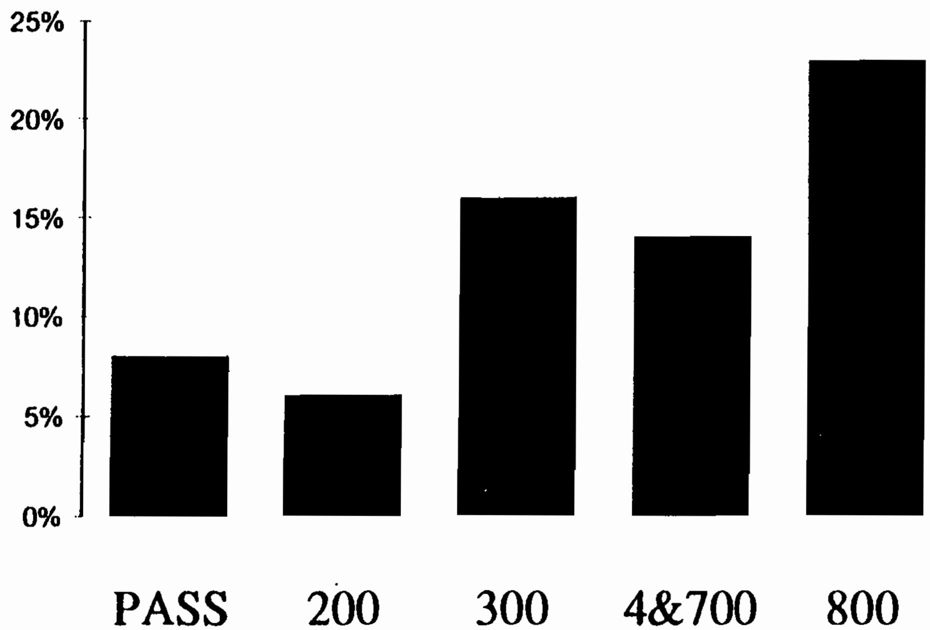
- Other Types of Delays will be Reduced:
  - 16% Authorized Set Back.
  - 20% Work Block Related Delays.
  - 10% Power Shortage.
  - 10% Congested Yard.
  - 5% Crew Rest.
  - 10% Derailment Delays.

- Equivalent Percent Run Time Reduction = 3.8%.

TOTAL RUN TIME REDUCTION = 3.8% + 3.1% = 6.9%.

RUN TIME & RELIABILITY:

Road Reliability Improvement:



Weighted Average Road Reliability Improvement = 12.2%

RUN TIME & RELIABILITY:

- Need to Estimate Door-to-Door vs. Over-the-Road Improvements:
  - Reliability is Linked to Run Time.
  - Cars Spend About One-Third of Their Time in Transit.
  - Rest of Time is Spent at Origin, Destination or Intermediate Yards.
  - Reduce the Run Time Improvement of 6.9% to One-Third Yields a Door-to-Door Run Time Reduction of 2.3%.
  - Similarly the Road Reliability Improvement of 12.2% is Reduced to 4.1% Door-to-Door.

BENEFIT CATEGORIES

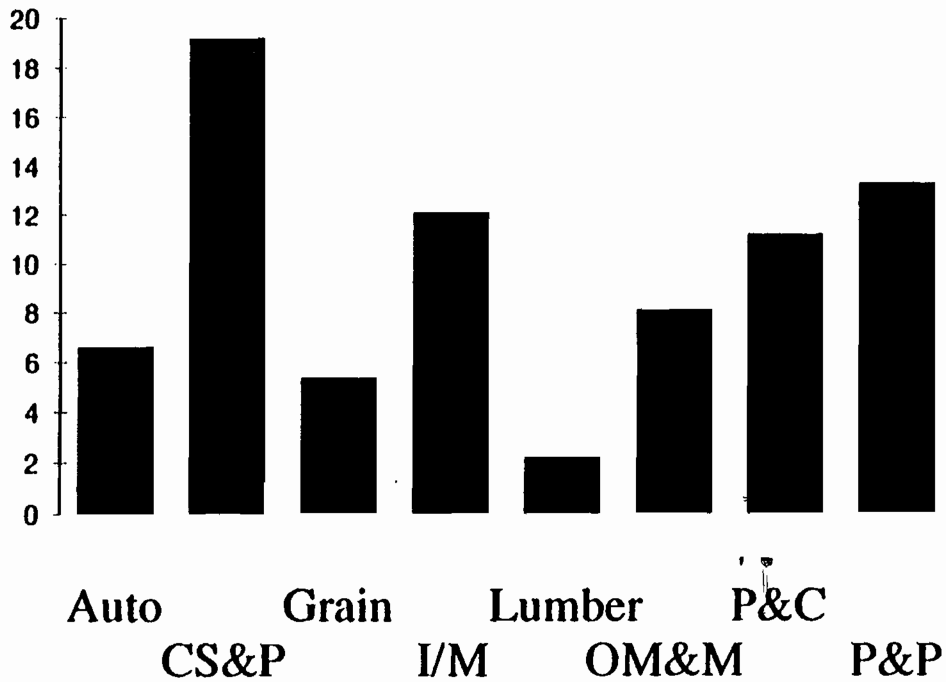
CUSTOMER SERVICE:

What is the Value of ATCS Improvements to the Customers?

- Each Business Unit Ranked the Importance to their Customers:
  - Improved Reliability.
  - Reduced Run Time.
  - Improved Equipment Availability.
  - Reduced Damage.
- Used BN's Price Elasticities.
- Applied to CN's 1989 Revenues and Costs.

CUSTOMER SERVICE:

Increase in Profit:



Increase in Profit = 78.1M

CUSTOMER SERVICE:

Comparison to a CN Confidential Contract:

- Used to Cross-Check that Customer Service Benefits Can be Achieved.
- Reliability Improvement Only.
- On Total CN Revenue.
- ATCS Will Increase Revenues and Profits by About 48.5M.
- Confirms Customer Service Benefits of 78.1M.

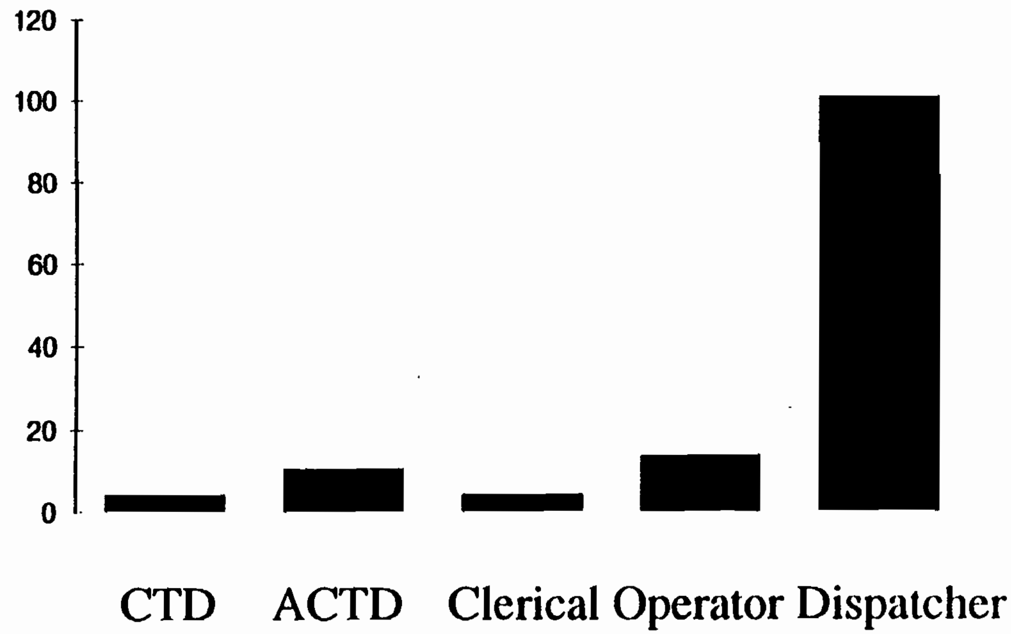
DISPATCH OFFICE:

Benefit Areas:

- Consolidation From 9 Offices to 3 (Montreal, Toronto, Edmonton).
- Productivity Tools:
  - Tactical Planner.
  - Computer Generated & Transmitted Authorities.
  - Interfaces to TRACS, TMOS, OMC, Marketing.
  - Data Link with Yard Masters.
  - Engineering Requests by Data Radio.

DISPATCH OFFICE:

Staff Reductions: 133 People



DISPATCH OFFICE:

- Benefits from Consolidation: 2.0M
- Benefits from Productivity Tools: 6.8M
- Total Dispatch Office Benefits: 8.8M

IMPLEMENTATION

ENGINEERING:

- More Productive Engineering Time Because:
  - Authority by Data Radio Not Voice Contact.
  - Reduced Travel and Wait Time.
  - Field Entry of Administration Data.
- Benefit Value is 7.1M.

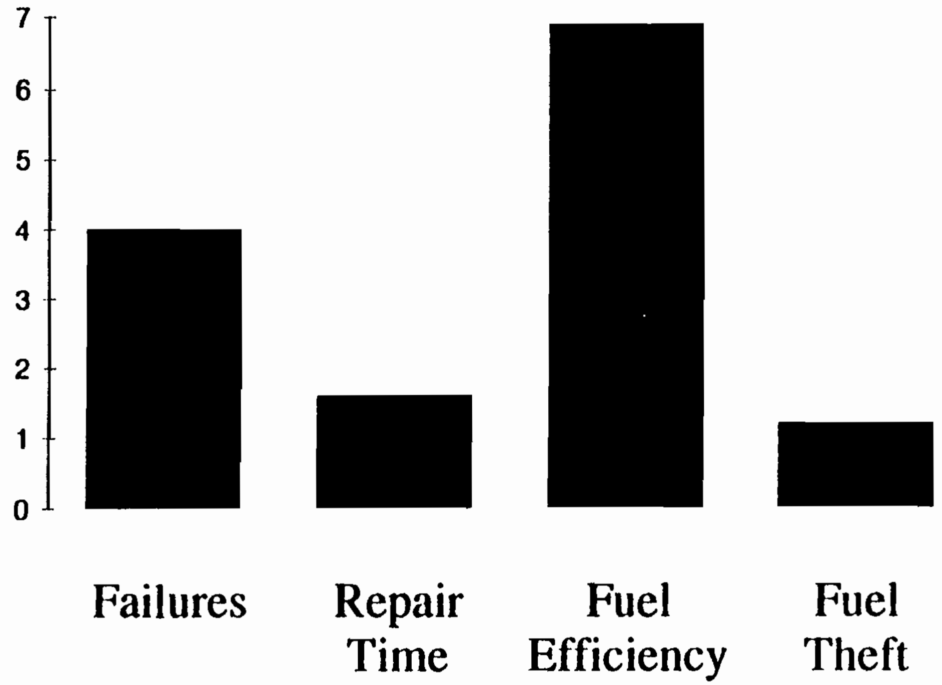
LOCOMOTIVE DIAGNOSTICS:

Provides Benefits for Maintenance & Power Control:

- Maintenance:
  - Fewer and Less Severe Failures.
  - Repair Time Reduced.
  - Utilization Benefits Not Included Yet.
- Power Control:
  - Most Fuel Efficient Locomotives Used First.
  - Reduction in Fuel Theft.

LOCOMOTIVE DIAGNOSTICS:

Locomotive Diagnostics Benefits are 13.7 M



EQUIPMENT:

Avoid Long Term Variable Equipment Costs:

☐ Meet/Pass Planner:	$ 2.9 M
☐ Other Delay Reductions:	$ 3.3 M
☐ Reduced Maintenance:	$ 0.5 M
Total Benefit Value:	**$ 6.7 M**

FUEL:

Pacing Opportunities Arise When Train is to be Stopped or Slowed:

- CIGGT Modeled Fuel Savings on the 3 Sample Subdivisions.

- Fuel Savings are Extrapolated from Model to System Based on:

  - Number of Meets.
  - Length of Subdivision.

- 60% of Savings are Achieved on Level 40 Subdivisions.

- Total Savings of $6.9 M (2.3% of Budget).

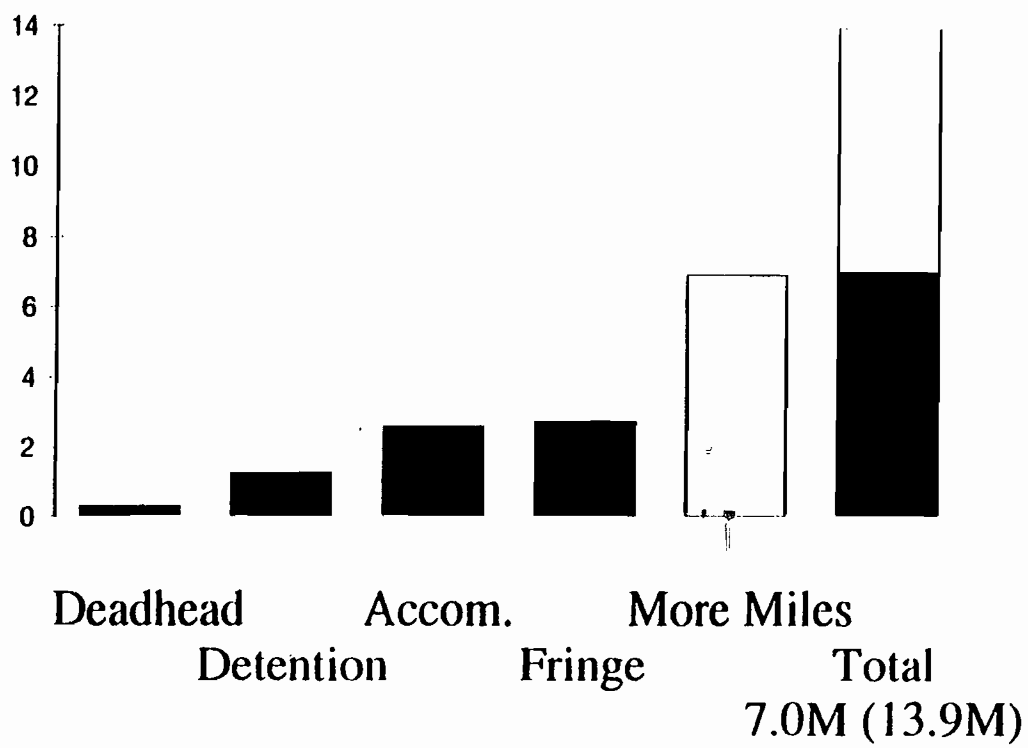
CREWS:

How are Benefits Achieved?

- ☐ 5-10% Improvement in Over-the-Road Run Time.
- ☐ Consistency & Reliability in Over-the-Road Run Times.

CREWS:

Crew Savings: 7.0 M



WORK ORDER REPORTING:

Sources of Benefits:

- Train Reporting Personnel Reductions.
- Asset Management:
  - Better Car Utilization & Reduced Car Hire.
- Improved Terminal Productivity:
  - Switching Assignment Productivity.
- Cost Avoidance - Remarshalling, Extra Switches.
- Capture Lost Revenue from Switches.
- Valued at $ 21.6 M.

WORK ORDER REPORTING:

Sources of Customer Service Benefits:

- Reduced Time in Yard:
  - Avoid Waiting for Information.
  - Avoid Waiting for Documentation.
  - Average of 2.5 Hours per Trip.

- Reduced Time at Customer's Site:
  - Some Cars Don't Wait for Tomorrow's Assignment.
  - In Effect, Pushes Back the Cutoff Time.
  - Average 1.6 Hours per Trip.

WORK ORDER REPORTING:

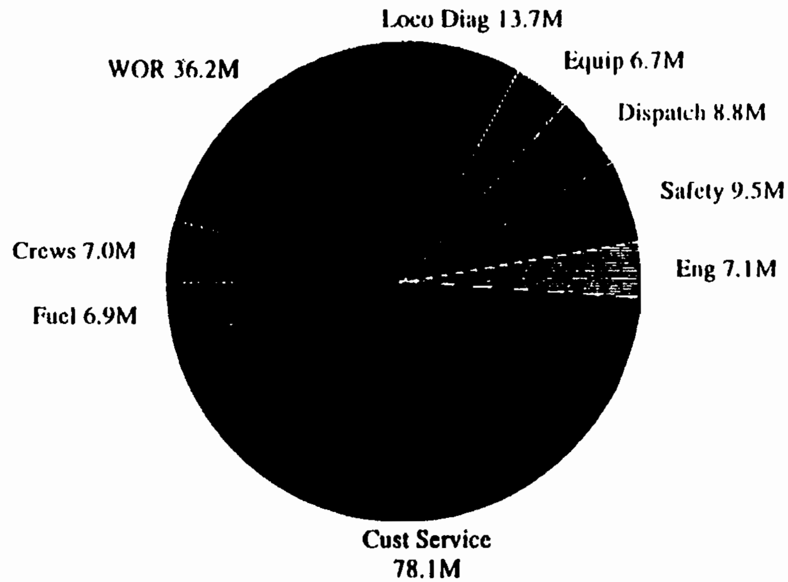
WOR Customer Service Benefits Includes:

- Only Carload Service.
- Only Customers who Value Reliability Highly.
- Only Traffic Originating on CN Served by WOR Equipped Assignments.

- Revenue and Cost Increased by 5.3%.

- WOR Customer Service Increases Profit by $ 14.6 M.

ATCS BENEFITS:

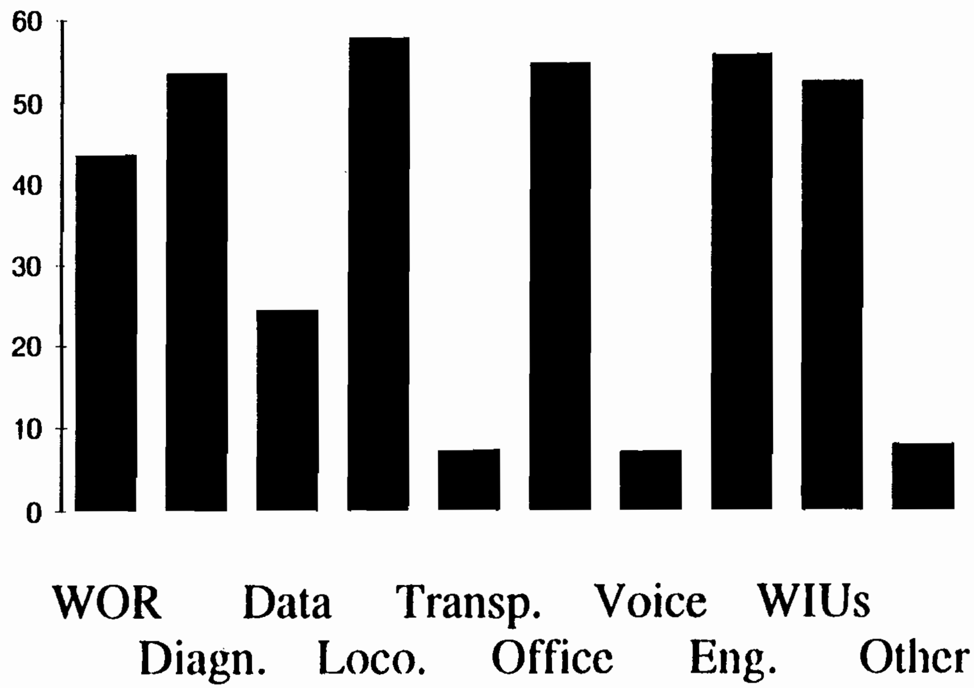


Total Mature-Year Benefits: $174.0 M

COST CATEGORIES

COSTS:

Total Capital Costs: $365.8 M



Annual Incremental Operating Costs: $23.6 M

IMPLEMENTATION

IMPLEMENTATION:

Looked at Two Basic Implementation Strategies:

- Biggest Bang for the Buck - Level 40 First.
- Risk Reduction - Atlantic First.

- Locomotive Diagnostics and WOR First.
- Other Benefits Very Dependent on Run Time & Reliability Improvements.

Sensitivity Analysis for Risk Reduction Strategy:

- IF Costs Reduce.
- IF Customer Service Benefits Increase.
- IF Customer Service Benefits Decrease.

IMPLEMENTATION:

Biggest Bang for the Buck - Level 40 First:

- Install Level 40 ATCS - Quickly!
  - Followed by Level 21 Installation.
- Get Big Benefits Early:
  - In Years 2-3.
- High Risk:
  - Fast Implementation.
  - Exposing Major Customers.
  - Unproven Technology.
- Very Optimistic Scenario.
- IRR = 29%, Payback = 5 Years.

IMPLEMENTATION:

Risk Reduction - Atlantic First:

- Install ATCS in Smallest Region First:
  - Followed by St. Lawrence & Great Lakes.
  - Then Prairie & Mountain.

- Controlled Costs, Delayed Benefits:
  - No Big Benefits until Years 7-8.

- Lower Risk:
  - Up Front Costs Reduced.
  - Interaction of Level 21 & 40.
  - Time for Technological Development.
  - Allows Evaluation Before Greatest Costs are Incurred.

- IRR = 24%, Payback = 7 yrs.

IMPLEMENTATION:

Plan Description	NPV (15%)	IRR	Capital Cost
Biggest Bang for the Buck	$ 275.8 M.	29 %	$ 365.6 M.
Risk Reduction	$ 144.9 M.	24 %	$ 365.6 M.
Sensitivity Analysis			
Reduce Costs (-10%)	$ 179.8 M.	26 %	$ 329.1 M.
Inc Cust. Serv. (+50%)	$ 222.2 M.	27 %	$ 365.6 M.
Dec Cust. Serv. (-50%)	$ 67.5 M.	20 %	$ 365.6 M.

CONCLUSIONS

GENERAL CONCLUSIONS:

1. There is Sufficient Justification for Adopting ATCS as Our Standard for New Train Control Technology.

2. ATCS Family Technologies are a Major Strategic Investment.

3. Locomotive Diagnostics and WOR are Stand Alone Projects.

4. Major "Train Control" Benefit Areas are High Risk. Employ Risk Reduction Strategies.

5. Local Tactical Planner is Key:

   - ☐ Built and Validated Before any Major Investment in Train Control.

GENERAL CONCLUSIONS:

6. Train Control Benefit Pot is Capital Intensive:

   - 70% of Cost is for Train Control.
   - Train Control Benefits Directly Related to Run Time and Reliability Improvements.
   - Install in Minimum Time - With Outside Contractor.

7. The Investment Potential Will Likely Improve:

   - Costs Continue to Decline.
   - Benefits (Buy-In).

GENERAL CONCLUSIONS:

8. Detailed Operating Specifications Should be Worked out as First Step of Major Pilot.

APPENDIX B.2 - Facts About CN Rail

CN Mission

At CN, our mission is to meet our customers' transportation and distribution needs by being the best at moving their goods on time, safely and damage free.

The following figures include CN rail only unless noted.

Organization

- 30,754 employees (1993)
- 5.385 MGTM per employee (1991)
- operating ratio about 95% (1991)

- 6 levels of management (CEO to train crews) (1993)
- HQ staff of 2,997 responsible for network coordination, policy, central service and strategic direction
- regional and district staff of 27,757 responsible for providing service
- 5 regions and 9 districts (1993)

Operations

- trains dispatched from 9 centers across the country (1992)
- approval to consolidate to 6 centers
- 62 dispatch desks (41 manned 24 hrs, 21 partially manned)
- 295 miles of track controlled per dispatcher desk
- dispatcher productivity tools
    - little use of meet pass planner
    - some software to automatically align signals

- crews called from 5 centers (1993)
- plans to consolidate down to 3 centers
- about 800 crews for mainline service and 500 crews for yard assignments
- average crew size of 2.63 on mainline road service, 3 in yard service
- basic day is 100 miles with about 150 paid miles in a crew day on average

- 3 OMC (Operations Management Control) centralized at Montreal for the St Lawrence and Atlantic regions, in Toronto for the Great Lakes region and in Edmonton for the Mountain and Prairie regions. (1993)
- OMCs are responsible for coordinating operations. They would authorize changes to train operation (eg. cancelling or delaying a train service), manage locomotive distribution and provide the initial responses to incidents or accidents. The Montreal OMC also coordinates operations across the system.

- yards (1993)
    - 5 hump yards
        - about 45,400 cars dispatched per week through the 5 system hump yards
    - 26 major flat yards
    - 34 minor yards
    - hundreds of non-customer pickup and setout locations

Plant

- 18,380 miles of track (25 Oct. 92 timetables) (1 mile of double track counted as 1 mile)
- runs from Atlantic to Pacific

    - 5,140 miles of mainline (CTC) track
    - 4,300 miles of branch lines
    - 9,130 miles of other lines

    - 1,700 miles of rail carries less than 0.2 MGTM/mile
    - 6,575 miles of rail carries between 0.2 and 2.0 MGTM/mile
    - 11,231 miles of rail carries over 2.0 MGTM/mile
    - 19,514 miles of rail (1990 figures)

- around 1,200 voice radio base stations spaced about 30 miles apart
- 17 data radio base stations
- have communications infrastructure in some territory including fiber optic cable

Equipment

- 55,000 - 60,000 CN owned cars (includes CV (Central Vermont Railway) and DWP (Duluth, Winnipeg and Pacific Railway)) (1993)

- 1,167 hi rail vehicles (1993)

- 1,599 locomotives (1993)
    - 808 in mainline service
    - 791 in yard, transfer, hump or switching service

    - 70.71 days mean time between failure for road fleet (based on Feb. 10, 1993 1-year rolling average). CN counts any problem as a failure if it is reported through the dispatching office. This implies that all online failures are captured and anything that the

engineer detects and reports through the dispatch office (eg. bell doesn't work or seat is broken).
- 718 GTM per US gal of fuel for the road fleet

Traffic

- RTM figures are all based on loaded miles only (1992)
    - 12.0 BRTM I/M
    - 35.4 BRTM carload
    - 44.4 BRTM bulk

Financial

1991 revenue (excludes GTW) - 2,967,702 ($US ,000)
1991 loss (excludes GTW) - 16,245 ($US ,000)

Legislative Environment

- Canadian tax environment
    - higher fuel taxes than in the US
    - higher property taxes than in the US
- government control of the line abandonment rate
    - maximum abandonment is 4% of system trackage per year
    - most of the grain lines are protected and can not be abandoned until the year 2000
- subsidies for grain transportation
    - Western Grain Transportation Act provides a subsidy to transport grain since the rates paid by the shippers are below the cost of the transportation