BENEFIT-COST ANALYSIS OF USING TYPE 105 TANK CARS INSTEAD OF TYPE 111 TANK CARS TO SHIP ENVIRONMENTALLY SENSITIVE CHEMICALS

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13. ABSTRACT

Among the environmentally sensitive chemicals of most concern to the railroad industry are ten halogenated hydrocarbons that are shipped in general purpose tank cars. The cost of cleaning up spills of these chemicals in 1980-1989 exceeded $50 million. This represented more than half of the major environmental cleanup costs resulting from railroad transportation incidents in this period, even though shipments of these chemicals accounted for less than 1% of the total carload volume of hazardous materials. Investing in more secure tank cars would increase the capital and operating costs but would reduce the risk of these spills. Under current packaging practices the average liability is estimated to be $788 per carload in 1990 dollars, and this liability is expected to at least double in 1992 as a result of more stringent hazardous waste disposal regulations. Use of more secure 105A300W or 105A500W tank cars would reduce the 1990 liability to $375 or $129 per carload, respectively. The analytical approach developed in this paper quantifies the benefits and costs of transporting these chemicals in such tank cars and estimates the net present value of replacing all the tank cars currently used to transport these chemicals. The results indicate that the reduced liability resulting from the use of type 105 tank cars would more than offset the increased capital and operating costs and therefore would be a cost-effective means of reducing the risk.

14. SUBJECT TERMS

111A100W1, 105A300W, 105A500W tank cars, benefit-cost analysis, chlorinated solvents, environmental cleanup costs, halogenated hydrocarbons, hazardous materials, transportation safety

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EXECUTIVE SUMMARY

In response to public concerns about the environment, regulatory requirements for cleaning up spills of certain chemicals have become more stringent and cleanup costs have increased dramatically. Due consideration must be given to environmental sensitivity as an element of transportation risk. The type of tank car used to transport environmentally sensitive chemicals should be commensurate with their environmental hazard. Among the environmentally sensitive chemicals of most concern to the railroad industry are ten halogenated hydrocarbons that are currently shipped in general purpose 111A100W1 tank cars. The cost of cleaning up spills of these chemicals in 1980-1989 exceeded $50 million. This represented more than half of the major environmental cleanup costs resulting from railroad transportation incidents in this period, even though shipments of these chemicals accounted for less than 1% of the total carload volume of hazardous materials. Investing in more secure tank cars would increase capital and operating costs, but reduce the risk of such spills.

This report quantifies the benefit and costs of transporting these chemicals in DOT specification 105 tank cars instead of 111 tank cars. The average environmental cleanup liability for each shipment of these chemicals in 111s is estimated to be $788 per carload in 1990 dollars, and is expected to at least double in 1992 as a result of more stringent hazardous waste disposal regulations. If these chemicals were shipped in 105A300W or 105A500W tank cars this liability would be reduced to about $375 or $129 per carload, respectively, because of the lower probability of release from a 105. The annual industry-wide benefit in 1990 dollars would be $4.9 million if 105A300W tank cars were used instead of 111s and $7.8 million per year if 105A500Ws were used.

The fixed cost would include $53.8 million to acquire new 105A300Ws or $83.3 million for new 105A500W tank cars, plus $3.0 million to modify terminals to accommodate the new cars. Similarly, the variable cost of transportation for the two types of 105 would increase by $1.0 million or $2.2 million per year, respectively, due to their lower capacity. An additional $2.5 to 3.0 million per year would be borne by the railroads in the form of increased car allowance charges.

The resulting net present value of the benefit minus the total cost over the 30-year lifetime of a tank car is $60.5 million for 105A300Ws and $94.7 million for 105A500Ws.

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1.0 INTRODUCTION

The railroad, chemical and car-building industries have a long history of fostering the development of safe equipment and operating practices for the rail transportation of hazardous materials. The Tank Car Committee of the Association of American Railroads dates back to 1903 and the Bureau of Explosives has been active since 1907. Over the years, the materials of most concern have been those which pose acute hazards to health and safety, such as poisons, flammables and explosives. More recently, however, knowledge about environmental pollution has led to increased concern with the impact of releases of chemicals that are hazardous to the environment.

This report describes the results of research conducted to identify the highest priority environmentally sensitive chemicals and evaluate the net economic benefit of replacing the tank cars currently used to transport these chemicals with others that are less likely to release their contents. In general, the direct expenses of environmental cleanup are borne by the carriers, whereas the cars are paid for by the chemical shippers. However, cleanup expenses that are unnecessarily high increase the overall cost of rail transportation and thereby affect shippers as well as carriers. Furthermore, liability may in some cases be shared with the shipper. It is in the interest of shippers, carriers and the public, that the type of tank car used to transport these chemicals be commensurate with their environmental hazard.

1.1 Identification of Environmentally Sensitive Chemicals

The process of identifying the environmentally sensitive chemicals of most concern began by evaluating 83 regulated chemicals currently being shipped by rail which are authorized by the U.S. Department of Transportation (DOT) for shipment in general purpose tank cars. These chemicals were evaluated for their relative potential to contaminate soil and groundwater in the event of a large, uncontrolled release. This evaluation was conducted by means of a three-stage hazard assessment of each of these chemicals: first, physicochemical models were used to estimate soil and groundwater dispersion; second, environmental engineering models were used to estimate the difficulty of cleanup based on each chemical's properties and the regulatory requirements for its cleanup (Lowenbach, 1989); third, the results of these models were supplemented by empirical evidence gathered from the railroads. This analysis indicated that fifteen halogenated hydrocarbons were among the chemicals having the highest environmental cleanup hazard. Ten of these chemicals were considered to pose the greatest risk of a costly environmental cleanup because of current packaging practices. These chemicals are: carbon tetrachloride, chlorobenzene, chloroform, dichlorobenzene, ethylene dibromide, ethylene dichloride, methyl chloroform (also known as 1,1,1-trichloroethane (TCA)), methylene chloride (METH), perchloroethylene (PERC), and trichloroethylene (TCE). Although authorized for shipment in general purpose tank cars, the other five halogenated hydrocarbons (allyl chloride, dichloropropane, 1,2- dichloropropene, epichlorohydrin, and ethyl chloride) are transported primarily in DOT specification 105 or 112 tank cars that exceed the minimum required by regulations, and thus pose a lower risk.

1.2 Background on Halogenated Hydrocarbons

Halogenated hydrocarbons have become the focus of intense regulatory scrutiny in recent years because they are widely used chemicals that can have negative environmental impacts and create chronic health problems. They were among the first hazardous substances generally banned from land disposal by the Environmental Protection Agency (EPA) in 1986 under the Resource Conservation and Recovery Act (RCRA) amendments. They pose a significant challenge in remediation because they are all denser than water and tend to quickly permeate deep into aquifers and stubbornly resist removal. Moreover, the standards for cleanup of contaminated soil and water are stringent because these chemicals are all suspected carcinogens.

The most familiar halogenated hydrocarbons are chlorinated solvents such as TCE, TCA, METH and PERC (Wolf and Camm, 1987). TCE has been a widely used degreasing agent for many years. It is classified as a probable human carcinogen, is listed as a hazardous air pollutant, and is the chemical most often detected at Superfund sites (Abelson, 1990). TCA has widespread application in metal cleaning for decontaminating and degreasing parts, and in electronics for cleaning circuit boards and semiconductors. Methylene chloride (METH) has diverse uses in paint removers, aerosols, and chemical processing. Perchloroethylene (PERC), also known as tetrachloroethylene, is used extensively by the dry cleaning industry and as a vapor degreaser for cleaning electrical equipment. TCE, TCA and PERC are the most frequently detected volatile organic compounds contaminating groundwater in the United States (Russell et al.,1991).

1.3 Transportation of Halogenated Hydrocarbons

Table 1 shows the number of carloads of the ten halogenated hydrocarbons reported for 1987, 1988 and 1989 to the TRAIN II data base, the record of rail freight movements maintained by the Association of American Railroads (AAR). The total transportation volume of these chemicals has been increasing in recent years, up to an estimated level of about 12,000 carloads in 1989. On a chemical-by-chemical basis, the trend has been downward or stable in some cases and upward in others. Some of them are being phased out of production over time (e.g., carbon tetrachloride, which is used as a precursor in freon production), while others continue to be produced and transported at increasing levels (e.g., ethylene dichloride, which is used extensively for polyvinyl chloride (PVC) production). In certain cases, even though domestic demand is declining due to environmental concerns, transportation volume is rising because of export demand.

Table 1

Number of Carloads of the Ten Selected Halogenated Hydrocarbons

Chemical	1987	1988	1989
Carbon tetrachloride	1,647	1,154	1,029
Chlorobenzene	648	624	952
Chloroform	1,155	1,041	1,250
Dichlorobenzene	73	96	55
†Ethylene dibromide	3	4	2
Ethylene dichloride	2,314	2,163	3,462
Methyl chloroform	292	914	1,133
Methylene chloride	227	664	883
Perchloroethylene	487	842	964
Trichloroethylene	271	227	153
PERC/TCE mixture	51	28	27
Total Reported Carloads	7,168	7,752	9,910
Estimated Actual Carloads*	8,533	9,228	11,798

* Based upon an 84% reporting rate

† Shipments originating on railroads that do not report to TRAIN II comprise approximately 300 additional carloads of ethylene dibromide.

In 1989, an estimated 1.2 million carloads of hazardous materials were shipped in tank cars in the U.S. and Canada. The ten halogenated hydrocarbons accounted for less than 1% of this volume. Despite this low percentage, they accounted for approximately 60% of the cost of major environmental cleanups from transportation-related spills reported by the railroads in 1980-1989, including four of the five most costly ones (Figure 1). We define a major cleanup as one that costs more than $250,000.

1.4 Approaches to Risk Reduction

Risk reduction can be achieved by reducing the impact of spills when they happen or, more fundamentally, by reducing the number of spills that happen. Spill impacts are reduced by the effectiveness of the remedial response, which for these chemicals depends on such factors as ease of access to the spill location, local geology, proximity of remediation equipment and personnel, and whether there is a simultaneous spill of other chemicals that may pose a more immediate concern, i.e., an acute hazard to human life or property. By contrast, the number of spills can be reduced by two approaches, accident prevention and improved resistance to tank car damage.

The first approach, accident prevention, has been a high priority for the railroad industry in recent years. The railroad accident rate has declined substantially over the past decade. The graph in Figure 2 shows that the annual rate of train accidents dropped by more than 60% in the period 1980-1989, to a level of about five accidents per million train-miles in 1989 (AAR, annual). Most of this reduction can be attributed to investment in physical plant improvements. Increased equipment and plant maintenance activities, expanded employee training programs and elimination of many low density lines have also contributed to the decline.

The other approach to spill reduction is to use tank cars that are more resistant to damage. The most notable example in recent years is the modification of DOT specification 112/114 tank cars used principally in liquefied petroleum gas (LPG) and ammonia service. These cars have been equipped with head shields, thermal protection and shelf couplers. The frequency of releases from these cars has declined substantially since these changes have been in place (Phillips and Role, 1989). General purpose 111 tank cars have also been improved over the past decade. Since 1978 all 111s in hazardous materials service have been retrofitted with shelf couplers and (where applicable) bottom outlet protection.

Figure 1

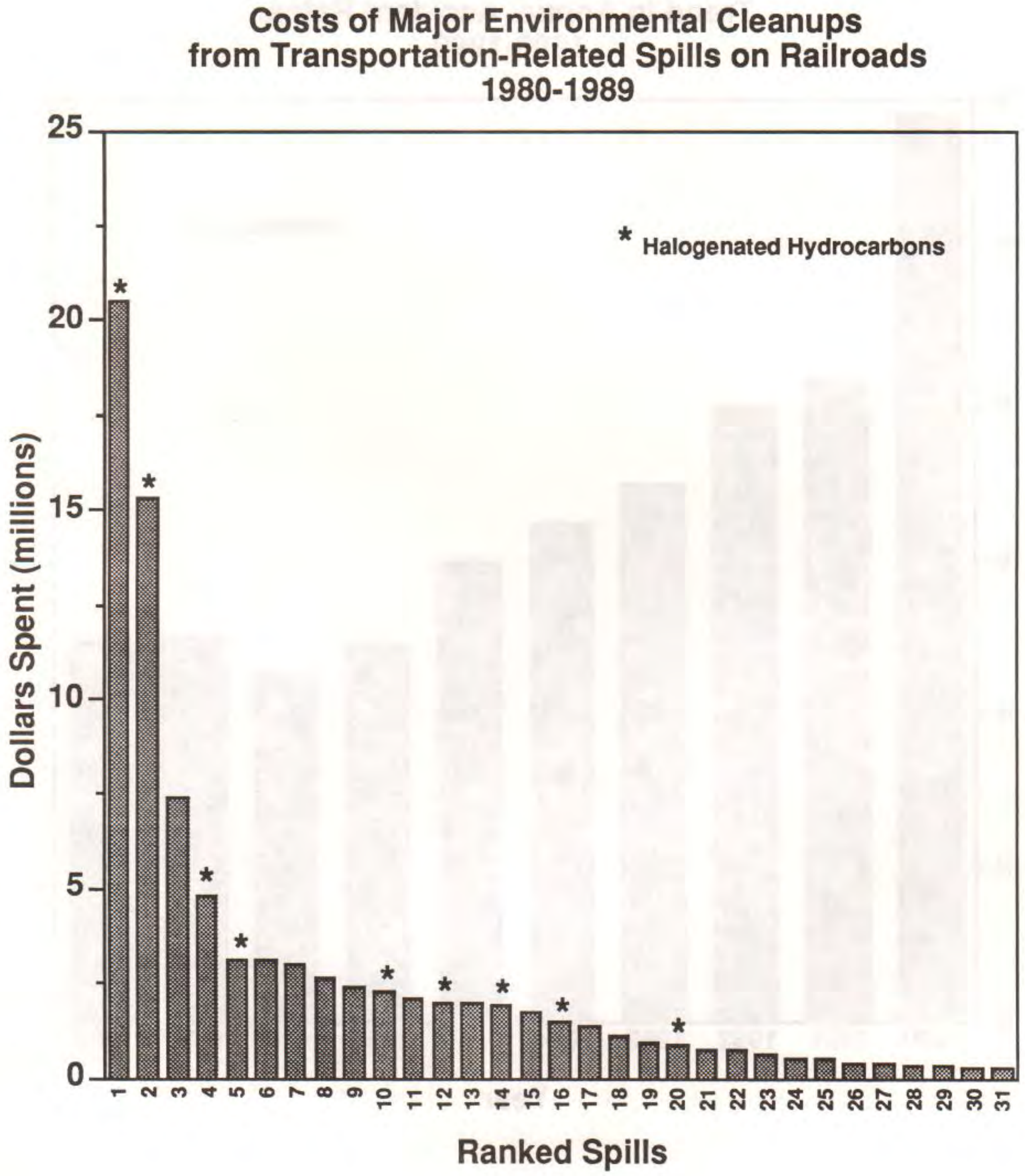
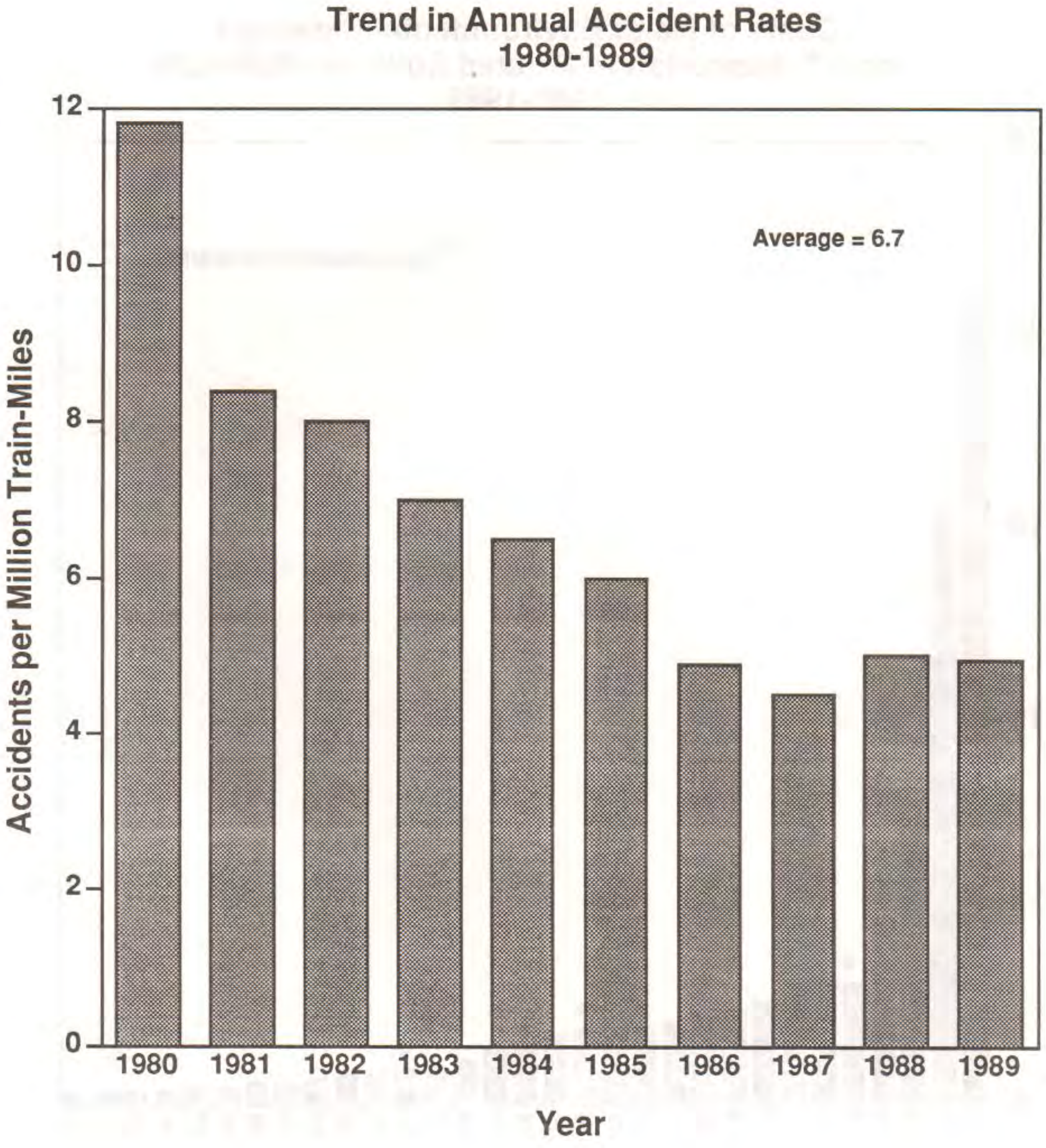

Costs of Major Environmental Cleanups
from Transportation-Related Spills on Railroads
1980-1989
* Halogenated Hydrocarbons
Dollars Spent (millions)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Ranked Spills

Figure 2


Trend in Annual Accident Rates
1980-1989
Average = 6.7
Accidents per Million Train-Miles
0
2
4
6
8
10
12
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
Year

1.5 Differences in Tank Cars

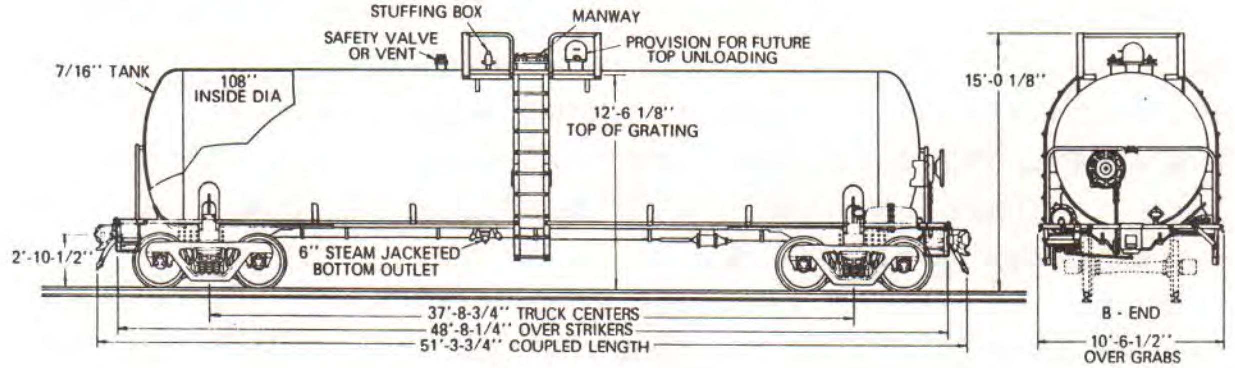
Resistance to damage varies among different types of tank cars. DOT specification 111 tank cars are generally more likely to suffer a release in an accident than are various pressure tank cars such as DOT specification 105 tank cars (Phillips, 1990). Most of the cars currently used to transport the ten halogenated hydrocarbons of interest are general purpose, non-insulated tank cars built to DOT specification 111A100W1. These cars have carbon steel tanks and usually come equipped with bottom outlets for convenience in unloading. General purpose 111 tank cars differ from 105A500W tank cars in several respects related to damage resistance. Most significant are the differences between the thickness and grade of steel used in the tank shell and head. A general purpose 111 tank car has a 7/16" head and shell, whereas a 17,000 gallon 105A500W typically has a head and shell greater than 3/4" thick, constructed of higher tensile strength steel, as well as a 1/8" steel jacket encasing the insulation. As a result, these 105 tank cars have a relatively low likelihood of suffering a puncture in an accident (Phillips and Barkan, 1990).

The other major difference is in the top and bottom discontinuities (fittings) and the accompanying protection. By specification, 105 tank cars have no bottom fittings, whereas general purpose 111 cars usually have a bottom fitting that extends below the tank and is vulnerable to damage in accidents. All new tank cars with bottom fittings ordered since the beginning of 1978 are required to have bottom discontinuity protection, and most older cars in hazardous materials service have been retrofitted under a program developed and administered by the AAR Tank Car Committee. All of the top fittings on a 105 tank car are consolidated and encased in a 3/4" protective housing, while a general purpose 111 car may have four or more separate top discontinuities, which are usually not protected (see Figure 3, from General American Transportation Corporation, 1985).

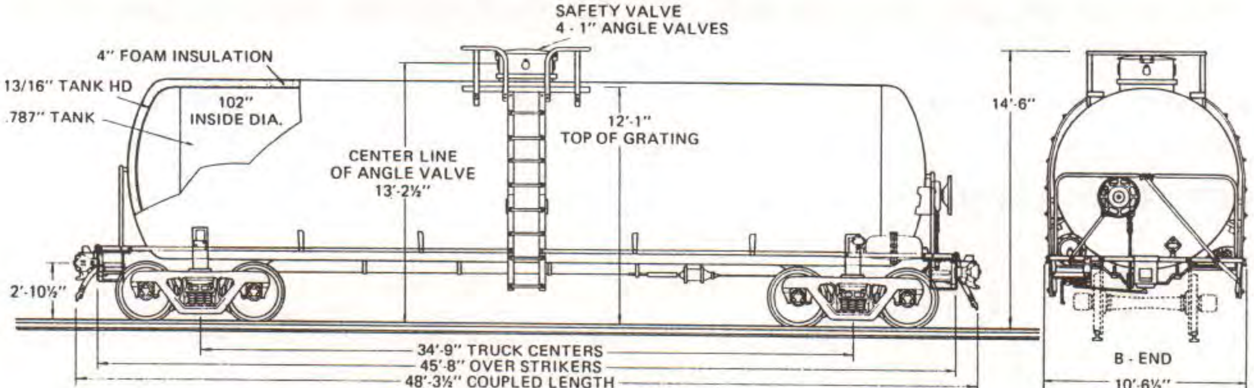
Figure 3

DOT Specification 111A100W1 and 105A500W Tank Cars

20,000 GALLON CAPACITY - NON INSULATED
DOT - 111A100W.
FOR GENERAL SERVICE COMMODITIES
4" SLOPE TO STRAIGHT CENTER SECTION.
(PRE 1983)



90 TON CAPACITY - INSULATED
DOT - 105A500W
FOR CHLORINE SERVICE
(POST 1982)



2.0 BENEFIT-COST ANALYSIS

We developed an analytical approach to determine whether the cost of replacing the 111s with the stronger 105A500W tank cars, which are heavier and more expensive, would be offset by the benefit of the avoided environmental cleanup expense. The benefit was calculated from data on the cleanup expense for spills of these chemicals, combined with data on the differences in tank car release probability developed by the Railroad Tank Car Safety Research and Test Project, a cooperative effort of the Railway Progress Institute (RPI) and the AAR. The costs of replacing 111s with 105s are the additional operating expense due to the heavier weight of the 105 tank cars and the net capital expenses associated with putting them in service and retrofitting the terminals for top unloading. We used a net present value (NPV) approach because of the relatively long period of time over which the benefits and costs would accrue.

2.1 Net Present Value Formula

The NPV of replacing the 111s with 105s equals the sum of the benefits of car replacement minus the associated costs, calculated over the years during which the benefits and costs are expected to accrue and discounted to constant (year 0) dollars. The equation used for this calculation is:

$$NPV = \{ \sum_{n=1}^{N} [B \prod_{j=1}^{n} (1+r_j) - C_t](1+i)^{-n} \} - (C_a + C_m)$$

where:

N is the expected lifetime of a tank car, i.e., 30 years,

B is the expected annual benefit in year 1 of replacing the 111s with 105s (i.e., the expected annual reduction in the total cost of cleaning up transportation spills),

r_j is the real rate of increase in cleanup costs in year j,

C_t is the average annual incremental cost of transportation if the 111s are replaced with 105s (i.e., the annual increase in the total variable cost of moving the tank cars),

i is the annual discount rate (i.e., the annual rate of increase in the real cost of capital),

C_a is the net investment required to acquire the 105s (i.e., the cost of the new cars minus the salvage value of the cars replaced),

C_m is the investment required to modify the terminals to accommodate the 105s (i.e., to retrofit the terminals for top unloading).

We made several assumptions to simplify the calculations. First, we assumed that all of the cars are replaced at the outset, which means that the benefits and the costs of car replacement are realized throughout the 30-year period. Second, we assumed that the total volume of the ten halogenated hydrocarbons shipped each year will remain constant at 1989 levels. Although overall traffic growth is anticipated for these chemicals, the NPV per tank car will hardly change. This is because B, C_t, and C_a are all proportional to the total volume to be moved and C_m, which is not proportional, has relatively little effect on the overall results.. Third, we assumed that the annual rate of car utilization, i.e., the number of trips per car each year, remains constant regardless of the type of car used. In actuality, the higher value of the 105 might provide an incentive to operators and carriers to improve the efficiency of their use of tank cars, which would increase the NPV of replacing 111s with 105s. Finally, we assumed as a starting point that the train accident rate will remain constant. The rapid decline observed in the 1980s appears to be leveling off. Therefore, unless there are technological breakthroughs in derailment prevention, further dramatic declines are not anticipated in the near future. The implications of removing this last assumption are discussed later. Sections 2.2, 2.3 and 2.4 which follow describe how we estimated the factors in the above equation.

2.2 Benefit Estimation

The annual benefit (B) of replacing the 111s with 105s is the average saving associated with having to clean up a smaller expected number of spills each year over the lifetime of the replacement cars. To estimate the magnitude of this saving, we reviewed the experience of the past decade. There were 15 train accidents from 1980-1989 in which one of the ten halogenated hydrocarbons was released from one or more damaged tank cars, involving a total of 41 tank cars. At least 35 other release incidents not caused by train accidents also occurred in this period, most of which involved much smaller spill quantities.

Data from the railroads indicate that eight of these 50 incidents were especially costly to clean up. Six of the eight were caused by train derailments and two (one involving a weld failure and the other a damaged bottom outlet that leaked) were not. The most costly was the result of a derailment on the Illinois Central Railroad that took place on the outskirts of Livingston, Louisiana in 1982. The railroad has already spent over $20 million to clean up the PERC that was absorbed into the soil and released into groundwater. Ongoing water treatment and site monitoring is costing approximately $25,000 per month. To date the total unadjusted cost of cleaning up the spilled halogenated hydrocarbons in these eight incidents is $50.4 million. Remediation efforts are still ongoing for six of the eight incidents. The present value of the future cost of completing the cleanup at these sites is conservatively estimated to be $5.0 million. Based on recent Superfund experience, however, these costs are likely to increase beyond the current estimates (General Accounting Office, 1988; Richardson et al., 1990; Schroeder, 1990).

To adjust the historical cleanup costs shown in Table 2a to 1990 dollars we asked the railroads involved to provide a detailed historical breakdown of the expenditures on these spills (the 1990 figures refer to ongoing remediation efforts from the earlier incidents). This was necessary to account for general inflation and changes in real costs. These costs apply only to incidents that occurred in the period 1980-1989. The most readily quantifiable change in real costs over the years since 1980 has been the more than 700% increase in the average cost of land disposal of soils contaminated with these chemicals (Figure 4). This cost has risen from approximately $25 per ton in 1980 to approximately $220 per ton in 1990 (Resource Consultants, 1991). We used these values to adjust the annual cost due to soil disposal in each year relative to the cost in 1990. The values of the resulting adjustment factors are shown in the first column of Table 3, where the 1980 value is 220/25 = 8.8 and the 1990 value is 220/220 = 1.0. Although the average real cost of meeting, monitoring and treatment requirements has increased over the past decade, we were unable to satisfactorily

Table 2

Actual and Adjusted Cleanup Costs

(a) Actual Cleanup Costs ($ thousands)

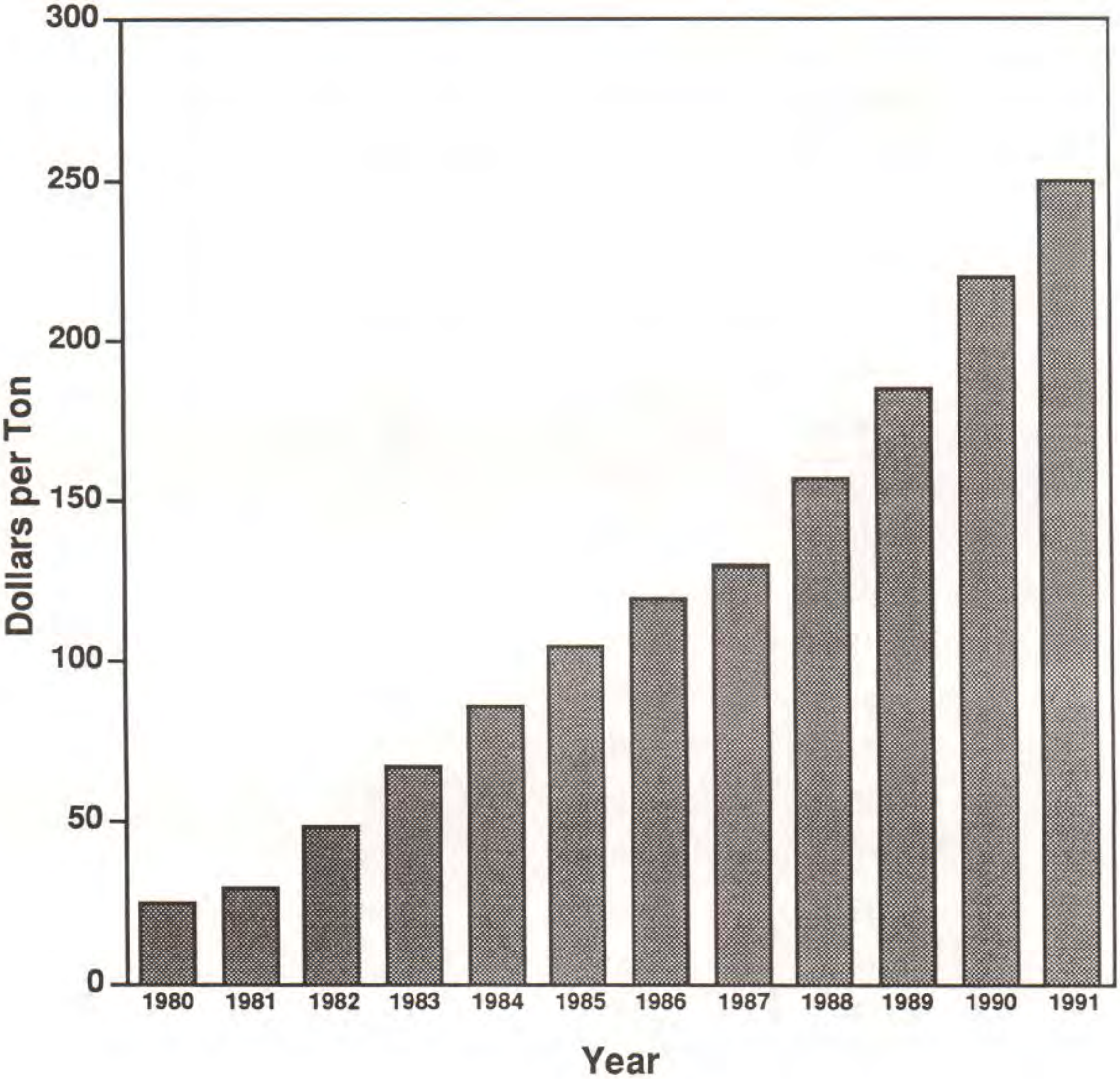
Year	Soil Disposal	Air-Stripped Water	Carbon-Treated Water	Other Costs	Total
1980	152	4,833	0	844	5,829
1981	0	4,833	0	0	4,833
1982	1,285	4,834	541	393	7,053
1983	3,625	0	1,855	6,740	12,220
1984	0	5	3,184	403	3,592
1985	0	534	2,666	350	3,550
1986	0	1,812	781	715	3,308
1987	1,386	1,421	520	1,879	5,206
1988	0	202	368	639	1,209
1989	0	265	413	1,668	2,346
1990	0	367	372	540	1,279
Total	6,448	19,106	10,700	14,171	50,425

(b) Cleanup Costs Adjusted to 1990 Dollars ($ thousands)

Year	Soil Disposal	Air-Stripped Water	Carbon-Treated Water	Other Costs	Total
1980	1,338	7,390	0	1,290	10,018
1981	0	6,737	0	0	6,737
1982	5,770	6,333	709	515	13,326
1983	7,169	0	2,339	8,499	15,935
1984	0	6	3,872	490	4,368
1985	0	631	3,149	413	4,193
1986	0	2,086	899	823	3,808
1987	2,345	1,586	580	2,097	6,608
1988	0	218	397	690	1,306
1989	0	275	428	1,730	2,433
1990	0	367	372	540	1,279
Total	16,622	25,628	12,745	17,088	72,082
Percent	23%	36%	18%	24%	100%

Figure 4

Cost of Disposal of Soil Contaminated with Halogenated Hydrocarbons



quantify the additional effect of these increases on the remediation cost of the specific sites under study. Therefore, we simply adjusted all other remediation cost components to 1990 dollars using a GNP index based on the general inflation rate, except in the case of the 1983 Lake Charles incident, which had an unusually high cost to begin with. The values of the GNP index are shown in the second column of Table 3. As of the end of 1990, the total cleanup cost due to spills of the ten halogenated hydrocarbons in railroad transportation incidents that occurred in the period 1980-1989 is estimated to be about $72.1 million in 1990 dollars, as shown in Table 2b. With the addition of $5.0 million, which is the present value of the future costs, the total becomes $77.1 million. This estimate is conservative because it does not include all of the litigation costs nor the real increases in site monitoring and more stringent contaminated soil removal standards (other than the unit cost of soil disposal). It also does not include all of the costs to parties other than the shipper, carrier and car owner.

Table 3

Cleanup Cost Adjustment Factors

Year	Hazardous Waste Index	GNP Inflator
1980	8.800	1.529
1981	7.330	1.394
1982	4.490	1.310
1983	3.284	1.261
1984	2.558	1.216
1985	2.095	1.181
1986	1.833	1.151
1987	1.692	1.116
1988	1.401	1.080
1989	1.189	1.037
1990	1.000	1.000

To calculate the per carload liability over this period, we estimated the number of carloads of the ten halogenated hydrocarbons shipped from 1980 to 1989 by fitting a curve to the estimated actual carloads for the three years in Table 1 and extrapolating back over the preceding seven years. This produced a total of 62,600 carloads. Dividing the total of $77.1 million by this number gives an average environmental cleanup liability of $1,232 per carload.

This per carload liability estimate then had to be adjusted downward to reflect the safer operating conditions in 1990 compared to the average conditions over the ten-year period used as the basis for the cost calculations. Three aspects of hazardous material transportation safety on the railroads have improved over the period from 1980 to 1989: train accident rate, non-accident caused release rate, and tank car performance in accidents. The estimate of current liability had to be corrected to account for each of these. Thus, we noted first that the 1989 train accident rate was 67% of the ten-year average of 6.7 accidents per million train-miles (see Figure 2). Second, we determined that the 1989 rate of non-accident caused release incidents was 75% of the ten-year average (Bureau of Explosives, annual). Third, calculations based on available data for tank cars indicated that the probability of release from a non-insulated, general purpose 111 tank car damaged in an accident averaged 0.25 over the period 1980-1989, compared to 0.225 for 1989 alone (Phillips and Barkan, 1990). Since the relative difference in these numbers is 10%, we estimated the 1990 accident-caused release probability for 111s damaged in accidents to be 90% of the ten-year average. Recalling that six of the eight incidents (3/4) were due to train accidents and the other two (1/4) were non-accident caused, we estimated the total industry liability in 1990 associated with transporting these ten chemicals to be [(3/4 x 67% x 90%) + (1/4 x 75%)] x $1,232 = $788 per carload. Multiplying this figure by the 11,798 carloads in 1989 yields an estimated annual industry-wide liability of $9.3 million due to the rail transportation of these chemicals.

Other things being equal, the average annual benefit of replacing the 111s by 105s is the portion of this cost that would be avoided because of the difference in the release probabilities for 105 and 111 tank cars. The relative reduction in the probability of a release in a train accident is equal to the relative reduction in the conditional probability of a release given that a tank car is damaged, providing the the probability of damage is the same for both types of cars.* Given estimates of 22.5% for the conditional release probability for non-insulated 111A100W1 tank cars, 10.7% for 105A300W tank cars, and 3.7% for 105A500W tank cars (Phillips and Barkan, 1990), the relative reduction in the probability of a release is estimated to be (22.5 - 10.7)/22.5 = 52.4% for the 105A300W and (22.5 - 3.7)/22.5 = 83.6% for the 105A500W. Hence, the estimated annual benefit for the 105A300W is $9.3 million x 52.4% = $4.9 million and for the 105A500W it is $9.3 million x 83.6% = $7.8 million. These are the annual, industry-wide liabilities that would be avoided by using one of the two kinds of 105 specification tank cars to transport these chemicals, i.e., they are the values of B in the NPV equation. In carload terms, these results mean that under current packaging practices, the estimated average liability per carload is $788, which reduces to $375 per carload for the 105A300W and $129 per carload for the 105A500W.

It is worth noting that the calculation of the relative reduction in release probability treated all eight incidents as if they were accident-caused, although two were not. This approach is reasonable, given that using 105s instead of 111s would have diminished the likelihood of occurrence in one of the two non-accidents, and virtually eliminated it in the other.

2.3 Cost Estimation

2.3.1 Variable Cost of Transportation

The transportation cost per mile is about the same for 111s as for 105s, but the reduced capacity of the heavier 105A500W means that more carloads are required to transport the same quantity of chemical. Therefore, to estimate C_t, the incremental average annual transportation cost associated with replacing the 111s by 105s, we multiplied three factors together: the average cost per shipment, the percentage increase in the number of cars required, and the current annual number of carloads shipped.

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* This follows mathematically from the fact that P(R) = P(R|D) P(D), where P(R) is the release probability, P(R|D) is the conditional probability of release given damage, and P(D) is the damage probability. When calculating the relative difference in P(R) for the two kinds of cars, their P(D) values will cancel out, leaving only the relative difference in the two values of P(R|D).

We estimated the first of these factors by using the 1988 Sample of Carload Waybill Statistics of the Interstate Commerce Commission (ICC) for U.S. terminations, supplemented by AAR TRAIN II data for Canadian terminations, to determine that the average length of haul for the ten halogenated hydrocarbons was about 850 miles. Then, using the ICC's Uniform Rail Costing Model, we determined that, for a tank car having a capacity less than 22,000 gallons traveling 850 miles, the average variable cost per shipment is $1,606.

To estimate the percentage increase in the number of cars required, we used a tank car size-and-weight program developed by Union Tank Car Company. The size of a tank car is often optimized for individual commodities as a function of the commodity's density. The objective is to maximize the ratio of lading to tank car light weight (tare), so that the loaded car does not exceed the current maximum AAR interchange limit of 263,000 lbs. for weight on rails. This must be accomplished within the constraints imposed by various DOT and AAR specifications including, among other things, clearances, tank thickness and car length. For each of the ten halogenated hydrocarbons we determined the optimum size and weight of a non-insulated 111A100W1 tank car and a 105A500W tank car and the percentage loss in capacity due to the heavier weight of the 105A500W. As Table 4 shows, the results ranged from about 7.2 % for ethylene dibromide, the heaviest of these chemicals, to 12.3 % for chlorobenzene, the lightest. Weighting each of these percentages by the corresponding number of 1989 carloads, we determined that the average loss in capacity would be 10.5 %. Therefore the number of shipments required to move the same volume of these chemicals is 1/(1 - 0.105) = 1.117. This means that 11.7% more shipments would be required for the 105A500W if there was no increase in car utilization. A similar analysis for the 105A300W tank cars indicates a 5.1% average loss in capacity, which corresponds to a 5.4 % increase in the number of shipments required.

Based on 1989 information, the estimated annual number of shipments is 11,798 carloads. Hence the product of the three factors is $1,606 x 11.7% x 11,798 = $2.22 million for the 105A500W ($1.02 million for the 105A300W). This is the estimated value of C_t under the assumptions of no real increase in the average cost per shipment, no growth in total traffic, and optimally sized tank cars. Analysis of the loading practices of these products indicates that if current inefficiencies in tank car use were eliminated, the 11.7 % weight penalty would actually be only approximately 7.5 %, which would reduce the estimated value of C_t from $2.22 million to $1.42 million for the 105A500W ($0.65

million for the 105A300W). In our calculation of the NPV we used the conservative (higher) estimates of \$2.22 million for C_t for the 105A500W and \$1.02 million for the 105A300W.

Table 4

Comparison of the Capacities of Non-Insulated 111A100W1 Tank Cars and Optimized 105A500W Tank Cars

Chemical	Density (lbs/gal)	Capacity (gallons) 111A100W1	Capacity (gallons) 105A500W	Percent Reduction in Capacity
Carbon tetrachloride	13.22	15,803	14,338	9.27
Chlorobenzene	9.24	21,890	19,186	12.35
Chloroform	12.41	16,764	15,123	9.79
Dichlorobenzene	10.90	18,876	16,819	10.90
Ethylene dibromide	18.16	11,713	10,873	7.17
Ethylene dichloride	10.45	19,607	17,401	11.25
Methyl chloroform	11.19	18,432	16,464	10.68
Methylene chloride	11.02	18,690	16,671	10.80
Perchloroethylene	13.54	15,453	14,049	9.09
Trichloroethylene	12.16	17,083	15,380	9.97
PERC/TCE mixture	12.85	16,053	14,544	9.40
Weighted Average				10.54

2.3.2 Fixed Costs

As far as fixed costs are concerned, replacing the 111s by 105s will necessitate two major capital expenses: the net cost of acquiring 105s and the cost of modifying the terminals for top unloading, which is required with 105s. The second expense is necessary because general purpose 111s are usually unloaded through bottom outlet valves, which are prohibited on the 105s.

2.3.2.1 Net Acquisition Cost

The net acquisition cost C_a is the difference between the total cost of replacing the existing 111s with new 105s and continuing to use the existing 111s. As mentioned earlier, the price of a new 105A500W tank car is approximately $88,000. By comparison, a new general purpose 111 costs approximately $58,000. Assuming that the current rate of car utilization continues at nine trips per year, the number of 111s in question is 11,798 ÷ 9 = 1,311 and the number of 105s required to replace them is, as previously discussed, 11.7 % greater, or 1,464 cars.

The cost of continuing to use the 1,311 existing 111s is the present value of the cost of replacing one-thirtieth of them each year due to attrition, assuming that their ages are uniformly distributed between one year old and 30 years old. We assume further that every such replacement will require a new car to be purchased and that the average salvage value of the old cars will be 10% of the new cost, for a net cost of $58,000 - $5,800 = $52,200. Hence the total annual cost of continuing to use the existing 111s is 1/30 x 1,311 x $52,200 = $2.28 million. Over thirty years, assuming a 10% discount rate, the total present value of this cost is $21.49 million.

The cost of replacing these 111s with 105s depends on the fate of the existing cars that are displaced from halogenated hydrocarbon service. There are two possible extremes: either all the cars are scrapped or they are all sold or transferred into other service. If they are scrapped, this cost is equal to the cost of the new 105s minus the scrap value of the 111s. The calculation is as follows: (1,464 x $88,000) - (1,311 x $5,800) = $121.23 million. Alternatively, if all of the cars are sold or transferred, we use the AAR replacement value of $31,900 for a 15 year-old car (the average age of cars in this service) minus the cost of cleaning, which is approximately $1,000 per car. Under this scenario the calculation changes to (1,464 x $88,000) - [1,311 x ($31,900 - $1,000)] = $88.32 million.

Assuming that half of the current fleet will be scrapped and half will be sold or transferred into other service, the cost of replacing the existing 111s with new 105A500Ws is (121.23 + 88.32) ÷ 2 = $104.78 million. The estimated value of C_a, the net acquisition cost, is thus 104.78 - 21.49 = $83.29 million ($53.80 million for the 105A300W).

2.3.2.2 Terminal Modification Cost

The cost of terminal modification C_m derives from the fact that many of the existing terminals that receive these products and are not equipped for top unloading would have to be modified to handle the 105s. The Chemical Manufacturers Association (CMA) estimates that the average cost of retrofitting a terminal for this purpose would be between $10,000 and $20,000. To estimate the number of terminals, we used 1989 AAR TRAIN II data to determine that the shipments of the ten halogenated hydrocarbons went to about 140 destinations in the U.S. and Canada. Some of the terminals at these locations may already have top unloading capability, whereas others may have multiple racks within the same facility. Allowing for this uncertainty and the fact that customer locations might change in the future, requiring some additional cost in constructing unloading facilities, we estimated that 200 terminals would have to be modified. The median value of the cost figures provided by CMA is $15,000 per terminal, resulting in an estimated value for C_m of 200 x $15,000 = $3 million.

2.4 Rate of Increase in Cleanup Costs

The rate of future increases in cleanup costs will depend on a number of factors, but we expect the influence of regulatory requirements to continue to dominate. The response to spills of hazardous substances that is currently required by the federal government comes under the provisions of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was revised in 1990 to reflect the 1986 amendments to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). CERCLA requires the Environmental Protection Agency (EPA) to define cleanup criteria known as "applicable or relevant and appropriate requirements" (ARARs). Depending on the hazardous substance and the specifics of the site, an ARAR may call for in situ remediation or removal and treatment of contaminated soil and groundwater. Effective in 1992, federal law will generally prohibit the disposal in landfills of soil that has been contaminated with halogenated hydrocarbons. More expensive alternative treatment methods such as high-temperature incineration or vitrification will usually be required when soil contaminated with halogenated hydrocarbons is to be treated or disposed. In addition, as state requirements for site remediation continue to become more stringent than federal requirements, cleanup expenses will be driven still higher.

Water treatment is also expected to become considerably more expensive within the next few years because of Title III of the Clean Air Act of 1990 (CAA). The most commonly used technique for treating contaminated water, known as air stripping, in which the volatile contaminant is removed from the water and released into the atmosphere, will no longer be allowed for the halogenated hydrocarbons. More costly methods will be required in which air pollution control devices are employed or activated carbon filtration is used. The unit cost of these methods can range from two to ten times greater than the cost of air stripping (Adams and Clark,1991; EPA,1989).

These recent regulatory and legislative developments mean that contaminated soil and water, the two principal disposal and treatment components resulting from spills of these chemicals, will become much more expensive in the near future. Soil incineration is considerably more expensive than disposal in a hazardous waste landfill (EPA,1988). A survey of major hazardous waste disposal firms conducted for the AAR (Resource Consultants, Inc., 1991) found that the average cost of incineration in 1990 was 5.5 times more expensive per unit of soil disposed than the average cost for landfilling. Analysis of the cleanup expense showed that soil disposal accounted for 23% of the total cost of site remediation in 1990 dollars (Table 2b, page 12). To calculate the impact of implementing the land ban in 1992, we multiplied this fraction of the total cost by 5.5 in year one, which resulted in a 104% increase in the entire total cost ($r_1 = 1.04$). In order to quantify the accompanying impact of the CAA on remediation costs, we noted from Table 2b that approximately 36% of the total cost of remediation was accounted for by water treatment using air stripping. When EPA promulgates the regulations mandated by the CAA however, this method of water treatment will no longer be permitted. The EPA timetable for implementation of Title III ranges from three to seven years after its passage in 1990, depending on the chemical (EPA,1991). We assumed a median value of five years and a four-fold increase in water treatment costs. The result is an additional 52% increase in the overall liability in year five ($r_5 = 0.52$). As mentioned in the discussion of benefit estimation, other cost factors are also expected to undergo real increases due to more stringent cleanup standards, stricter monitoring requirements, additional third party expenses, and social inflation (Wolfe,1984). However, since we were not able to quantify these factors satisfactorily, we assumed $r_j = 0$ for all other years.

2.5 Railroad Share of the Total Cost

Part of the total cost estimated above will be borne by the railroads through the payment to car owners of increased car allowance charges. These charges are based on the per car-mile rates published in Exhibit Q of the Official Railway Equipment Register. These rates depend on the age and value of the car. For younger cars (30 years or less), a ceiling of \$0.849 is imposed on cars valued at \$67,000 or more. Based on 1990 TRAIN II data, we estimated a mean value of \$35,240 for all the cars currently used to ship the ten halogenated hydrocarbons. Assuming they are all 30 years old or less, the applicable rate is \$0.604. For 11,798 carloads moving an average of 850 miles each, the total charges are thus \$6.0 million.

By comparison, if new 105A300W tank cars valued at \$72,000 were to be used, the car-allowance charges would be approximately \$8.5 million per year, and if new 105A500W cars valued at \$88,000 were used, the car-allowance charges would be approximately \$9.0 million. The difference in the total annual car allowance between these two car types is due to the greater number of car-miles required for the heavier 105A500W compared to the 105A300W. The extra cost to the railroads over and above the estimate for the current annual car-allowance charges are thus \$8.5 - \$6.0 = \$2.5 million for the 105A300W and \$9.0 - \$6.0 = \$3.0 million for the 105A500W.

2.6 Results

Summarizing the estimates of the factors in the benefit-cost equation for the 105A500W, we have: B, the expected annual benefit = \$7.8 million; C_t, the average annual incremental cost of transportation = \$2.2 million; C_a, the net investment to acquire the 105s = \$83.3 million; C_m, the investment to retrofit terminals for top unloading = \$3.0 million; r_1, the rate of increase in cleanup costs in year one = 1.04; r_5, the rate of increase in cleanup costs in year 5 = 0.52; and all other $r_j = 0$. The discount rate i was assumed to be 0.10, based on the 1988 ICC value of 10% for the before-tax real cost of capital. The resulting NPV is \$94.7 million. Dividing by 1,464, the number of tank cars required, the corresponding NPV per 105A500W tank car is approximately \$64,700. A similar analysis was conducted for the 105A300W by substituting the following values in the formula: B = \$4.9 million, C_t = \$1.0 million and C_a = \$53.8 million. The total NPV for conversion to 105A300W tank cars is thus \$60.5 million. Dividing this number by 1,380, the estimated number of 105A300Ws required, yields an NPV per tank car of approximately \$43,900.

To examine the effect that a reduction in train accident rate would have on the NPV, we inserted the term $(1 - \Delta)^n$ ahead of B in the formula, where Δ represents the annual percentage decline in accident rate. A 1% or 2% compounded annual reduction in the train accident rate sustained over the 30-year period yields respective NPVs of $75.8 million and $59.3 million for the 105A500W, and $48.6 million and $38.3 million for the 105A300W. For either of the two 105 specifications, an annual reduction in train accident rate of about 7% would have to be sustained over the 30-year period to yield an NPV of zero (Figure 5).

These results do not reflect the additional costs and benefits associated with changes in the accident rate. We did not attempt to quantify the effect that the 11.7% increase in the number of carloads would have on the probability of accident involvement. Although the number of cars derailed increases with number of car-miles, the actual functional relationship between these two variables depends on the accident cause. For example, the most likely impact of more cars would be longer trains. The number of cars derailed per derailment is positively correlated with train length, but the rate of change in the functional relationship is much less than one (Delcan, 1987). The influence of more tank cars would also be counteracted somewhat by smaller expected spill sizes due to the lower capacity and greater strength of the 105s.

The effect of a change in the car utilization rate is also of interest. The rate assumed in the model was nine trips per year, which is lower than the rate reported by several major chemical shippers. The NPV if either of the two kinds of 105s is used is an increasing function of the rate of car utilization (Figure 6) because the greater the number of trips per year, the fewer the number of cars required and the lower the corresponding value of C_a, the cost of acquisition. Better car utilization is in the mutual interest of both the railroad and chemical industries since it lowers the capital outlay required of the shippers, thereby improving the cost-effectiveness of more secure tank cars, while providing industry and the public with the benefits of fewer spills. The railroads can contribute to better utilization by moving tank cars more expeditiously and the chemical shippers can contribute by providing incentives to their customers to unload and return cars promptly.

Figure 5

Effect of Train Accident Rate on Net Present Value

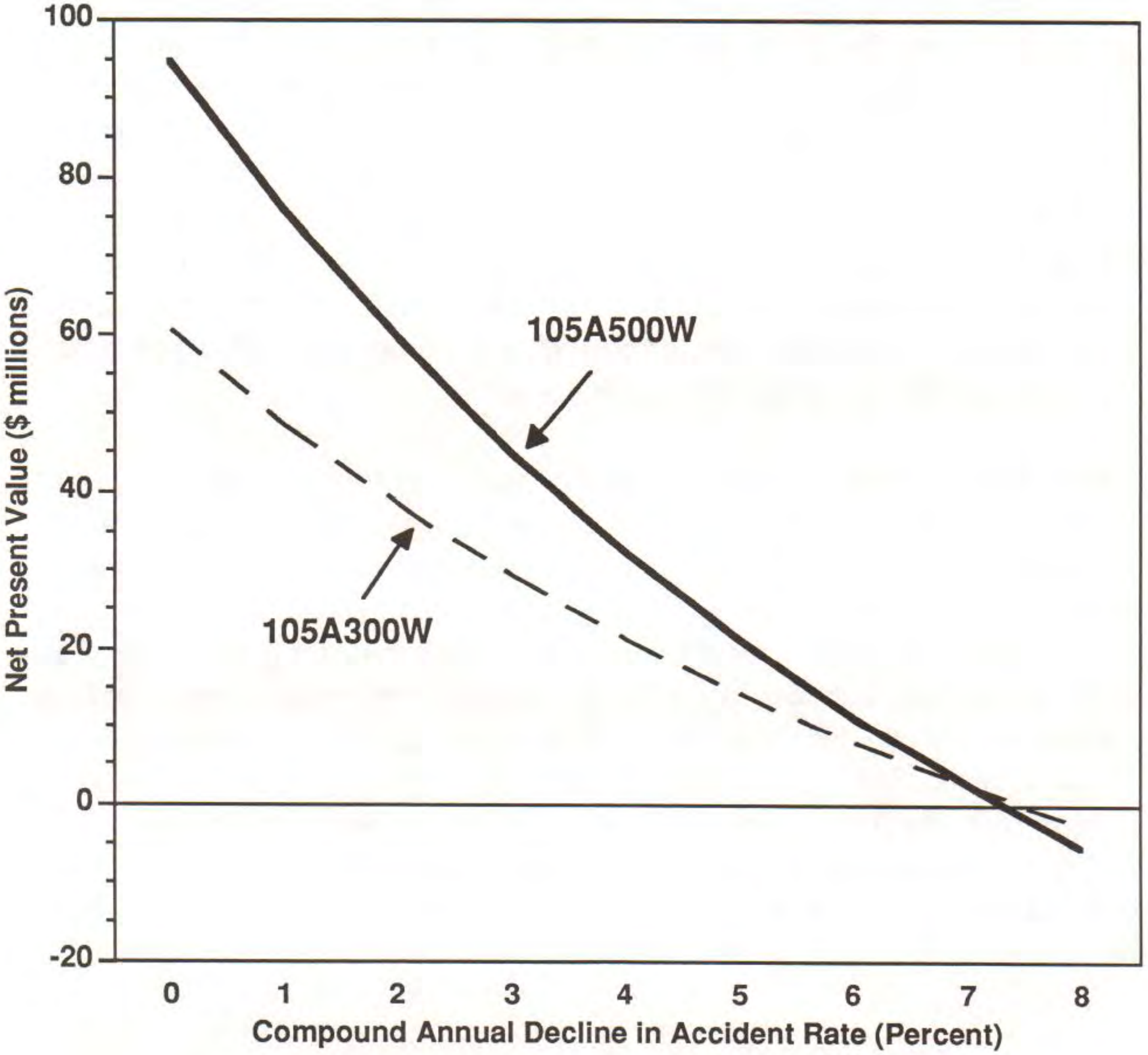
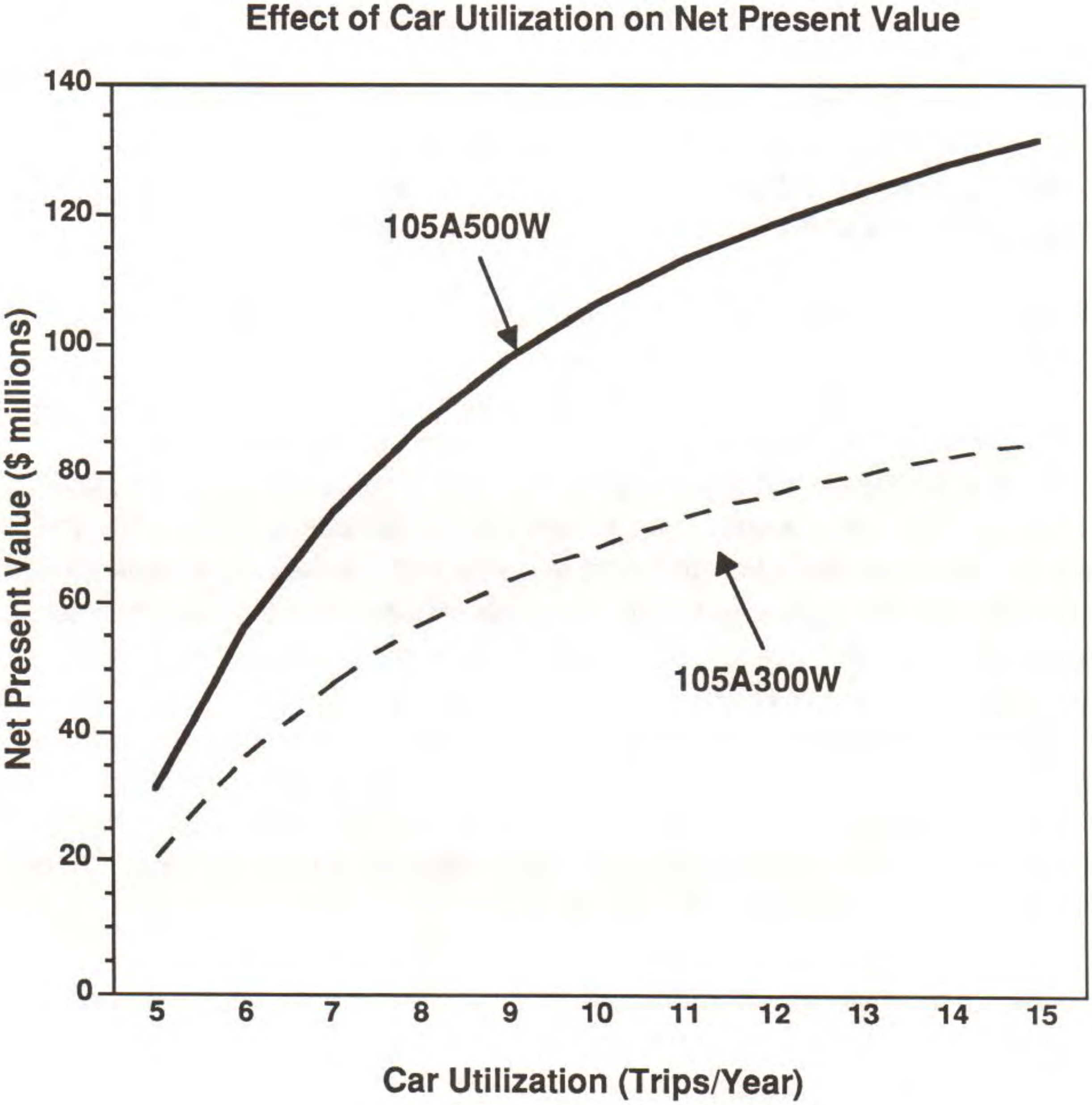


Figure 6


Effect of Car Utilization on Net Present Value
Net Present Value ($ millions)
140
120
100
80
60
40
20
0
105A500W
105A300W
5
6
7
8
9
10
11
12
13
14
15
Car Utilization (Trips/Year)

3.0 SUMMARY AND CONCLUSIONS

The ten halogenated hydrocarbons considered in this analysis are transported in general purpose tank cars because of their relatively low acute hazard to human health and safety. As the general awareness and understanding of environmental hazards and the health effects of chronic exposure to potential carcinogens have increased, so have the requirements for cleaning up spills of these chemicals. But transportation packaging practices have not kept pace with the environmental and economic impacts of these spills. Another hazard must be considered along with the more traditional hazards of acute toxicity, flammability, explosivity and corrosivity. This hazard, which we have referred to as environmental sensitivity, needs to be factored in when evaluating the transportation risk of chemicals.

In deciding how to best respond to this need, analogies with packaging practices for other chemicals that rank highly with respect to other hazards are appropriate. Beginning in 1918, the railroads and the car-building and chemical industries recognized that there was a need to "over-design" tank cars carrying chemicals that were considered life-threatening (Heller, 1970). This was the reason for the development of the Type V tank car (precursor to the current 105) for transportation of chlorine and sulphur dioxide, and later the 105 car for tetraethyl lead. Subsequent experience with 105 tank cars carrying acutely toxic or flammable materials over the years has been excellent. Due to the wide range in hazards, this degree of over-packaging is not necessary for all chemicals. However, our results suggest that in the case of these ten halogenated hydrocarbons, switching to 105s (or another specification tank car with similar accident performance and cost) would be a cost-effective means of reducing the risk of severe environmental impacts due to rail transportation spills of these chemicals. The type of tank car used to transport environmentally sensitive chemicals should be commensurate with their environmental hazard.

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