lock-off. These load cells showed an average of 4 percent increase in load over a 12-month period, most of which occurred in the first 3 months. Some maintenance of the timber lagging has been required. In general, performance of the wood facing has been as expected.

CONCLUSIONS

Tieback walls can be an economical way to stabilize railroad embankment.

Their construction usually does not interrupt railroad traffic.

A thorough geotechnical study is required.

The machanism by which the wall will be loaded must be known.

Tiebacks must be tested to verify design assumption.

Evaluation of wood lagging facings must include costs of periodic maintenance.

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Methodology for Allocating Loss and Damage to the Railroad Transport Cycle

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ABSTRACT

A methodology for allocating loss and damage costs to various parts of the railroad transport cycle is presented. Specific estimates of loss and damage attributed to line-haul shock and vibration and flat and hump yard coupling impacts are developed. In addition, loss and damage estimates are provided for various levels of overspeed impacts in hump yards.

In calendar year 1983, Association of American Railroads (AAR) statistics indicate that North American railroads paid out a total of $162 million in freight loss and damage (L&D) (from Information and Public Affairs, AAR). Industry sources indicate that the indirect costs to railroads and shippers of processing and handling L&D claims may be as much as eight times greater than the direct L&D payments (1). If this is true, the total costs of L&D to railroads and shippers may be on the order of $1.3 billion per year.

Even though the railroad industry has been vitally concerned with L&D for many years--the 1983 loss is the lowest since 1965--these figures indicate that the magnitude of the L&D problem is still large enough to warrant new approaches. Any decrease in the L&D payments translates directly to increases in net income (i.e., "bottom-line") on a one-to-one basis. Thus improvements to the L&D payment situation can significantly affect the health and viability of the entire railroad industry.

There is a lack of information about and understanding of the L&D costs that can be attributed to shock and vibration (rough handling) in the transport cycle. In particular, it would be nice to know how much L&D can be attributed to railroad yards versus the line haul. In yards, the amount of L&D that can be attributed to hump yards versus flat yards and how L&D increases with impact speeds in yards are unknown. Over the line haul, the contribution to L&D of longitudinal train slack action versus vertical vibration should be assessed.

This L&D transport cycle information is necessary to assess the benefit-cost impact of any specific proposed countermeasures to mitigate the effects of shock and vibration. Also, this L&D transport cycle information is important to assist in planning research priorities for future L&D countermeasures. Examples of potential areas for countermeasure development include

- Countermeasures to reduce L&D due to train slack action over the line haul,
- Countermeasures to reduce L&D due to vertical vibration over the line haul, and
- Countermeasures to reduce L&D due to overspeed impacts in hump or flat yards.

This research presents a methodology for allocating L&D to shock and vibration in the transport cycle. Although the data needed to perform this allocation precisely are lacking, estimates are developed on the basis of available data that allocate L&D to the following:

- Yards versus line haul,
- Hump versus flat yards, and
- Levels of overspeed impact in yards.

The approaches and procedures presented here represent a first approximate step in structuring a methodology. The method can be useful in developing L&D countermeasure technology.

METHODOLOGY OVERVIEW

The AAR each year provides aggregate statistics on L&D (2) in the following 12 categories:

1. Shortage, package shipment;
2. Shortage, bulk shipment;
3. All damage not otherwise provided for;
4. Defective or unfit equipment;
5. Temperature failures;
6. Delay;
7. Robbery, theft, pilferage;
8. Concealed damage;
9. Train accident;
10. Fire, marine, and catastrophies;
11. Error of employee; and
12. Vandalism.

Unfortunately, these 12 categories do not indicate the L&D due to shock and vibration (i.e., rough handling), which is germane to this work. Freight damage resulting from excessive shock and vibration would probably be listed in Category 3, "all damage not otherwise provided for," and Category 8, "concealed damage." Almost $71.4 million or 44.1 percent of the total 1983 freight loss and damage payments was classified in Category 3, and $0.5 million or 0.3 percent was classified in Category 8 (2). Other major factors that affect L&D in Categories 3 and 8 are inadequate packaging, improper loading, and claims incorrectly assigned to these categories.

The methodology consists essentially of allocating Categories 3 and 8 L&D to shock and vibration in the transport cycle using the "tree-structured top-down" approach shown in Figure 1. The steps can be summarized as:

- Step 1: Categories 3 and 8 L&D are allocated between shock and vibration versus "others."
- Step 2: Shock and vibration L&D is allocated between line haul and yard.
- Step 3: Line-haul L&D is allocated between shock (caused by the slack action of trains) and vibration.
- Step 4: Yard L&D is allocated to hump yards versus flat yards. (It is implicitly assumed that yard-related L&D is due to shock, not vibration, because the distances that cars travel in a yard are small and thus the exposure to vibration damage is minimized.)
- Step 5: Hump yard shock L&D is allocated to overspeed impact levels.

DETAILS OF METHODOLOGY

In this section the data and details for implementing each step in the methodology are presented.

Allocation to Shock and Vibration Versus Others (Step 1)

Categories 3 and 8 L&D amounted to $71.9 million in 1983. How much of this amount can be attributed to shock and vibration (i.e., rough handling) versus other causes such as inadequate packaging, improper loading, and claims incorrectly assigned?

The data to perform this allocation are scarce and imprecise. In their corrugated container study, Ostrem and Godshall (3) indicate that 80 percent of the damage could be attributed to rough handling. However, the Whirlpool appliance study (4) indicates that, at a minimum, 43 percent of appliance L&D could be attributed to shock and vibration. This leads to the conjecture that the percentage of damage that can be attributed to shock and vibration varies with the type of commodity under consideration.

The obvious answer to the problem is to get more data. However, in lieu of this possibility, an attempt is made to estimate the percentage of Categories 3 and 8 L&D that can be allocated to shock and vibration using a systematic procedure based on the data that exist.

Table 1, obtained from Braddock et al. (5), gives the gross claims paid by cause and commodity. Although the "damage" category in Table 1 contains damage causes in addition to Categories 3 and 8 (e.g., temperature failures, delay, fire, and train accidents), let it be assumed that the percentage of L&D for each commodity item under the "damage" category in Table 1 applies to Categories 3 and 8 L&D for each commodity group. It is known that 80 percent of corrugated container L&D can be attributed to rough handling and that a minimum of 43 percent of appliance L&D can be attributed to shock and vibration. The procedure will then be to associate each commodity grouping in Table 1 with either an 80 percent or a 43 percent L&D due to shock and vibration.

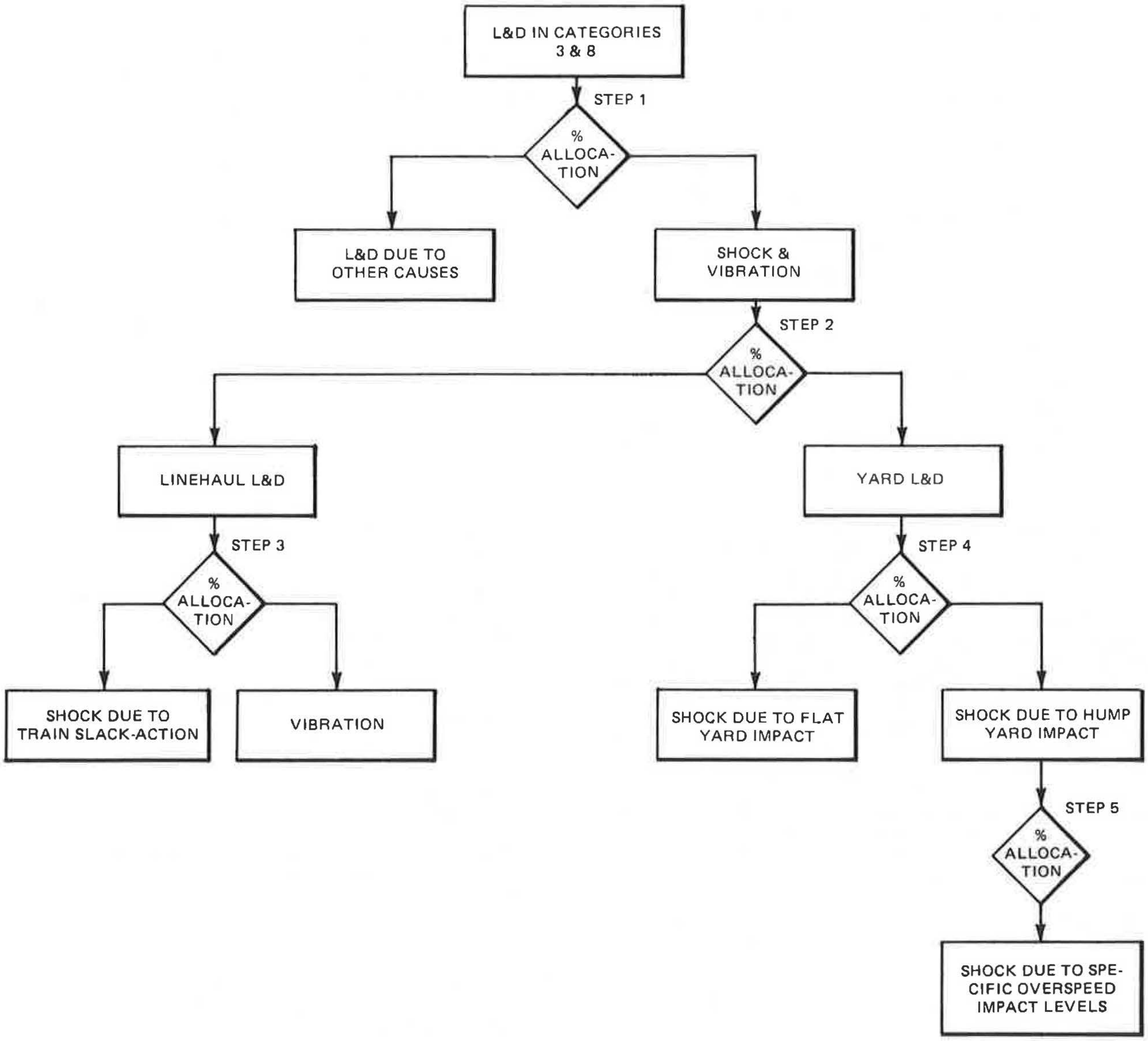

FIGURE 1 **Methodology for allocating L&D in Categories 3 and 8 to the transport cycle.**

TABLE 1 **Gross Railroad Claims Paid by Cause and Commodity (*5*)**

	Shortage		Theft		Damage		Total	
Commodity Grouping	Value ($)	Percentage	Value ($)	Percentage	Value ($)	Percentage	Value ($)	Percentage
Food and food products	12,522,827	28.5	3,295,481	12.6	203,849,028	45.0	219,667,336	42.0
Alcoholic beverages	1,889,409	4.3	915,411	3.5	3,623,983	0.8	6,428,803	1.2
Tobacco products	659,096	1.5	1,909,287	7.3	1,358,994	0.3	3,927,377	0.8
Wood products and furniture	2,592,445	5.9	680,020	2.6	44,846,786	9.9	48,119,251	9.2
Chemicals, petroleum, rubber, and plastic	5,800,046	13.2	2,196,987	8.4	32,162,847	7.1	40,159,880	7.7
Metal products and hardware	3,734,878	8.5	1,987,750	7.6	22,196,894	4.9	27,919,522	5.3
Machinery (except electrical)	2,372,746	5.4	732,329	2.8	13,136,937	2.9	16,242,012	3.1
Electric machinery, including appliances	2,153,047	4.9	3,263,326	12.5	22,196,894	4.9	27,619,267	5.3
Transportation equipment, including motor vehicles	8,304,612	18.9	10,331,071	39.5	45,299,784	10.0	63,935,467	12.2
Clothing and textiles	0	0	0	0	0	0	0	0
Jewelry and coins	0	0	0	0	0	0	0	0
Instruments	0	0	0	0	0	0	0	0
Medicines, drugs, and cosmetics	0	0	0	0	0	0	0	0
Others	3,910,637	8.9	836,948	3.2	63,419,698	14.0	68,167,283	13.0
Total	43,939,744	100	26,154,610	100	452,997,840	100	523,092,195	100
Percentage of total loss	8.4		5.0		86.6		100	

TABLE 2 L&D in Categories 3 and 8 Attributed to Shock and Vibration

Commodity Grouping	Value ($)	Percentage of Loss Due to Damage	Percentage Attributed to Shock and Vibration	Percentage of Total L&D Due to Shock and Vibration
Food and food products	203,849,028	45.0	80	36.00
Alcoholic beverages	3,623,983	0.8	80	0.64
Tobacco products	1,358,994	0.3	80	0.24
Wood products and furniture	44,846,786	9.9	43	4.26
Chemicals, petroleum, rubber, and plastic	32,162,847	7.1	61.5	4.37
Metal products and hardware	22,196,894	4.9	43	2.11
Machinery (except electrical)	13,136,937	2.9	43	1.25
Electric machinery, including appliances	22,196,894	4.9	43	2.11
Transportation equipment, including motor vehicles	5,299,784	10.0	43	4.30
Clothing and textiles	0	0	–	–
Jewelry and coins	0	0	–	–
Instruments	0	0	–	–
Medicines, drugs, and cosmetics	0	0	–	–
Others	16,419,693	14.0	61.5	8.61
Total	452,997,840	100		63.89
Percentage of total loss	8.4			

Table 2 gives percentages assigned to commodities on the basis of whether the commodity group is "closer to" corrugated containers or to appliances. In difficult cases, it was assumed that the percentage of L&D attributed to shock and vibration is the average of 43 percent and 80 percent (i.e., 61.5 percent). If this procedure is followed, and the percentage of L&D is "weighted" by commodity group by the percentage that the commodity contributes to total L&D, then the following is obtained: approximately 64 percent (actually 63.9 percent) of Categories 3 and 8 L&D can be attributed to shock and vibration. (It should be noted that if it is assumed that the percentage allocation lies between 43 and 80 percent, and the arithmetic mean of these two numbers is taken, the estimate is 61.5 percent.)

Using the 64 percent estimate,

Total 1983 Categories 3 and 8 L&D allocated to
shock and vibration = 0.64 ($71.9 million)
= $46.0 million (1)

If $46.0 million is divided by 18,800,172 revenue car loadings for 1983 (6),

Average 1983 L&D payments per loaded trip
due to shock and vibration
= $46.0 million/18,800,172 car loadings
= $2.45 (2)

A number of experienced railroad personnel believe that the 64 percent allocation is too low and should be closer to 70 percent. On the other hand, there are people who believe the allocation should be closer to 50 percent.

Allocation to Line Haul Versus Yard (Step 2)

There exist few data that allow the allocation of the $46.0 million L&D costs associated with rough handling to line-haul train slack action and vertical vibration versus coupling impacts in yards.

B. Gallacher, formerly assistant to the Chief Engineer of the Southern Pacific Transportation Company, has recorded data on shifted loads of lumber and pipes occurring in yards versus the line haul. His data indicate that 55 percent of the shifted loads occurred in yards versus 45 percent in the line-haul movement. If it is assumed that there is a correlation between the percentage of shifted loads and the percentage of L&D, it can be assumed that 55 percent of the L&D occurs in yards. Using these percentages,

Total 1983 Categories 3 and 8 L&D allocated to
line-haul train slack action
and vertical vibration
= 0.45 ($46.0 million) = $20.7 million (3)

Total 1983 Categories 3 and 8 L&D allocated
to coupling impacts in yards
= 0.55 ($46.0 million) = $25.3 million (4)

If these numbers are divided by 18,800,172 revenue car loadings for 1983 (6),

Average 1983 L&D payments per loaded trip
due to line-haul train slack
action and vertical vibration
= $20.7 million/18,800,172 car loadings
= $1.10 (5)

Average 1983 L&D payments per loaded trip
due to coupling impacts in yards
= $20.7 million/18,800,172 car loadings
= $1.35 (6)

Some industry personnel believe that the 55 percent allocation of L&D to yards is too low and should be closer to 60 percent.

Allocation to Line-Haul Shock Versus Vibration (Step 3)

In the previous section, $20.7 million L&D has been allocated to line-haul shock and vibration. The shock is mainly due to train slack action; the vibration is mainly the vertical component from the wheel-rail interface. Currently, there do not exist any data by which to allocate L&D between line-haul shock and vibration. A number of industry personnel believe that train slack action is the major cause, whereas others feel that vertical vibration is the main cause. Their viewpoints may depend on the commodity with which they are most closely associated. The author suspects that the type of commodity being transported has great bearing on whether line-haul shock or vibration is the major L&D cause. Because of the lack of data, this allocation cannot be made. This is clearly an area where more data are required.

Allocation to Flat Versus Hump Yards (Step 4)

The total Categories 3 and 8 L&D due to coupling impacts in yards is $25.3 million; the average L&D per loaded trip due to coupling impacts in yards is $1.35 (see the previous section).

Petracek et al. (7) indicate that 80 percent of total U.S. switching occurs in flat yards and 20 percent in hump yards. Therefore it will be assumed that a car spends 80 percent of its yard time in flat yards and 20 percent in hump yards.

However, simply allocating 80 percent of the L&D costs to flat yards and 20 percent to hump yards will not work because the relative L&D in hump and flat yards is unequal. More specifically, the relative time spent in flat and hump yards should be "weighted" by the relative damage occurring in flat versus hump yards; this "weighted relative time" should be used to apportion L&D to the time a loaded car spends in hump yards. In particular,

Total 1983 Category 3 and 8 L&D associated
with time spent in hump yards
= {0.2 (hump damage)/[0.8 (flat damage)
+ 0.2 (hump damage)]} $25.30 (7)

Average L&D per loaded trip associated with
time spent in hump yards
= {0.2 (hump damage)/[0.8 (flat damage)
+ 0.2 (hump damage)]} $1.35 (8)

These equations could be solved if some idea could be gotten of the relative damage occurring in flat versus hump yards. An attempt to estimate the relative damage in flat versus hump yards is made in the remainder of this discussion.

Simmons and Shackson (8) indicate that "the damage impulse increases as the square of the speed." Furthermore, in Figure 2, reproduced Simmons and Shackson (8), acceleration in g's at the car floor is plotted versus impact speed in miles per hour. It appears that there is little if any damage at 4 mph coupling and that the damage impulse increases with the squared difference between 4 mph and the coupling speed. Therefore the following relationship between damage and speed will be assumed. Damage is proportional to the squared difference between 4 mph and coupling speed, i.e.,

$$\text{Damage} = (\text{coupling speed} - 4\text{ mph})^2 \qquad (9)$$

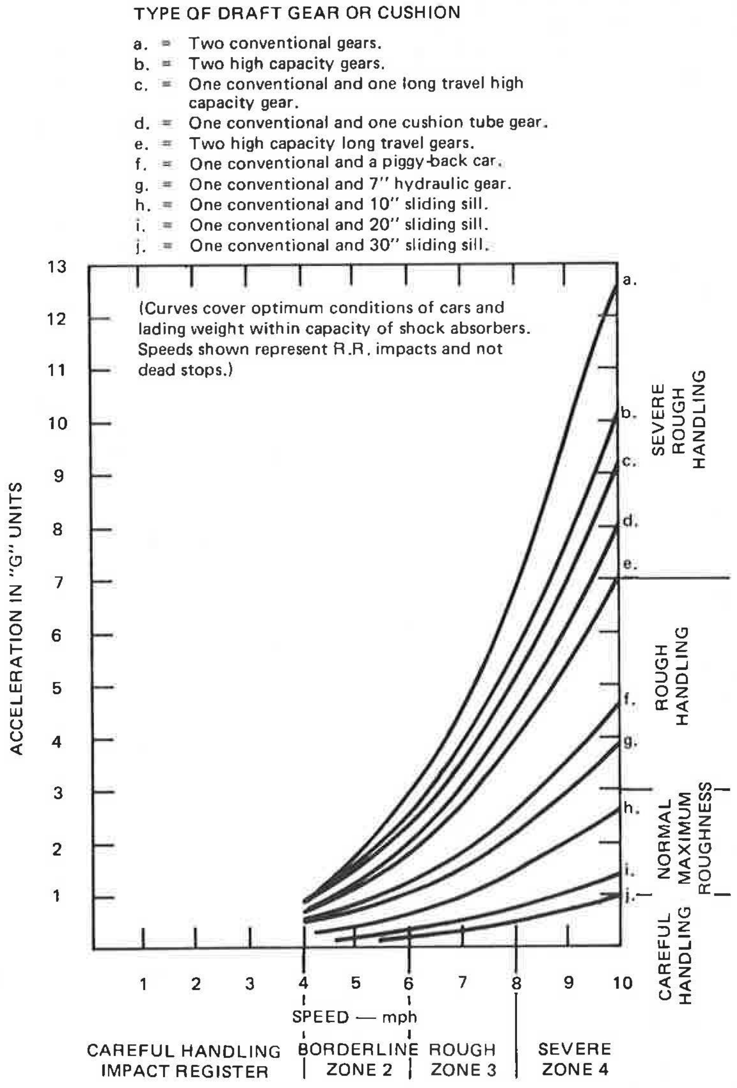

FIGURE 2 Car floor acceleration versus impact speed.

TABLE 3 National Careful Car-Handling Observation Day Results

Coupling Speed (mph)	Retarder/Hump Yards Percentage of Total		Flat Switching Yard Percentage of Total	
	1969	1970	1969	1970
4 or less	51.6	65.6	71.2	80.0
4.1 to 4.9	23.1	12.7	20.7	11.0
5.0 to 5.9	13.1	12.6	5.7	5.6
6.0 to 6.9	5.0	3.6	1.3	2.0
7.0 to 7.9	4.7	3.7	0.7	0.9
8.0 to 8.9	1.1	1.1	0.2	0.3
9.0 to 9.9	0.9	0.5	0.2	0.1
More than 10	0.5	0.2	0.1	0.1
Sample size	3,949	10,493	14,642	26,933

Table 3 gives the frequency of occurrence of overspeed impacts in flat versus hump yards for data taken in 1969 and 1970 by the Association of American Railroads. The 1969 and 1970 AAR data have been combined, and in Figures 3 and 4 these frequencies of occurrence versus coupling speed and (coupling speed - 4 mph)^2 for both flat and hump yards have been plotted. [For each occurrence of coupling in an interval (e.g., 5 mph to 6 mph), it is assumed that the coupling speed is at the mean or midpoint of the interval (e.g., 5.5 mph).] Using the assumption of Equation 9, the relative damage in flat versus hump yards is proportional to the areas under the curves in Figures 3b and 4b, respectively. In particular, the area under Figure 3b representing damage in flat yards is 0.508, and the area under Figure 4b representing relative damage in hump yards is 1.718. Therefore, substituting these values into Equations 7 and 8 gives

Total 1978 Categories 3 and 8 L&D associated with the time spent in hump yards

$$= \{0.2\ (1.718)/[0.8\ (0.508) + 0.2\ (1.718)]\}\ \$25.3 \text{ million} = \$11.6 \text{ million} \qquad (10)$$

Average 1983 L&D per loaded trip associated with time spent in hump yards

$$= \{0.2\ (1.718)/[0.8\ (0.508) + 0.2\ (1.718)]\}\ \$1.35 = \$0.62 \qquad (11)$$

The corresponding cost associated with flat yards is simply found as follows:

Total 1983 Categories 3 and 8 L&D associated with time spent in flat yards

$$= \$25.3 \text{ million} - \$11.6 \text{ million} = \$13.7 \text{ million} \qquad (12)$$

Average 1983 L&D per loaded trip associated with time spent in flat yards

$$= \$1.35 - 0.62 = \$0.73 \qquad (13)$$

Equations 11 and 13 indicate the average L&D per loaded trip associated with time spent in hump and flat yards, respectively. A more interesting statistic would be the average L&D per hump yard coupling or per flat yard coupling. The calculation is performed as follows: Petracek et al. (7) indicate that a loaded car, on the average, goes through six yards on its loaded trip journey. Because a loaded car is assumed to spend 20 percent of its yard time in hump yards and 80 percent of its yard time in flat yards (7), it is assumed that a loaded car on the average goes through 1.2 hump yards (i.e., 1.2 = 0.2 x 6) and 4.8 flat yards (i.e., 5.8 = 0.8 x 6). If it is further assumed that a car has only one coupling per hump yard or flat yard (i.e., it is assumed that the number of rehumped or reswitched cars is small), then using the results from Equations 11 and 13

Average 1983 L&D per hump yard coupling

$$= \$0.62/.2(6) = \$0.52 \qquad (14)$$

Average 1983 L&D per flat yard coupling

$$= \$0.73/.8(6) = \$0.15 \qquad (15)$$

Allocation to Hump Yard Overspeed Impact Levels (Step 5)

In the previous section it was calculated that the average L&D per hump yard coupling is \$0.52. Using this average value, the expected L&D associated with various levels of coupling speed can be calculated in the following manner.

Figure 4a shows the frequency of occurrence of coupling impact speed for the following intervals: less than 4 mph, 4 to 5 mph, 5 to 6 mph, ..., greater than 10 mph. The percentages in Figure 4a are interpreted as probabilities of occurrence. It is also assumed that all couplings occurring between 4 and 5 mph take place at the mean interval value of 4.5 mph; similarly it is assumed that couplings in the other intervals occur at the mean interval values of 5.5 mph, 6.5 mph, ..., 10.5 mph. (It is assumed that cars coupling at speeds greater than 10 mph all couple at 10.5 mph.) Let $D_{4.5}$, $D_{5.5}$, ..., $D_{10.5}$ represent the unknown value of L&D due to couplings at the mean interval values of 4.5 mph, 5.5 mph, ..., 10.5 mph. The definition of average (or expected value) allows the following equation to be written:

Average 1983 L&D per hump yard coupling

$$= \$0.52 = .613(0) + .156_{4.5} + .127D_{5.5} + .04D_{7.5} + .011D_{8.5} + .01D_{9.5} + .003D_{10.5} \qquad (16)$$

where the probabilities are taken from Figure 4a, and $D_{4.5}$, $D_{5.5}$, ..., $D_{10.5}$ are the unknowns. Note that the 61.3 percent of the cars that couple at less than 4 mph are assumed to have "zero" L&D.

To aid in the solution of Equation 16, the assumption stated in Equation 9, namely that damage is proportional to the squared difference between coupling speed and 4 mph, is used again. Using this assumption, the following relationships can be written:

$$D_{5.5} = [(5.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 9D_{4.5} \qquad (17)$$

$$D_{6.5} = [(6.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 25D_{4.5} \qquad (18)$$

$$D_{7.5} = [(7.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 49D_{4.5} \qquad (19)$$

$$D_{8.5} = [(8.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 81D_{4.5} \qquad (20)$$

$$D_{9.5} = [(9.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 121D_{4.5} \qquad (21)$$

$$D_{10.5} = [(10.5 - 4)^2/(4.5 - 4)^2]D_{4.5} = 169D_{4.5} \qquad (22)$$

Equations 17-22 can be substituted into Equation 16 yielding one equation and one unknown, $D_{4.5}$, as follows:

$$\begin{aligned} \$0.52 &= .152D_{4.5} + .127(9)D_{4.5} + .04(25)D_{4.5} \\ &\quad + .04(49)D_{4.5} + .011(81)D_{4.5} \\ &\quad + .01(121)D_{4.5} + .003(169)D_{4.5} \\ &= 6.867D_{4.5} \end{aligned} \qquad (23)$$

By solving Equation 23 for $D_{4.5}$ and using Equations 17-22, expected L&D can be calculated for var-

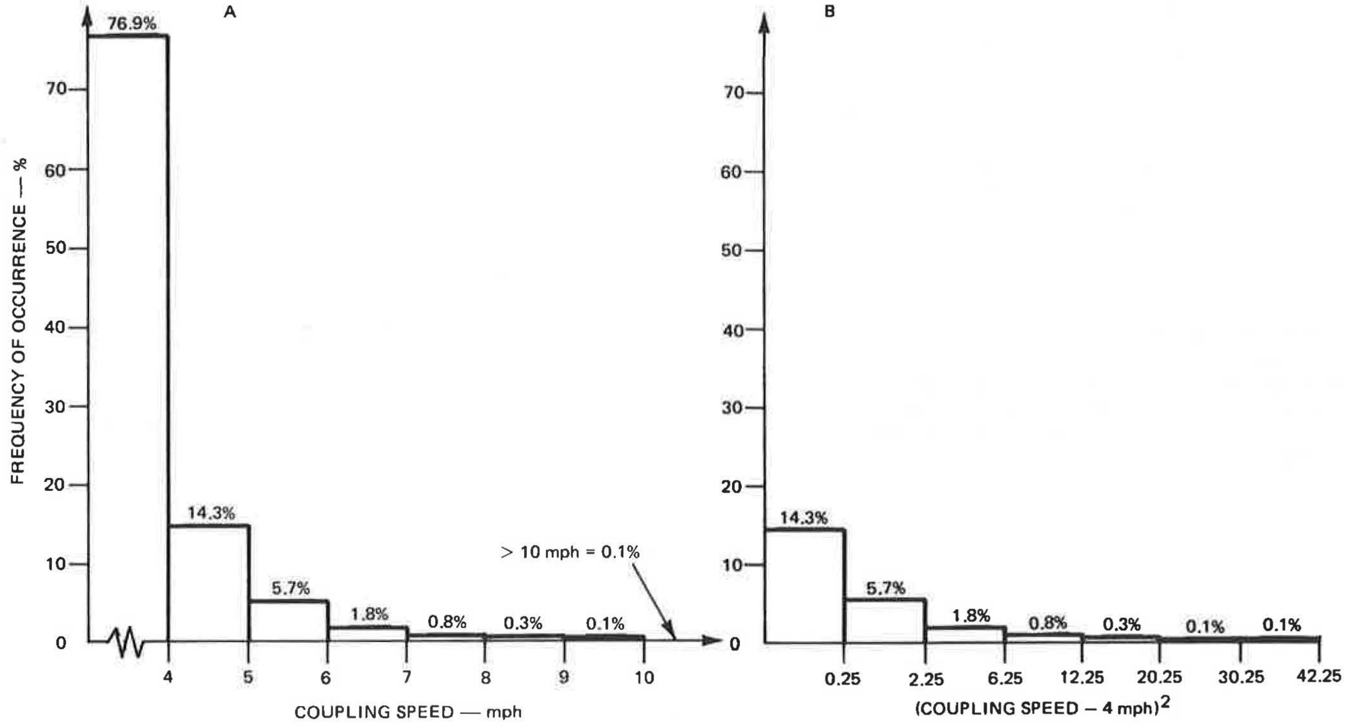

FIGURE 3 Frequency of flat yard impacts for coupling speed and (coupling speed – 4 mph)^2.

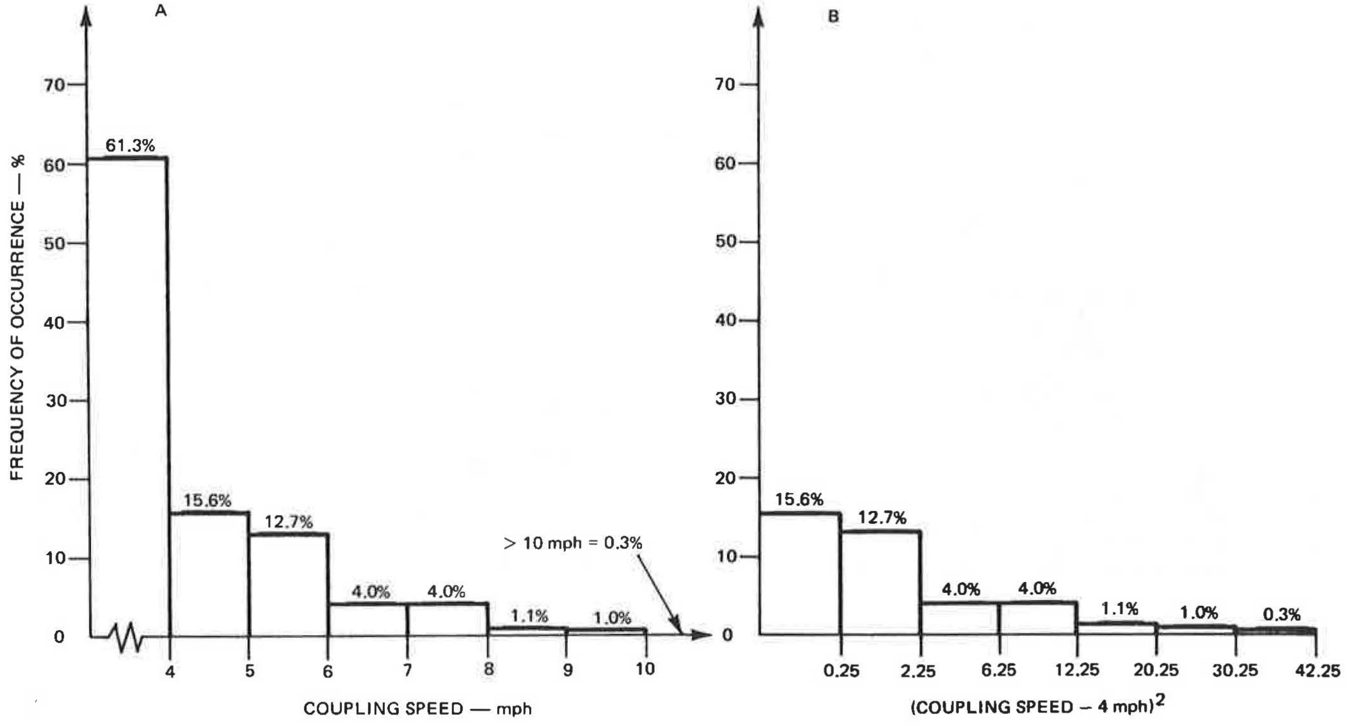

FIGURE 4 Frequency of hump yard impacts for coupling speed and (coupling speed – 4 mph)^2.

TABLE 4 L&D Versus Overspeed Impact

Overspeed Impact	Expected 1978 L&D per Occurrence ($)
4 mph	0.00
4-5 mph	0.08
5-6 mph	0.68
6-7 mph	1.90
7-8 mph	3.71
8-9 mph	6.14
9-10 mph	9.17
10 mph	12.81

ious levels of overspeed impacts; the results are given in Table 4.

Figure 5 shows a summary of the findings about allocation of payouts to the various causes shown in Figure 1. The dollar amounts are obviously only as good as the sketchy data used and are shown to illustrate the method.

CONCLUSIONS AND RECOMMENDATIONS

A methodology for allocating loss and damage costs to shock and vibration (i.e., rough handling) in various elements of the transport cycle has been presented. Although the quantitative estimates are important, the methodology itself, viewed as a "prototype," is more important. It is likely that the methodology can be refined to give more precise estimates with more definitive empirical data. In particular, the methodology presented here could form the basis of an experimental plan to obtain more refined estimates of L&D costs.

Because the magnitude of loss is large when both direct and indirect costs are considered, it is clear that the potential for improvement is great and that continued effort should be made to develop countermeasures to reduce the loss and damage due to shock and vibration in line haul and in yards (especially hump yards).

Research is needed to obtain better data. Data from other than National Car Handling Day should be used. Frequency of impact today should be deter-

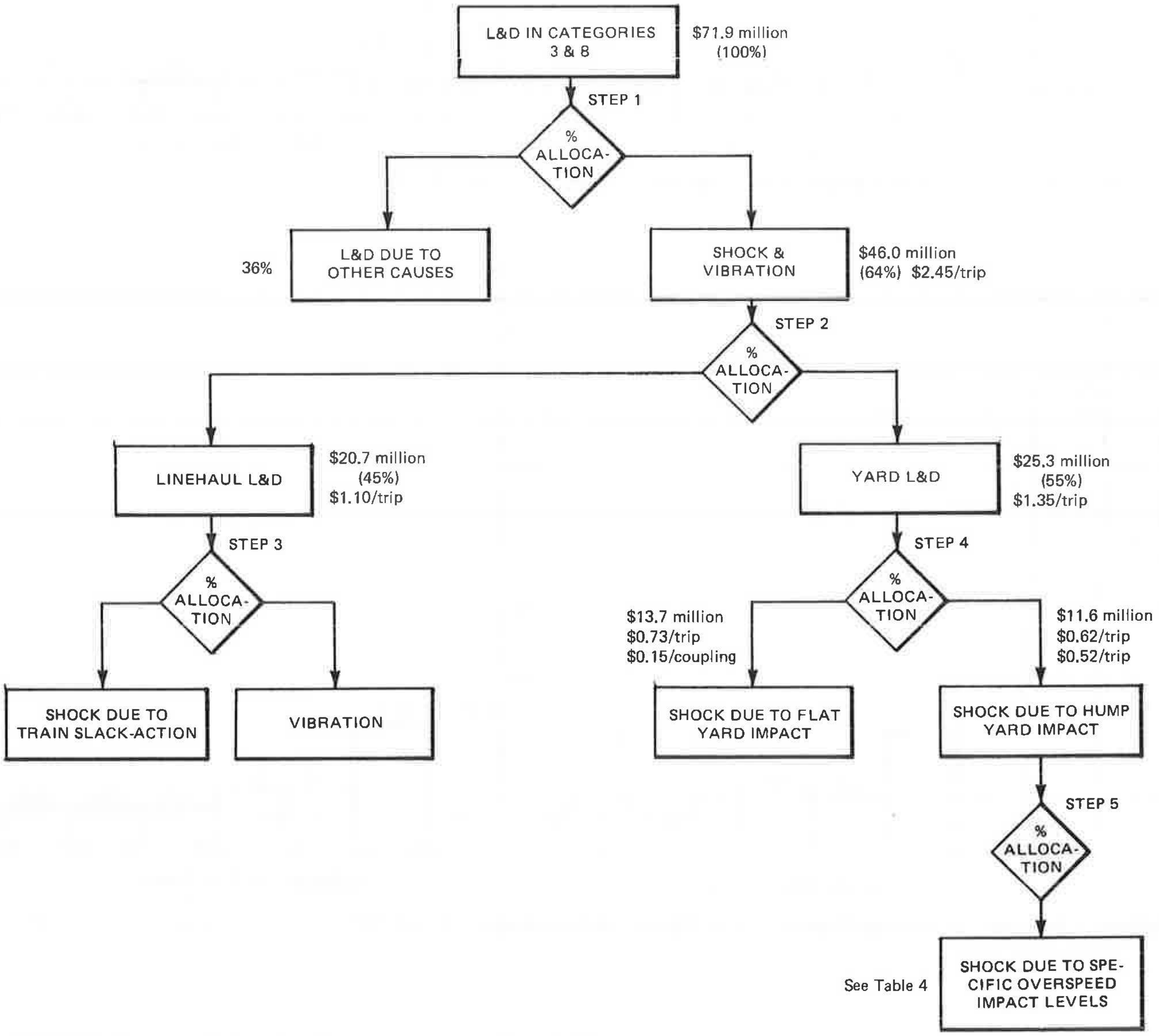

FIGURE 5 Summary of allocation of payments to causes shown in Figure 1.

mined. Obviously the only data available may not represent today's practices so up-to-date data are needed to validate the procedure. Efforts should be made to determine if shifted loads are more susceptible to damage than loads that have not shifted.

An extensive bibliography on loss and damage is presented elsewhere (9).

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Economic Design Methods for Automated Miniyards

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ABSTRACT

Changing traffic patterns and operating methods will continue to reduce the number of cars to be classified in yards. This trend promotes a need for economically designed, built, and operated miniyards. Such small-scale yards can be designed in ladder track or balloon formation, both with minihumps and suitable for 1,000 to 2,000 cars per day throughput. To attain low-cost, efficient operation of these yards they will need to be automated in an economical manner with automatic route setting and simple car speed control. The system described in this paper could control the humping procedure to give continuous, discontinuous, and manual modes of car throughput as appropriate to the measured rollability category and track address for each car.