On A Rational Relationship For Certain Costs Of Handling Motor Freight

I. Over the Platform

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ABSTRACT

The cost of handling freight on the platforms of motor carriers of general freight amount to roughly $2,000,000,000 per year being easily 20 per cent of the total cost of transportation of general freight by truck. The aim of this paper is to learn how certain costs on the platform vary with the weights of shipments. The Interstate Commerce Commission carried out in 1969-70 a study of the time required to move shipments of various weights, from truck to platform, platform to truck, and truck to truck. The data on costs (in terms of man-minutes per shipment) from this study are found to follow a simple rational functional relationship. This relationship, fitted to the data from the ICC-study, shows that the man-minutes required to move (e.g.) 5000 pounds truck-to-truck by manual methods on the average platform with no dragline are only 4.6 times the man-minutes required to move 500 pounds. The man-minutes required to move 5000 pounds truck-to-platform by manual methods are 5.3 times the number required to move 500 pounds. The man-minutes required to move 5000 pounds by fork-lift are only about 3 times the number required to move 500 pounds (Table II, Appendix). These results are important in the adjudication of rates for hauling freight. They also indicate to carriers of motor freight possible ways by which to try to achieve better economy on the platform.

Dr. Deming is a Consultant in Statistical Studies, Washington. The immediate data for this analysis were reconstructed to his specification by the Central States Motor Freight Bureau, Inc., of Chicago, from the "Motor Carrier Platform Study," Statement No. 2S51-70, June 1973, Interstate Commerce Commission, to show minutes against average weight and number of shipments within a weight-bracket. The calculations to find a, b, c, by least squares, including the computation of the correlation matrixes, were carried out by Dr. Benjamin J. Tepping, the cost of which was underwritten by the Central & Southern Motor Freight Tariff Association. The author wishes to thank also Homer S. Carpenter, John W. McFadden, Norman Powell, Otis E. Lancaster, William T. Bono, Dabney T. Waring, John P. Thompson, and Robert W. Burdick.

INTRODUCTION

Is the cost per pound for handling motor freight over the platform greater, about the same, or less, for heavy weights than for light weights? These questions have been in controversy for years. Cases are perennially before the Interstate Commerce Commission (hereafter ICC) in which the carriers of general freight contend that the cost per pound for handling light weights (e.g., under 500 pounds) on the platform is greater than the cost per pound for handling heavy weights (e.g., 1800 pounds). Shippers of light weights have persistently refuted the arguments, claiming that proposals to increase the rates on small shipments, and to decrease in compensation the rates on heavy shipments, would be unfair to them. The absence of solid evidence on costs has left the ICC and the courts and the carriers in a difficult position in pleadings of the carriers for higher rates on small shipments, and in attempts to adjust rates to costs.

It turns out, by the results of this paper, that a rational functional relationship exists between the man-minutes required to move shipments over the platform, and the weights of the shipments (Eqs. 1-4 infra). The same relationship holds for the man-minutes of stop-time on pickup and delivery, to form the basis for a second paper.

Some idea of the importance of costs of labor on the platform may be had from the fact that we are talking about an annual figure close to $1,700,000,000. This figure allows from the facts that (a) the revenue from common general motor freight less-than-truckload is about $11,000,000,000; (b) the average operating-ratio (cost: revenue) is about 94 per cent; and (c) the cost of labor on the platform is 16 per cent of the total expense.

SUMMARY OF SOME RESULTS

It turns out that the man-minutes required for any of the three movements are not at all proportionate to the weight moved (Table II, Appendix.). For example, the man-minutes required to move 5000 pounds truck to platform is 10 times the man-minutes required to move 500 pounds, but the cost of movement platform to truck:

a. By manual handling is only 5 times as much.
b. By fork-lift is only 3 times as much.

The economy of the fork-lift, where it can be used, is thus brought into focus. Expansion of the use of pallets, to render more shipments adaptable to the fork-lift, could accordingly be a goal of both carriers and shippers, though there are complexities such as the cost of pallets, and the cost of returning them.

Substantial differences in the efficiencies of different ways of handling freight on the platform should be of interest, not only for better basis for adjudicating rates, but even more to the management of carriers for reduction of costs.

It should be pointed out that the man-minutes for the fork-lift do not include the cost and maintenance of the fork-lift and pallets. Likewise, the man-minutes for a dragline do not include its cost and maintenance, nor do they give credit for the extra speed and service that it can generate in a large terminal.

Need for new types of studies on the platform is indicated, such as ratio-delay (work sampling) as a basis for reduction of cost with reduction in human effort, through improved handling and supervision [4]. More observations are needed for extra heavy weights (18,000 pounds or over), along with information about what type of freight constitutes these shipments.

SOURCE OF DATA

The data analyzed here came from a study conducted by the ICC in 1969-70 [1]. This study was conducted at 40 terminals selected by judgment to embrace small terminals, large terminals without dragline and large terminals with dragline. (There is no small terminal with dragline.) Thretypes of movement were studied at each terminal: (1) truck to platform, (2) platform to truck, and (3) truck to truck. The selection of terminals followed good statistical practice except for failure to use random numbers to select terminals from strata (defined by size and by carrier and by presence or absence of dragline). As the aim of the study was analytical, viz., to estimate relationships between the costs of handling various weights, and not to learn how many shipments of various weights pass over platforms of different kinds, a proportionate sample of terminals from strata would not have been the correct approach. It is an accepted principle of science that a relationship or a comparison that is discovered by use of a judgment sample is a contribution to knowledge [2].

There is a certain amount of paperwork and start time in connection with the movement of a shipment on the platform. Every shipment has to be accounted for and compared with the driver's manifest as it comes off the truck, and again as it moves on to a truck for delivery or for onward journey over the road. Illegible addresses cause delay; likewise suspicion of damage. A shortage requires search. A shipment must not be set down just anywhere. It must not be mixed with other destinations. Thus, there must be an average overhead time for handling shipments (the constant a in the equations that follow.)

At a terminal equipped with a dragline, shipments are set off on to carts. A shipment may require several carts, but in the usual practice there must never be more than one shipment on a cart. The movement from an incoming truck on to a cart, or on to the platform to await an empty cart, is counted as truck to platform. The cart moves off, propelled by a dragline under the floor. The cart is destined to a specified bay on some terminals by a poster, usually by pins inserted in holes as the cart moves off. The freight in the cart awaits, in the cart or on the platform, stowage on to an outgoing truck (platform to truck).

The time that a shipment spends on the platform or on the dragline awaiting stowage was outside the scope of the ICC's study of the platform. Hence truck-to-truck movement on terminals with a dragline is absent in Table II, Appendix.

Truckloads that move without handling over a platform were outside the scope of the ICC study.

METHOD OF ANALYSIS

Search of a relationship between minutes and the weight handled settled on the form

$$y = a + b(x/100)^c \qquad (1)$$

where

- x is the weight of a shipment in pounds, $x/100$ its cwt
- y is the average minutes required to handle shipment of weight x
- a is a constant number of minutes, independent of weight; allowance for paperwork, sorting, studying illegible addresses, plus other overhead costs that are about the same for light weights as for heavy weights.
- b is a constant
- c is a constant (the slope) in Figures 1 and 2
- y-a is the variable cost (measured in minutes) of handling weight x.

A derivation of Eq. 1 is as follows. If the variable number of minutes is y-a for weight x, how many additional minutes Δy will be required for weight $x+\Delta x$? The question is what value to give to c in the differential equation

$$\frac{\Delta(y-a)}{y-a} = c\frac{\Delta x}{x} \qquad (2)$$

If c were a constant, the integral of this differential equation would be Eq. 1, wherein b is a constant of integration. The logarithmic form of Eq. 1 is

$$\text{(3)} \quad \log(y-a) = \log b + c \log(x/100)$$

Plots of log $(y-a)$ against log x, for the constant *a* at or near its least square value in each case, indicate good conformity to a linear relationship. Figure 1 and 2 are examples of the eight charts. The intercept on the vertical scale for $y-a$ at $x=100$ is log b, and the slope of the fitted line is *c*. The average time in minutes required to handle 100 pounds is $b+a$.

An alternative form of Eq. 1 is helpful for comparing the cost of handling a heavy weight against the cost for a low weight. Let y_1 be the number of minutes required to handle weight x_1, and y_2 the number of minutes for weight x_2. Then Eq. 1 gives

$$\text{(4)} \quad (y_2-a)/(y_1-a) = (x_2/x_1)^c$$

Slope less than unity means that the minutes required to handle heavy weights is less than proportionate to the weight. For example, let us compare the minutes required to handle 1000 pounds with the minutes required to handle 100 pounds when $c=.77$. Then

$$\text{(5)} \quad (y_2-a)/(y_1-a) = (1000/100)^{.77} = 10^{.77} = 5.9$$

This would mean that the average variable man minutes required to handle 1000 pounds is not 10 times the variable man minutes to handle 100 pounds, but only 5.9 times. With $c=.70$, the ratio would drop to $(1000/100)^{.70}=5.0$.

METHOD OF FITTING THE LINES

The most important requisite in fitting curves is to start with a rational function,

Figure 1. Plot of Eq. 3, the logarithmic form of Eq. 1, for manual handling, truck to truck, no dragline. Equation of the line fitted by least squares,

$$\log(y-.28) = 1.96 + .68 \log(x/100)$$

y in minutes, x in pounds.

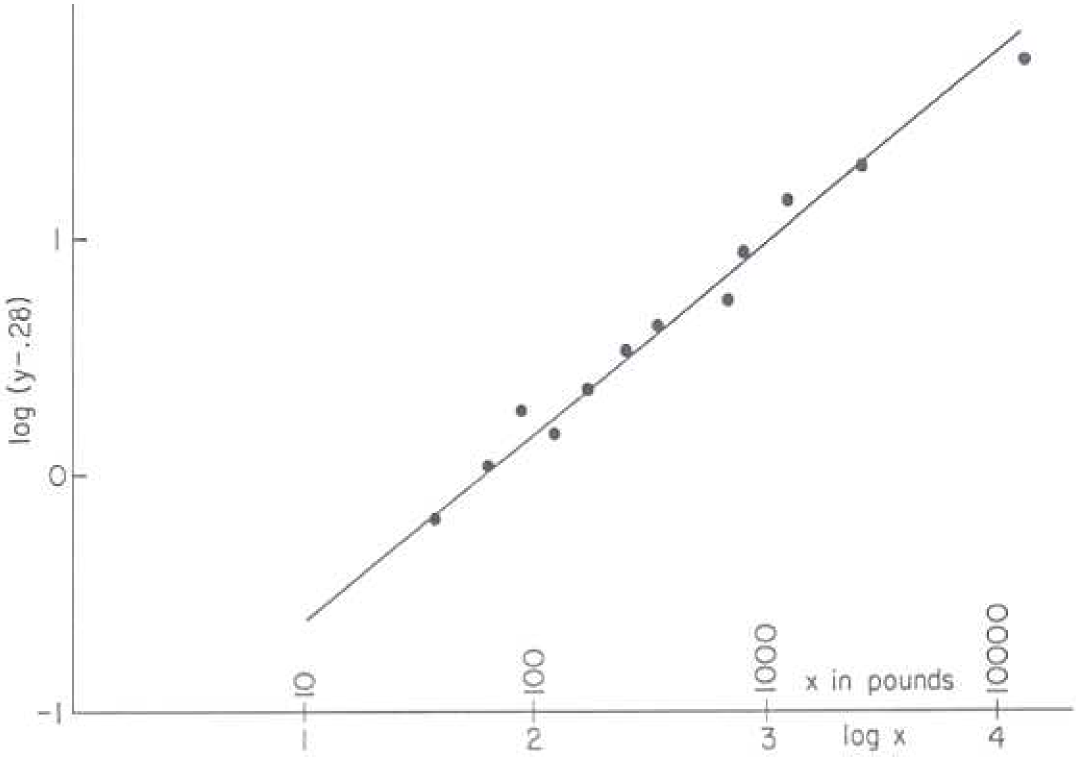
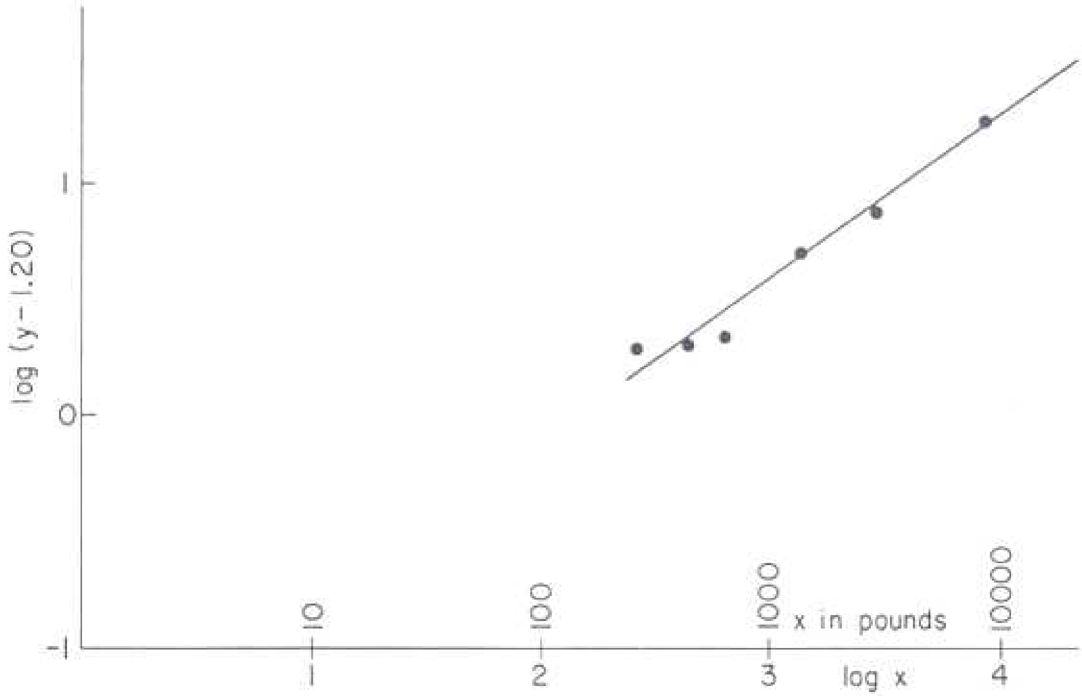


Figure 2. Plot of Eq. 3, the logarithmic form of Eq. 1, for handling freight by fork-lift, truck to truck. Equation of the line fitted by least squares,

$$\log(y-1.20) = .50 + .70 \log(x/100)$$

y in minutes, x in pounds.



suggested by knowledge of the subject matter (accounting, engineering, physics, physiology, or other subject).

It may be pointed out that a straight line fitted to the logarithmic form in Eq. 3 yields results far more accurate and useful than can be derived from fitting by eye a curve to a graph of y/x against x, which is the usual way to treat the data from the platform, also data on stop time in pick-up and delivery. Such treatment buries most of the information in the data. As a matter of fact, one can produce by random numbers, in the space of a few minutes, a fair duplication of a chart of y/x vs. x derived from the ICC's study.

The method of fitting attempted here is least squares, ascribing constant variance to log (y−a), and no error to log x. In justification of this procedure, we remark that the standard deviation of the observed minutes y is roughly proportionate to y, which means (following Gauss) that the standard deviation of log y is nearly constant, independent of y. As a good approximation, we may attribute all the error of observation to the minutes (y), even though the weights of the individual shipments are scattered above and below the average weight within a weight bracket [3]. Sparsity of the number of shipments observed for the fork-lift led to a decision to fit two of the lines by eye, rather than by least squares, identified by the asterisks in Table II, Appendix.

The method of least squares maximizes the coefficient of determination, denoted here by ρ^2. The rel-variance of the slope c is then estimated as

(6) $\text{Rel-}\hat{\text{V}}\text{ar } c = (1-\rho^2)/[(n-2)\ \rho^2]$

where n is the number of points fitted. The maximum coefficient and determination thus corresponds, for practical purposes, to the minimum standard error of *c*.

The man minutes required for loads of roughly 18,000 pounds and over appear to be far lower than would be consistent with the time required for lesser weights. Points for heavy weights were excluded from the fitting, for the reason that extremely heavy loads are usually handled by trailer drop.

RESULTS

Table I, Appendix, shows the values of a, b, and c obtained by least squares, for the various movements and types of handling. Table II shows for illustrative weights the calculated total minutes for the various movements and types of handling, and the minutes per hundred-weight. Values of b and c were for this calculation pooled for any two movements for which the difference was inconsequential and well below the standard error of the difference.

The contrasts in man-minutes shown in Table II for manual and fork-lift, especially for heavy weights, are impressive and can be accepted for purposes of management, even though the standard errors of y are large for heavy weights (Eq. 9).

The main purpose of this investigation was to compare, for any method of handling freight, the man minutes for heavy weights with the man minutes for light weights. The constant *c* (the slope) in Table I is the determinant for this comparison, as was explained in the text that follows immediately after Eq. 5. Slopes *c* below unity in Table II indicate that the cost of handling a shipment on the platform is not proportional to the weight of the shipment, but is less, as has been pointed out. In spite of the standard errors of *c*, the comparison of man-minutes for different weights is useful for management.

The constant time *a* also offers an aid t management. This is the portion of th total man minutes on the platform that constant, independent of weight. It may b possible to reduce this constant and at th same time to lighten the burden of huma effort by improved supervision and im provement of arrangements on the pla form. Reduction of the constant *a* by a little as 3 seconds per shipment on the ave age would bring forth a substantial decrea in costs.

The constant *b* reflects the speed of m tion. If the motion were to speed up, would decrease.

How to decrease *a* or *b* was not th purpose of this investigation, though w may mention that changes that are the re sponsibility of the management are r quired. Exhortations and posters to sho day by day (e.g.) how far the average loa failed to meet the goal of 38,000 pounds, o the number of claims month by month, a ineffective [5]. Statistical studies by Ti pett's ratio-delay methods would thro light on losses and on excessive human e fort, and might be included in any ne study of man minutes on the platform [4

Variance of the calculated minutes. Th variance of the calculated minutes y th arises from the variances of a, b, c is a proximately

$$(7)\qquad \sigma_y^2 = \sigma_a^2 + (x/100)^{2c}\sigma_b^2 + [b\ (x/100 \ldots \ \ell n\, x/100]^2 \ldots$$

$$+ 2b(x/100)^c\,\sigma_{ab} + 2b(x/100)^{c} \ldots (\ell n\, x/100) \ldots$$

$$+ 2b(x/100)^{2c}(\ell n\, x/100)\ \sigma_{bc}$$

For example, take manual handling, pla form to truck.

a = .724
b = .645
c = .787

The correlation matrix (thanks to D Tepping) is

$$\begin{array}{lll} .0437 & & \\ -.0457 & .0510 & \\ .0316 & -.0379 & .0366 \end{array}$$

wherefore Eq. 7 gives, term-by-term, for $x = 5000$ pounds, $y = 15.01$,

$$(8) \quad \sigma_y^2 = .044 + 24.085 + 220.084 - 1.986 + 3.465 - 87.227$$

$$= 158.465$$

The relative standard error of y at this point is

$$(9) \quad \sigma_y / y = \sqrt{158}/15 = .84$$

or 84 per cent. Clearly, the only term of importance is the 3d one, which involves σ_c^2, in agreement with the statement that the slope c is the most important one of the three constants a, b, c. The precision is better at lower weights. The consistency of the results is a better basis than the standard errors for the conclusions reached.

It is important to note that the standard error of y tells us nothing about the stability of the relationship over future years; hence even a 100 per cent coverage of all the platforms in the country, and all the shipments that moved over them during a year, would leave us in the same predicament. Judgment on whether a relationship derived from past data is useful over a period of years is an act of faith, derived from knowledge of engineering and economics, not from standard errors. The ICC might, therefore, with good reason conduct new studies on the platform at intervals of possibly five or six years, to follow trends and to elicit information on extra high weights.

Trends in the proportions of freight moved by hand, by dragline, and by forklift, could perhaps be measured from time to time on a regional and national basis by simple extensions to the ICC's Form 10, which asks carriers for the number of shipments by weight bracket handled over the platform.

FOOTNOTES

[1] Motor Carrier Platform Study, Statement No. 2S51-70, June 1973, Interstate Commerce Commission, Washington.

[2] W. Edwards Deming, SOME THEORY OF SAMPLING (Wiley, 1950), Ch. 7; "On probability as a basis for action," *The American Statistician*, vol. 29, No. 4, pp. 146-152. "The logic of evaluation," being a chapter in Streuning and Guttentag, HANDBOOK OF EVALUATION RESEARCH, vol. 1 (Sage Publications, 1975).

[3] W. Edwards Deming, STATISTICAL ADJUSTMENT OF DATA (Wiley, 1943), p. 37.

[4] L. H. C. Tippett, "Ratio-delay study," *Journal of Textile Institute Transactions*, vol. XXXVI, No. 2, Feb. 1935. R. L. Morrow, TIME STUDY AND MOTION ECONOMY, New York, The Ronald Press, 1946, pp. 176-199; C. L. Brisley, "How you can put work sampling to work," *Factory*, vol. 110, No. 7, July 1952, pp. 84-89; J. S. Petro, "Using ratio-delay studies to set allowance," *Factory*, vol. 106, No. 10, Oct. 1948, p. 94; Marvin E. Mundel, MOTION AND TIME-STUDY (Prentice-Hall, 1970), p. 128; A. C. Rosander, CASE STUDIES FOR SAMPLE DESIGN (Marcel Dekker, 1977), Chapters 14, 15, 16.

[5] W. Edwards Deming, "On some statistical aids toward economic production," *Interfaces*, vol. 5, 1975, pp. 1-15.

APPENDIX

Table I. Estimates of parameters and of their standard errors for movements on the platform

Movement	a	σ_a	b	σ_b	c
	minutes		minutes		minutes
		Manual, no dragline or dragline not used			
T to P	1.314	.06	.352	.09	.942*
P to T	.724	.21	.645	.23	.787
T to T	.280	.11	1.964	.34	.682
		Manual at terminals where dragline is used			
T to P	.562	.26	.718	.27	.875
P to T	.494	.34	.624	.33	.850
			Fork-lift		
T to P **	.60		1.00		.53
P to T **	.60		.66		.55
T to T	1.195		.787		.700

* Two points for weights 17 and 36 excluded as outliers.
** The lines for these movements were fitted by eye, as the data were not amenable to least squa

Table II

Total minutes required to handle freight on the platform by method and movement, for selected weights calculated by Eq. 1

Weight of shipments in pounds	Truck to platform		Platform to truck		Truck to truck	
	Minutes total	Minutes per cwt	Minutes total	Minutes per cwt	Minutes total	Minutes per cwt
	Manual handling, no dragline or dragline not used					
	a=1.31 b=.35 c= .942		a=.72 b=.65 c=.79		a=.28 b=1.96 c=.68	
50	1.49	2.98	1.10	2.19	1.50	3.01
100	1.66	1.66	1.37	1.37	2.24	2.24
500	2.90	.58	3.04	.61	6.14	1.23
1000	4.37	.44	4.73	.47	9.66	.97
2500	8.57	.34	8.99	.36	17.77	.71
5000	15.26	.31	15.01	.30	28.31	.57
7500	21.75	.29	20.41	.27	37.20	.50
10000	28.11	.28	25.43	.25	45.18	.45
15000	40.57	.27	34.76	.23	59.44	.40
	Manual handling at terminals where dragline is used					
	a= .56 b=.72 c=.88		a=.49 b=.62 c=.85			
50	.95	1.90	.83	1.67		
100	1.28	1.28	1.11	1.11		
500	3.53	.71	2.93	.59		
1000	6.02	.60	4.88	.49		
2500	12.79	.51	10.05	.40		
5000	23.07	.46	17.73	.35		
7500	32.73	.44	24.82	.33		
10000	41.99	.42	31.56	.32		
15000	59.76	.40	44.35	.30		
	Fork-lift					
	a=.60 b=1.00 c=.54		a=.60 b=.66 c=.54		a=1.20 b=.78 c=.70	
50	xxx	xxx	xxx	xxx	xxx	xxx
100	xxx	xxx	xxx	xxx	xxx	xxx
500	2.98	.60	2.17	.43	3.61	.72
1000	4.07	.41	2.89	.29	5.11	.51
2500	6.29	.25	4.35	.17	8.62	.34
5000	8.87	.18	6.06	.12	13.26	.27
7500	10.89	.15	7.39	.10	17.22	.23
10000	12.62	.13	8.53	.085	20.79	.21
15000	15.57	.10	10.48	.070	27.22	.18