

Computerized load planning for railcar shipments of large rolls

Robert W. Haessler

If two railcars are to be used to ship paper rolls, the carload and incentive rates make it more economical to load one heavily and the other lightly.

Many large rolls such as those used in the corrugated industry are shipped in railcars, because the economics of long-haul transportation still favor rail shipments. When shipping rolls of paper by railcar, the relationship of weight to volume is such that volume is the critical factor in determining the amount of product that can be shipped in a single railcar.

In some cases, possibly as a result of policy decisions, a railcar shipment may be no more complicated than loading 20 or 22 rolls on end on the floor of the car. In many situations, however, there are opportunities to reduce shipping costs by using the second level of the railcar. One way to use the second level is to vertically stack rolls that are narrow enough to permit such an arrangement.

A more common opportunity for wide rolls is the use of combination, or T-loading, of rolls. This technique involves laying 1-9 rolls on a base of twice as many vertical rolls of equal height. Although combination loading is widely used, it is not universally accepted. There are legitimate concerns regarding product damage and operator safety during loading and unloading. Care must be taken to block and brace the rolls properly to avoid accidents.

If opportunities for using the second level do exist, a mill manager interested in minimizing freight cost by maximizing the weight shipped in each railcar must solve what appears to be a three-dimensional packing problem. Generally, three-dimensional packing problems are difficult, and there is little published research on this topic. Fortunately in this case, the problem can be simplified to a one-dimensional problem by specifying the number of floor spaces available.

Here, we look at a procedure for planning railcar shipments of large rolls. The mathematical model is given in the appendix. In this procedure, based on linear programming, we assume that the number of floor spots for a railcar of any size is easily obtained. We also assume that floor rolls will be stacked on end.

The procedure is generalized so that it can be used in a variety of ways. It can be run at order entry time to

suggest how to size the order to maximize the use of space or to determine the mix of railcars that will minimize total shipping cost for an order. It can be used at the time of shipment to assign the railcars actually available (assuming there is more than one size) to the orders to be shipped or to help sequence the trim patterns to facilitate direct loading of the rolls into the railcar. Finally, it can be used in a study to determine the impact that changing roll widths would have on freight cost.

The procedure can be run also without using combination loading, so it could be used to assess the potential savings in freight cost to be gained from implementing combination loading.

Loading one railcar

The simplest problem is an order for which large rolls of varying width but similar diameters are to be shipped in a single railcar of known dimensions. If the problem is considered at order entry time, the first question is whether or not all the rolls on the order can be shipped in one railcar. Second, how can we take full advantage of the available space?

If all the rolls will not fit in the railcar, perhaps the order should be reduced before trimming to avoid having to leave rolls on the loading dock. If more rolls will fit in the railcar than the order calls for, perhaps the order should be increased to utilize the available space and avoid shipping "air," which increases overall freight costs per ton.

There may be cases in which one roll of some size could be subtracted from the order and two rolls of some smaller size can be added, lowering the overall freight cost per ton. This gets into the issue of trading off freight cost against customer service. These questions must be resolved on a case-by-case basis. For our purposes, we will assume that the user can control whether or not the roll is deleted from the order or added to it.

Carload and incentive rates

The economic incentive for maximizing the weight of a single railcar shipment can be seen in Fig. 1. Rarely will a shipment that does not utilize the second level of the railcar weigh enough to get any tonnage shipped at the incentive rate. As the figure shows, the only way to reduce

Haessler is associate professor at University of Michigan, School of Business, Ann Arbor, Mich. 48109

the average cost per ton below the carload rate is to load more than the weight at which the incentive rate begins to apply to all additional tons. If two identical railcars are used to ship an order, the total cost can be reduced by loading one heavily and the other lightly, rather than loading each equally.

To minimize freight costs, the objective is to use as much of the second level of the railcar as possible. Vertically stacking one roll on top of another will permit two rolls to be shipped per floor space. Assuming the roll sizes ordered are between 50 and 98 in., vertical stacking will be better than rollback loading in terms of increasing the weight in the railcar.

For a computer-based, load-planning system to be useful, the solutions generated must satisfy the ground rules for shipments set by both the mill and the customer receiving the shipment. Because these ground rules may vary from mill to mill, they should be read in as parameters so they can be easily controlled by the user of the program. The following ground rules are those followed by a major U.S. producer of linerboard.

1. One roll can be stacked vertically on top of another provided there is a 4-in. clearance with the top of the railcar everywhere but the four floor positions in the doorway, where there must be a 12-in. clearance.
2. Two rolls can be laid across the top of four rolls in either end of the car, provided there is a 4-in. clearance at the top of the car. The four rolls forming the platform for the rollbacks must all be of the same height. A maximum of seven rollbacks can be placed in a 50-ft car, and nine can be placed in a 60-ft car. (This mill does not lay a single roll across a base of two rolls because of stability problems.)

The use of combination loading at this mill also requires the availability of blocking rolls that extend at least 9 in. above the base rolls. Two blocking rolls would be needed if combination loading is used in one end of the vehicle, and four would be needed if it is used in both ends.

Example problem

This example shows how the mathematical model can be used at order entry time to size the order to minimize freight cost. The usable railcar dimensions are

Width: 9 ft 6 in., or 114 in.

Length: 50 ft 6 in., or 606 in.

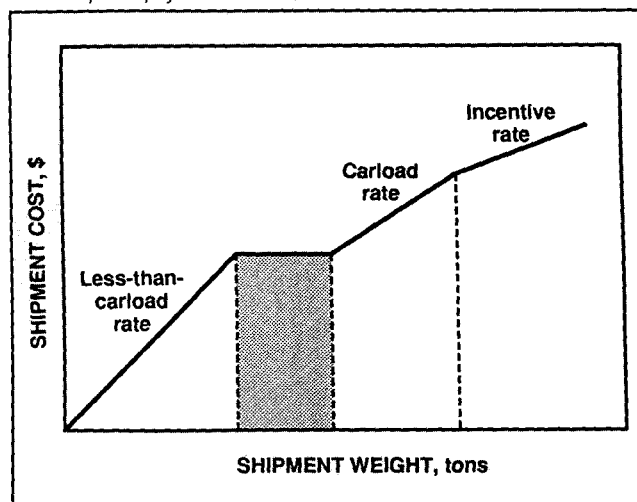
Height: 11 ft 2 in., or 134 in.

This is a 50-ft railcar that has a maximum weight capacity of 160,000 lb. The original customer order is for the following 58-in.-diameter rolls:

- 10 rolls of 82 in.
- 4 rolls of 78 in.
- 6 rolls of 74 in.
- 4 rolls of 70 in.

The floor capacity of the car is 20 rolls in two columns of 10, slightly offset, because the roll diameter is more than half the width of the railcar. There are no vertical stacking possibilities because the rolls are too wide, but rolls can be placed horizontally on top of both the 71-in. and 69-

1. Though the shipment costs rise with more weight, the increase is not as sharp, meaning that the costs per ton are less. In the shaded region, it is cheaper to pay the carload rate.



in. rolls. A 58-in. diameter roll on top of the 71-in. roll would give a total height of 129 in., leaving a clearance of 5 in., which is much more than the minimum needed.

The 82-in. rolls exceed the 9-in. blocking requirement for combination loading using the 71-in. rolls as a base. Based on the original order quantities, three wide rolls can be laid on top of the six 71-in. rolls, and two wide rolls can be laid on top of the four 69-in. rolls. This would be a total of 25 rolls (20 + 5), one more than ordered.

However, there is room for two more rolls in the 50-ft car. If two 71-in. rolls are added, the capacity is increased to 26 rolls, and the two 71-in. rolls can be added without dropping any ordered rolls. Also, if one 82-in. roll is dropped from the order, two more 69-in. rolls can be added, increasing the total number of rolls in the car to 27 by increasing the rollbacks to 7, which is the maximum.

The net effect of all this adjusting is to increase the weight of the shipment by about 12,000 lb. This is only a suggested increase in the order, however. Considerations pertaining to the specific case will dictate if these changes can be made.

Two or more railcars

If the order is to be shipped in three railcars all the same size, the right-hand side values of Constraints 3, 4, and 5 in the mathematical model must be simply multiplied by 3. Once the solution is found, the rolls can easily be assigned to railcars in an unbalanced way such that each railcar has at least the minimum weight for the carload rate to apply. Once that is done, the second objective is to get as much tonnage as possible in the range for the incentive rate to apply.

If two different railcar sizes are available, the mix that maximizes the total shipment cost can be found by enumerating over each combination of railcars that can ship the order. If Car 1 is a 50-ft car, and Car 2 is a 60-ft car, the following combinations can be tried:

- 4 of Car 1, 0 of Car 2
- 3 of Car 1, 1 of Car 2

- 2 of Car 1, 2 of Car 2
- 1 of Car 1, 3 of Car 2
- 0 of Car 1, 4 of Car 2.

To consider two different railcar sizes simultaneously, the variables have to be defined for each railcar. For example, XR_{jk} would be the number of rollbacks using pattern j in railcar k . Constraints 3, 4, and 5 in the model would have to be stated for each railcar being used. Again, the assignment of rolls to cars should unbalance the cars to get as much tonnage in the incentive range as possible. Order fulfillment can be a problem here and may require that some of the railcar combinations be dropped. The best solution can be selected based on both order fulfillment and the average cost/ton of all rolls shipped.

This procedure can also be used to assign railcars to orders at the time of shipment. In this case, because the rolls are on hand, there may be no way to change the order. The issue here is finding the best way to deal with what is available.

Suppose that 10 orders are to be shipped and that two 60-ft high-cube and eight 50-ft regular railcars are available. Assume either that no previous railcar load planning has been done or that the mix of railcars is different than expected. The problem here is to allocate the two 60-ft railcars to the orders that can make the best use of their height and thereby maximize the tonnage in the incentive rate range. This allocation can be done easily by systematically increasing or decreasing the minimum weight required to use a 60-ft railcar until the number used equals the number available.

Conclusions

Although vehicle loading problems in general appear to be quite complex and intractable, it is possible in certain cases to take advantage of the rate structure, solve the problem, and save money. A linear programming-based procedure can help determine how large rolls can be loaded into railcars to maximize the weight shipped.

This carloading procedure was originally designed for a linerboard producer and was intended to be run at order entry time to determine if the incoming orders represented full carload quantities. Those orders that are for full carload amounts are accepted as entered. Those orders that are for less than full carload amounts are increased to make better use of the railcar and reduce the freight cost per ton shipped. Those orders that are more than some number of full carloads are flagged for possible reduction to avoid having to store finished goods because of the made-to-order nature of the business.

Once the basic tool has been developed, it can be used for a number of purposes, including studies to determine the impact of changing roll widths or changing loading policies.

Appendix : mathematical model

The mathematical model is formulated to minimize the number of floor spots required in a single railcar. The original order calls for a minimum of R_i rolls of width W_i for $i = 1, \dots, m$, where m is the number of sizes ordered. All the rolls are for nominal diameter D . Let RCH be the

height of the railcar. Rolls loaded horizontally on the second level are referred to as rollbacks.

Minimize

$$Z = \sum_j XS_j + \sum_j XD_j + 2 \sum_j XR_j + \sum_j X_j \quad (1)$$

subject to

$$\sum_j AS_j XS_j + \sum_j AD_j XD_j + \sum_j AR_j XR_j + \sum_j A_j X_j \geq R \quad (2)$$

$$\sum_j XS_j + 2 \sum_j XR_j \leq FC - 4 \quad (3)$$

$$\sum_j XD_j + \sum_j X_j \geq 4 \quad (4)$$

$$\sum_j XR_j \leq RC \quad (5)$$

and

$$XS_j, XD_j, XR_j, X_j \geq 0, \text{ integer } XR_j \neq 0$$

where

XS_j = the number of stacks of rolls in locations other than the doorway using pattern j , the doorway stacking pattern

XD_j = the number of stacks of rolls in the doorway using stacking pattern j

XR_j = the number of rollbacks using rollback pattern j

X_j = the number of rolls with nothing on top of them

AS_j = a vector of elements AS_{ij} defining a stacking pattern such that

$$\sum AS_{ij} W_j \leq RCH - 4$$

$$AS_{ij} \geq 0, \text{ integer.}$$

AD_j = a vector of elements AD_{ij} defining a stacking pattern for the doorway such that

$$AD_{ij} W_j \leq RCH - 12$$

$$AD_{ij} \geq 0, \text{ integer.}$$

AR_j = a vector of elements AR_{ij} defining a rollback pattern such that

$$\sum_i AR_{ij} = 3$$

$$\sum_i \delta(AR_{ij}) = 2$$

$$AR_{ij} W_j / 2 < RCH - (4 + \text{diameter}) \text{ for all } i$$

$$AR_{ij} \geq 0, \text{ integer}$$

where

$$\delta(a) = 0 \text{ for } a = 0$$

$$\delta(a) = 1 \text{ for } a > 0$$

A_j = a vector of elements A_{ij} such that

$$A_{ij} = 1 \text{ for } i = j$$

$$A_{ij} = 0 \text{ otherwise}$$

R = a vector of order requirements, R_i

FC = the number of rolls that can be placed on end on the floor of the car

RC = the maximum number of rollbacks that can be placed

in the car. If rollbacks are not being used, then this value should be set to zero. If no blocking rolls are available, then this value must be set to zero.

If the integer restriction is relaxed, this problem can be solved easily using a Gilmore-Gomory^{1,2} type of linear programming code. The minimum four-roll base for rollbacks can be met by not permitting a size with requirements less than four from being used in a rollback pattern. Because the patterns are not complex, the linear programming answer will usually be integer valued. If it is not, it is easy to round to integer values.

The value of Z from Eq. 1 specifies the number of floor spaces needed to meet the order requirements as specified. If Z is greater than FC , the number of floor spaces available, the order must be reduced, or another railcar size must be used. If Z is less than FC , the order can be increased to make use of the open spaces that are available, or a smaller car size can be considered. □

Received for review Nov. 1, 1989.

Accepted Nov. 27, 1989.

¹Gilmore, P. C. and Gomory, R. E., Operations Research 9: 848(1961).

²Gilmore, P. C. and Gomory, R. E., Operations Research 17: 863(1963).