Decreasing the Cost of Hauling Timber

Through Increased Payload

by

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(ABSTRACT)

The potential for decreasing timber transportation costs in the South by increasing truck payloads was investigated using a combination of theoretical and case-study methods. A survey of transportation regulations in the South found considerable disparities between states. Attempts to model the factors which determine payload per unit of bunk area and load center of gravity location met with only moderate success, but illustrated the difficulties loggers experience in estimating gross and axle weights in the woods. A method was developed for evaluating the impact of Federal Bridge Formula axle weight constraints on the payloads of tractor-trailers with varying dimensions and axle configurations.

Analysis of scalehouse data found log truck gross weights lower on average than the legal maximum but also highly variable. Eliminating both overloading and underloading would result in an increase in average payload, reduced overweight fines, and improved public relations. Tractor-trailer tare weights were also highly variable indicating potential for increasing payload by using lightweight equipment.

Recommendations focused first on taking steps to keep GVW's within a narrow range around the legal maximum by adopting alternative loading strategies, improving GVW estimation, and using scalehouse data as a management tool. When this goal is achieved, options for decreasing tare weight should be considered. Suggestions for future research included a study of GVW estimation accuracy using a variety of estimation techniques, and field testing of the project recommendations.

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Introduction

The transportion of timber[1] from the woods landing to the mill or concentration yard represents a significant portion of the raw material cost to the forest products industry. Transportation cost is dependent on a number of variables but can often approach 50 percent of the total harvesting cost (Smith, 1981). In 1983, 64 percent of southern wood fiber requirements were delivered by truck, and this is projected to increase to 66 percent by 1988 (A.P.A. 1984). Wood delivered by other means must usually be trucked for some part of its journey so keeping trucking costs under control is of great interest to the forest products industry.

Several factors distinguish the hauling of timber from the transportation of most other commodities. Timber is exceedingly heterogeneous in terms of its size, shape, density and center of gravity location. It is loaded at remote temporary landings, where facilities such as a weigh bridge are not available for controlling gross vehicle weight (GVW). In addition, load redistribution after loading is difficult. Log trucks and trailers must be capable of withstanding the abuse of low quality woods roads and yet be efficient and safe on public highways. Haul distances are relatively short, seldom exceeding 100 miles. A survey in Virginia found the average one-way haul distance to be approximately 38 miles (Shaffer, 1984).

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[1] For the purposes of this dissertation the term *timber* refers to unprocessed forest products in roundwood form.

In recent years, several trends have emerged in timber hauling. Transportation by log truck is becoming increasingly expensive. Costs consist primarily of three components: labor, fuel and vehicle ownership and operating expenses. With the exception of a recent downturn in fuel prices, the real cost of all three of these elements has been increasing. Many other areas of industrial activity face the same cost increases, but often these are offset by gains in productivity. The productivity of a log truck is determined largely by its average speed and payload, length of haul, and loading, unloading and turn-around times. Since GVW and travel speed are restricted by law, and loading, unloading and turn-around time are beyond the driver's control, transportation costs have inevitably increased.

A second trend has been the movement to increasingly restrictive laws governing vehicle weights on public roads. The insistence of the Federal Government that states enforce the Federal Bridge Formula and intense lobbying by transportation groups for special treatment have left the transportation regulations of many states in disarray. Enforcement of the Federal Bridge Formula necessitates a far more exacting distribution of weight over the vehicles axles than may be possible with existing trailer fleets. For this reason, many states have instituted grandfather clauses for existing vehicles, but these serve only to delay the day of reckoning. The authorization of alternative vehicle configurations has added to the confusion.

Changes have also occured in the characteristics of timber hauled by log trucks. These changes emanate from two sources. First, the raw material base of the forest products industry in the South is shifting gradually from natural to plantation stands. In general, this has resulted in harvested trees being smaller and more limber. With smaller trees there is a tendency for loads to reach the legal height limit before the maximum gross vehicle weight is reached. (Izlar, 1983). Second, the form in which the material leaves the woods has shifted away from shortwood[2] towards tree-length longwood. In the South, the percentage of roundwood fiber delivered by truck in tree-length form was 48 percent in 1981, 53 percent in 1983 and is projected to reach 62 percent by 1988 (A.P.A.

[2] Shortwood is defined as wood cut to lengths of 8 feet or less.

1982a and 1984). In many cases this change has been accomplished simply by altering the bunk arrangement on existing trailers. In the short term this is the least expensive solution, but there may be long-term opportunity costs associated with using trailers for a purpose for which they were not designed.

The logging industry is, of necessity, becoming more image conscious, and the hauling phase of a logging operation is the most visible to the public. While the sight of a truck load of tree-length stems may gladden the heart of the logger, to other road users it may be an untidy and dangerous looking spectacle (Figure 1). The industry is gradually recognizing that it must uphold not only the letter, but also the spirit of the law if the trend toward more restrictive hauling regulations is to be halted (Thomson, 1984).

Given these changes in the operating environment of the timber transportation industry, what can be done to keep costs under control? Koger (1981) listed 22 factors which earlier authors had identified as affecting truck productivity. Fourteen of these dealt with road conditions and legal restrictions which are largely out of the control of timber haulers. The importance of maximizing payload was not addressed specifically. Smith and Tse (1977) considered the most useful suggestions for increasing productivity and reducing costs to be:

1. Load the vehicle to capacity every trip.
2. Balance the trade-off between road standard, truck speed and maintenance of the road and truck to achieve lowest cost.
3. Reduce delays through improved dispatching and careful selection of the number of trucks.
4. Extend the life of the vehicle.
5. Consider preloading or other different operating techniques.

From the point of view of the hauler, a rational strategy would be to minimize per mile operating costs and maximize payload. Operating costs depend greatly on the selection of equipment, the repair and maintenance program and driving style. The selection of specifications for truck power

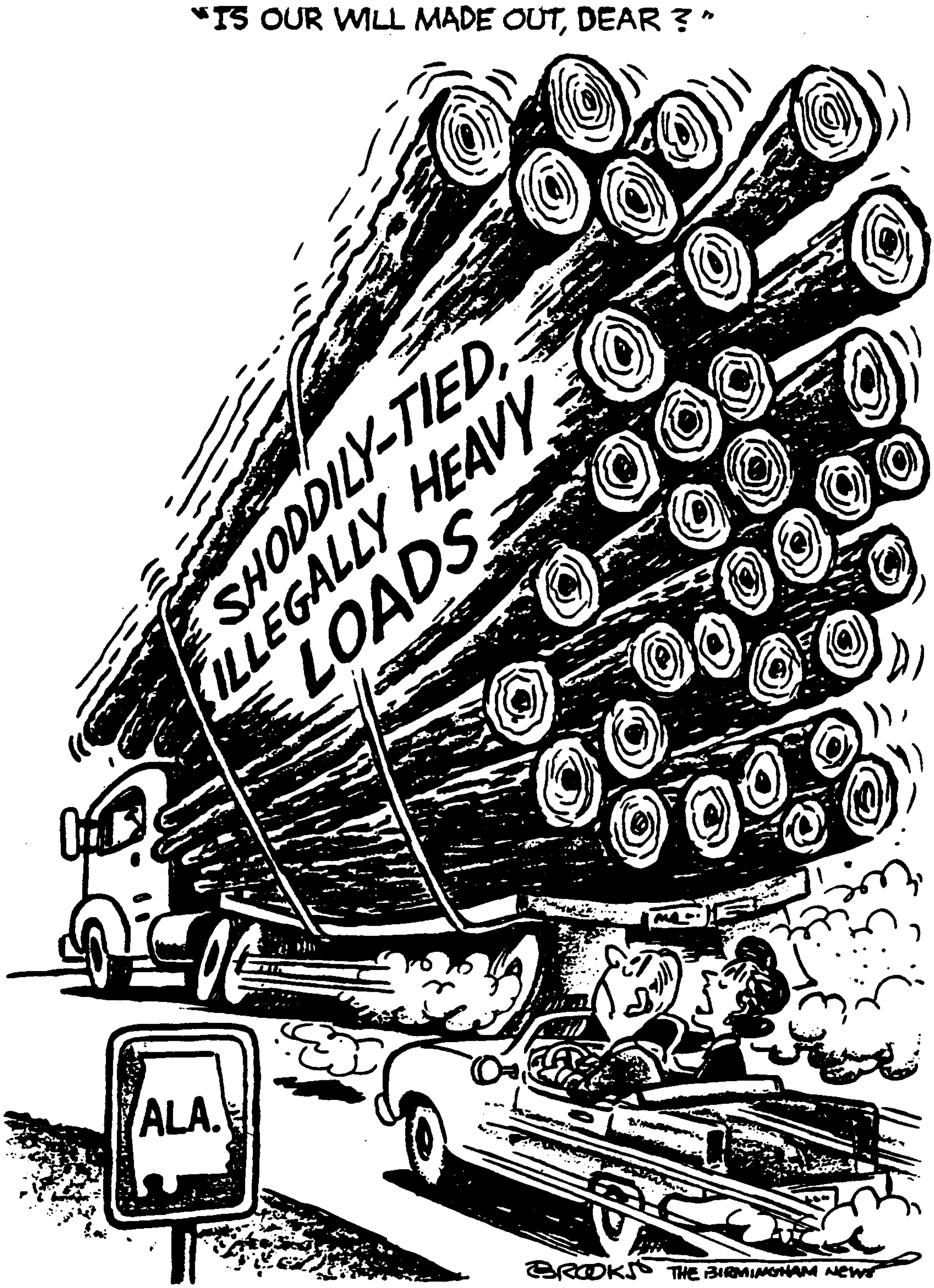


Figure 1. Cartoon Illustrating Public Perceptions of Timber Hauling: From The Birmingham News.

unit and drive train components is a well developed science. Major diesel engine manufacturers use sophisticated computer models to match equipment specifications to customer needs. Improvements in this area can be best achieved by working closely with such companies and will not be considered in this research. The thrust of this research, therefore, is to investigate the use of increased payload to reduce timber transportation costs.

The payload of a log truck is usually limited for one of three reasons. First, the truck may be loaded up to the point where it reaches the legislated GVW or axle weight limits. In this case payload can be increased by decreasing the weight of the truck, configuring it to so that axle weight limits are not exceeded before the GVW limit is reached, or by changing the legal weight limits. Second, payload may be limited due to uncertainty about how much wood has been loaded onto the truck. The average GVW may be below the legal limit because fines on occasional overweight loads make it uneconomical to aim for higher payloads. Solutions to this problem would include onboard scales and other devices and techniques which improve the loader operator's weight estimates. The third limit on payload pertains when the load reaches legislated limits on height, width or length before the GVW limit is reached. The options here are to either adopt a different loading strategy, which will allow a greater load in the same space, or design the truck with increased available loading space.

The objective of this research is to investigate the potential for increasing payload through modifications to existing equipment, design of new equipment, and changes in operating procedures.

Literature Review

A computer search for timber transportation literature was conducted using the Commonwealth Agriculture Bureau and AGRICOLA databases and was supplemented by a manual literature search. The review is organized in five sections:

1. Contraints on timber hauling.
2. Current and proposed truck configurations.
3. Transportation cost models.
4. Weight distribution models.
5. Loading techniques.

Constraints on Timber Hauling

Legal Constraints

Timber transportation over public roads is regulated at federal, state and sometimes county levels. At the federal level, trucking is regulated through two bodies: the Interstate Commerce Commission (ICC) and the Federal Highway Administration's Department of Transportation (DOT). Most unmanufactured forest products are included in a list of agricultural commodities which are exempt from ICC regulations. The list includes "...trees which have been felled and those trimmed, cut to length, peeled or split but not further processed..." (APA, 1981; Izlar, 1980). The DOT is charged with regulating traffic on the interstate highway system. DOT regulations cover safety (U.S Department of Transportation, 1976) and weight and dimension restrictions. Congress recently overhauled trucking regulations with the Surface Transportation Assistance Act of 1982 (Izlar, 1983).

Attempts to change trucking regulations have greatly stimulated timber transportation research. A proposal to change axle spacing requirements in Oregon prompted Dykstra and Garland (1978) to conduct a survey of the state's log-trucking industry. With the resulting information, it was projected that increasing the minimum tandem axle spacing from 18 feet to 36 feet would increase the annual cost of hauling timber over public roads in Oregon by $14 million, while an increase to 30 feet would cost $1.48 million (Dykstra and Garland, 1977; Garland and Dykstra, 1978). Watson and Matney (1981) examined the influence of Mississippi's legal truck weights on log transportation costs in comparison to neighboring states. It was estimated that it cost $19.90 per MBF more to produce and deliver Mississippi lumber to Alabama distributors than it did for Alabama lumber transported over the same distance due to legal weight differentials. Leister and von Segen (1979) evaluated the impact of proposed restrictions on tree length hauling in Arkansas. The proposal was to limit load length to 75 feet, limit load overhang from the rear of the trailer to 15 feet, and to adopt a minimum clearance between the load and the ground of 2 feet. The authors estimated that the 15 foot overhang limit could result in 15,583 cords of wood being left to rot in the woods each year.

It is clear from the literature that trucking regulations have an immense impact on both the cost of timber transportation and the vehicle configurations used. Federal and state trucking regulations affecting timber transportation were documented in the American Pulpwood Association's Southern Guide to Federal and State Trucking Regulations (APA, 1981). However, due largely to the Surface Transportation Assistance Act, much of this information is now out of date. A prerequisite to meeting the objectives of this research, therefore, was to conduct a survey to update this information.

Tree Constraints

Tree characteristics can constrain payload in two ways. First, the center of gravity of loads of tree length material may be in such a position that trailer tandem axle weight limits are reached before GVW limits (Watson and Matney, 1981). Second, small trees, which have low specific gravity, low stacking densities, and short load lengths, result in the legal height limit being reached before the GVW limit (Izlar, 1983). Thus, the tree characteristics which are of primary interest are center of gravity location and the weight of trees that can be packed inside a given volume.

Several investigators have developed prediction equations for tree center of gravity location. Steinhilb and Erickson (1970; 1972) estimated center of gravity prediction equations for quaking aspen, red pine, white spruce and balsam fir. The independent variable, center of gravity distance from the butt, was predicted using tree height and the square of tree height. Ford (1976) developed equations for various Appalachian hardwood species using more complex model forms. Lynch

(1977), working with loblolly pine, experimented with nine model forms for predicting center of gravity location. The best model for prediction was of the form:

$$CG = b_0 + b_1 H$$

where CG was the center of gravity distance from the tree butt, and H was total tree height.

Stems transported on a truck may be trimmed to various top diameters and may have had a log removed from the butt end of the tree. To account for this in center of gravity prediction, Watson and Matney (1984) developed a model based on a tree taper equation by Matney and Sullivan (1979). Their technique was to divide the tree into short sections and calculate the sum of moments for each section about the butt of the tree. Dividing by total weight then gives the tree's center of gravity location. Since the sections were equal in length, the square of the diameter at the section mid-point was used as a proxy for section weight. The assumption was made that green density is constant over the length of the stem, but the authors showed how the model can be generalized to include a density function. The model was extended to predict the center of gravity for a load of butt aligned stems using Montecarlo simulation. A problem with this model is that it demands a large number of computations, especially since the height to the specified top diameter must be solved for iteratively.

The weight of butt indexed stems which can be loaded inside a given bunk area is greatly influenced by the tree stacking density. Lavoie (1980) defined the coefficient of effective occupancy (CO) as the basal area occupied by the tree butts divided by the available loading area. Trials using stems sorted by diameter class indicated that CO is a linear function of butt diameter (D) of the form:

$$CO = b_0 + b_1 D$$

No hypothesis was advanced to explain this relationship and the model has the unfortunate property of allowing CO to exceed 100 percent. Using these estimates of CO, a volume equation and an assumed specific gravity, maximum loads were predicted for a range of tree and bunk sizes.

System Constraints

System constraints on log-trucking include the form of the product produced by the harvesting system, the loader used to load the truck, the road network the truck must travel, and the woodyard unloading and processing systems.

The product form produced in the woods depends largely on mill specifications, which can vary immensely from one processing plant to another. Older southern pulpmills were designed to take 5′ 3″ shortwood which would fit safely on a rail car (Izlar, 1983). The trend in recent years has been to convert these woodyards to handle random-length and tree-length longwood (APA, 1984). Sawmills may take log-length or tree-length wood.

A 1979 timber producer census found the *big stick loader* to be the most common loader in the South, though the volume handled by this machine type is relatively small (Weaver et. al. 1981). Of loaders capable of handling tree-length material, the hydraulic knuckleboom loader is the most common, followed by the front-end loader.

Roads may constrain transportation because of their gradient, alignment or surface quality. Della-Moretta and Hanna (1978) developed a model to predict the off-tracking of trailer wheels around curves. The intent was to calculate the required curve widening when building a road, but the model would serve equally well to calculate the maximum trailer length which could negotiate existing roads.

Three types of tree-length unloading machines are common in southern mills, the circular-boom loader, the mobile log loader, and the portal crane (Martin and Valia, 1979). Each type may have different requirements for load clearance above the trailer frame and these requirements may be different from mill to mill for the same machine.

Mechanical and Safety Constraints.

Mechanical and safety constraints are pertinent to both the construction and operation of the log truck. Some of these are mandated by law, but many are at the discretion of the operator and manufacturer.

An important consideration in trailer manufacture is the selection of design loadings. Baas and Stulen (1985) conducted dynamic loading tests on a log truck equipped with strain gauges. From this data they recommended design dynamic loadings of 2.0 g.[3] vertically, 1.0 g. foreward, and 0.5 g. rearward and laterally. In addition, they found that loading and unloading can result in forces equivalent to 6.0 tonnes applied horizontally and inward at the top of the standards. Truck design criteria developed by Fontaine Truck Equipment Company from dynamic loading tests are 2.5 g. vertically, 2.0 g. fore and aft, and 0.5 g. laterally (Bixler, 1985).

Many logging industry organizations publish guidelines on truck safety. Concerns common to all of these are loading safety and the use of load securing devices (APA, 1982b; Stulen, 1984; Lavoie, 1981).

Log-Truck Configurations

A log-truck configuration is characterized by the number and spacing of axles, the number and location of articulation points, and the arrangement of bunks which hold the load. In this review, we will consider the configurations which are currently predominant in the South, configurations

[3] g = acceleration due to gravity.

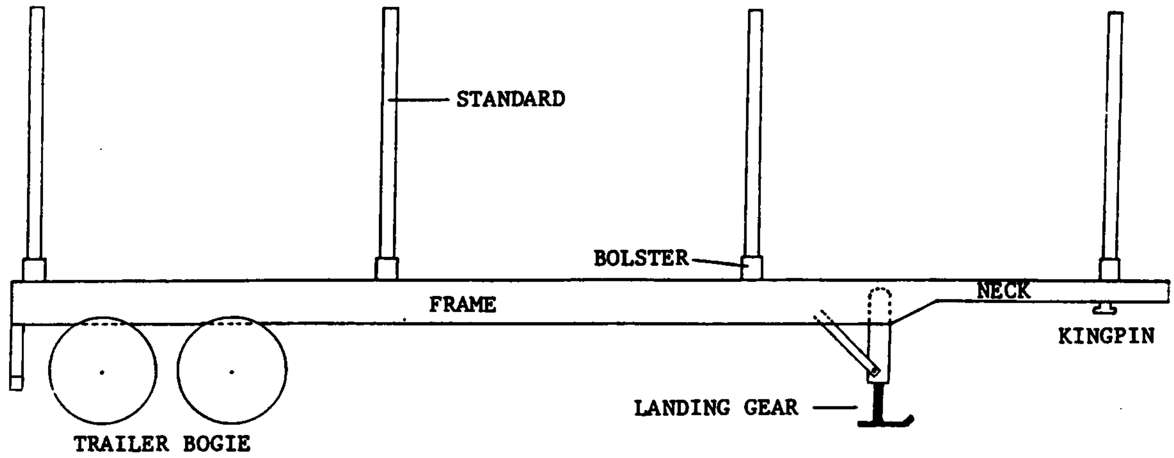
in use in other parts of the U.S. and the world, and configurations which have been proposed but not yet built.

Literature dealing directly with truck configurations in the South is sparse and consists mostly of equipment reviews in trade magazines. Southern Loggin' Times (Anon, 1984a), in a review of logging trailers, listed 38 manufacturers, of which 22 are located in the South. In another trade review, Timber Harvesting (Anon, 1984b) listed 11 manufacturers of truck tractors which might be used to haul logging trailers. From these reviews, conversations with transportation managers, and observations at mill woodyards, it is apparent that the standard for treelength roundwood highway transportation in the South is a three axle tractor and two axle semi-trailer. The tractors vary in wheelbase and cab style, but almost invariably have a single steering axle with single wheels, and tandem drive axles with dual wheels. There is considerably more variability among log trailers but the most common types are:

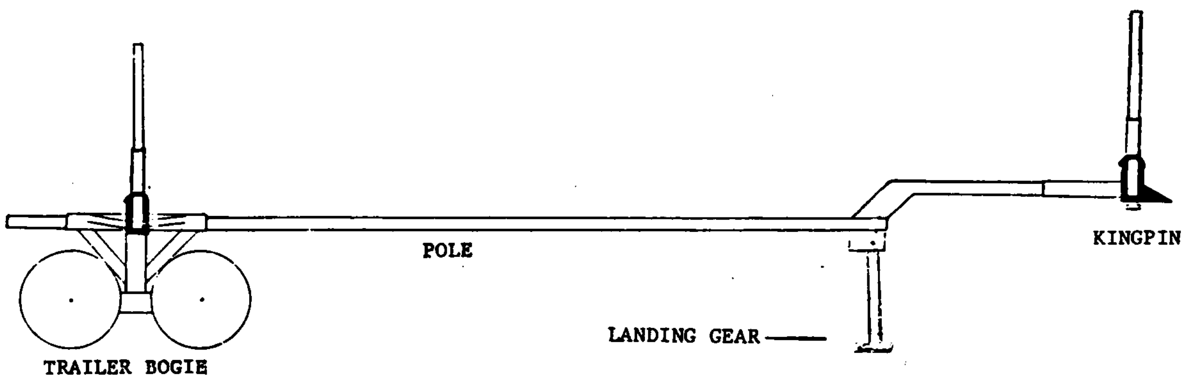
1. Frame Trailers: a rigid frame attaches to the truck by means of a kingpin and is supported at the rear by a tandem axle set or, less commonly, a group of three axles. The frame is designed to support loads at intermediate points between the kingpin and axles. Various bunk arrangements are used to transport shortwood, log length and tree-length material (Figure 2).

2. Pole Trailers: the trailer is attached to the truck by means of a pole which has the function of steering the trailer bogie and does not bear vertical loads. A variation has a bolster over the landing gear so that the trailer can be set out without exerting bending moments on the pole.

Three types of log trucks are predominant in the western United States (Dykstra and Garland, 1978). The most common is the three axle tractor and two axle semi-trailer. These differ from most southern pole trailers in the location of the point of articulation. One bunk is mounted over the tractor axles on a swivel base and the second is mounted similarly over the trailer axles. The tractor frame terminates in a rigid stinger which attaches to the trailer by means of a compensating head



DOUBLE-BUNK FRAME TRAILER



POLE TRAILER

Figure 2. Typical Frame and Pole Trailers Used in the South.

which slides in and out. This "stinger steer" arrangement allows the vehicle to negotiate tighter curves, since moving the point of articulation towards the trailer wheels reduces off-tracking (Smith, 1981). The arrangement also has the advantage that the trailer can be loaded on the tractor for the return haul. The self loader truck is similar except that the tractor frame is extended to allow a hydraulic knuckleboom loader to be mounted behind the cab. The short logger consists of a three axle truck and two axle full trailer. Both truck and trailer have two bunks so that each can carry a load of short logs.

Smith (1981) compared three configurations for long distance highway hauling in Canada. The five axle configuration, a three axle tractor and two axle pole trailer, had an average GVW of 95,400 pounds. A six axle configuration, with an average GVW of 112,777 pounds, consisted of a three axle tractor and three axle full trailer. The third configuration was a three axle tractor pulling a train of two semi-trailers and had a GVW of 126,053 pounds. In spite of the large difference in payloads for these configurations, no substantial difference was found between their associated unit transportation costs.

Gordon (1980) conducted an economic comparison of 17 different five and six axle configurations for operation in New Zealand. The combinations of axle groupings and articulation points, shown in Figure 3, are novel by comparison to those currently seen in the southern United States.

Wilson (1980) proposed a radical new trailer design for hauling longwood. The triaxle trailer would have a capacity of 15 cords with the tree butts to the rear and the tops extending over the tractor cab. The design has the advantages that the load is not cantilevered over the rear of the trailer and the full backboard could have a complete set of lights, allowing night operation. A serious problem with the design is that it would require a substantial increase in the legal limits on GVW and length in most states.

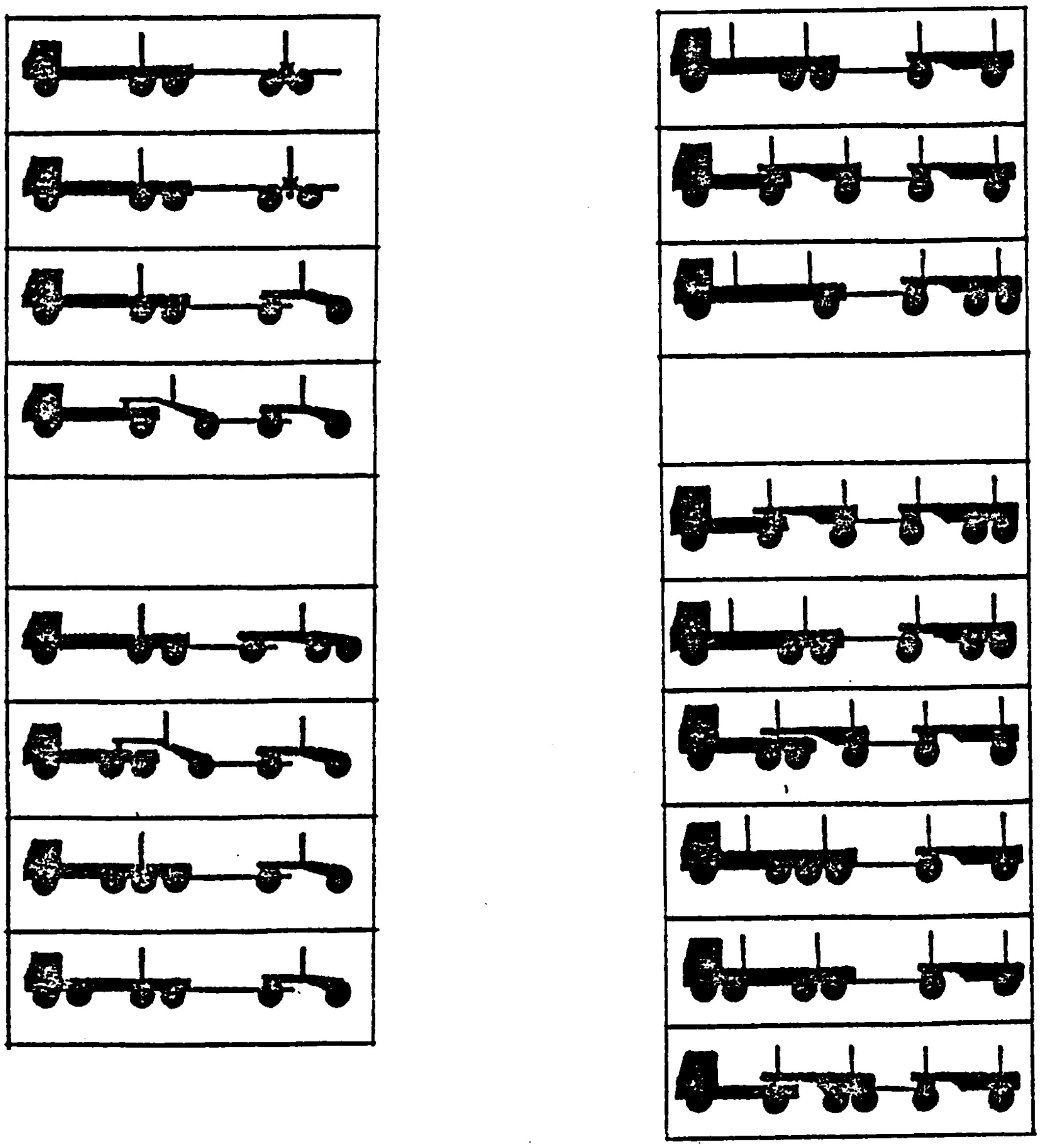


Figure 3. Log Truck Configurations Analyzed by Gordon for Use in New Zealand: (Gordon, 1980)

Transportation Economic Models

Economic modeling is an integral part of much transportation research and transportation cost is frequently of primary concern. Such models can be very simple or highly complex, depending on the kind of comparison they are being used to make.

Dykstra and Garland (1977) were interested in evaluating the economic impact of new weight regulations on Oregon's log-trucking industry. From survey data they obtained the average cost per trip and average payload. These were combined with figures for the state's annual log production to obtain an estimate of the total annual cost of hauling timber in the state. The average payload under the proposed regulations was estimated and used to calculate the number of additional trips which would have to be made in order to transport the same annual production. The increase in state-wide transportation costs, if these regulations were adopted, was estimated as the product of the number of extra trips and the average trip cost. It was assumed implicitly that trip cost is independent of payload.

A similar model was used by Watson and Matney (1981) to estimate the impact of a differential in legal GVW between Mississippi and Louisiana. The starting point of the analysis was an assumed cost per mile which was adjusted, somewhat arbitrarily, by three percent to reflect the cost increase associated with a 20 percent increase in payload. Haul costs per unit of product were then calculated assuming a one-way haul of 30 miles. The authors went on to postulate that the cost differential would be shared between the forest products industry, forest landowners, and consumers of forest products.

The majority of transportation cost models use the machine rate method. The technique is to estimate the cost of owning and operating a machine for a unit of time, estimate production per unit of time, and hence obtain a cost per unit of production. Koger (1981) used this method to compare the economics of different truck types. The starting point is to hypothesize an operating scenario in terms of machine hours per year, miles per year and machine life. Total annual costs are calculated as the sum of fixed costs, operating costs and labor costs. Fixed costs comprise depreciation, insurance, interest, taxes, license and fees. Depreciation is the equipment purchase price, less tires and salvage value, divided by the equipment life. Interest, insurance and taxes are calculated as a percentage of average fixed investment, and license and fees are actual values. The model structure can be crucial when sensitivity analyses are performed. Koger (1981) presented costs per mile for a range of travel speeds. The cost per mile and travel speed were always in a fixed ratio such that if travel speed was halved, cost per mile would double. This would only be true if the truck spent all of its time in travel and variable costs per hour were independent of travel speed.

Some authors break down truck cycle time in their models so that costs associated with hours in use can be separated from those associated with miles traveled (Smith, 1981; Smith and Tse, 1977). The problem then is in allocating different costs to each category. A truck owner may retire a piece of equipment after a fixed number years, operating hours or miles. The choice made can have a great impact on sensitivity analyses. Smith and Tse (1977) examined the sensitivity of transportation cost to operational delays, truck ownership period, and operating hours per year. The model structure was such that truck life was assumed to be independent of the hours of operation per year and the percentage of operating hours spent in travel. It was concluded that increasing ownership period reduces costs, yet repair and maintenance cost per mile were kept constant over the life of the machine. This model structure would lead to the conclusion that the economic life of a truck is an infinite number of years.

In addition to the problem of creating an appropriate structure for the machine rate model, it is questionable whether the technique provides a valid economic measure. Stuart (no date) notes that treatment of depreciation in this model is more appropriate to a company operation as a means for the operating unit to pay the parent company for the use of equipment. The cost of equipment ownership to the private contractor may be better reflected by his schedule of loan repayments. This and other arguments lead to the use of a cash flow model where actual cash flows over the life of the machine are estimated. Cummins Engine Company adopted this approach in the economic analysis module of a vehicle mission simulation model (Schultz, Klokkenga and Stattenfield, 1970). Inputs for the model include the costs of the truck, fuel, oil and tires, the pay of the driver, maintenance and depreciation schedules, salvage value, a distribution of payloads, and revenue in cents per ton-mile. The output includes a cash flow statement, net present value of the equipment and the return on investment.

Load Distribution Models

The distribution of weight over the axles of a truck is important because axle weight limits can restrict payload before the legal GVW is reached. Weight distribution models are used to analyze how different loading strategies affect payload and to *spec out* new trucks for given load characteristics.

Baumgras (1975) modeled load distribution of tandem axle log-trucks in West Virginia. These vehicles have a legal GVW of 48,000 pounds, a tandem axle limit of 32,000 pounds, and a steering axle limit of 18,000 pounds. The weight distribution model considers a simple beam, supported at one end by the steering axle, and at the other by the tandem drive axles. The assumption that the tandem axles act at a point midway between the axles is reasonable for equalized axles. The weight distribution for a given load center of gravity is calculated using the theory of moments. The location of the load center of gravity is restricted by the cab length and the length of the logs. The model is presented in the form of a nomograph which can be used to calculate the required wheelbase and cab length for a desired axle weight distribution.

The load distribution for a tractor-trailer is more complex. It is a function of the tractor wheelbase, the distance between the trailer's kingpin and axles, and the location of the tractor fifth wheel and the center of gravity of the load. A model created by International Harvester predicts axle weights given the vehicle geometry and load location (Thill, 1984). Included in the output is a sensitivity analysis for a range of fifth wheel settings. The model is structured to answer the question, given the vehicle and load characteristics, will the axle weights be within legal limits?

Watson and Matney (1984) created a load distribution model specifically for trucks hauling tree-length stems. The structure is somewhat different in that it solves for the maximum legal payload given the vehicle geometry and load center of gravity. The assumption is made that the kingpin load acts at the center of the tractor tandem, so no weight is transferred to the steering axle. It is also assumed that the butt end of the logs are in a fixed position so the location of the center of gravity for a given pile of trees is invariable. This assumption is reasonable for a pole trailer with only two bunks, but not for a frame trailer with four bunks where the load could be moved back to the second bunk.

Loading Strategies

Tree-length transportation often suffers from the problem that payload is limited by load height (Izlar, 1983). Different loading strategies have been employed to overcome this problem. If stems are loaded *butt to top*, that is with part of the load with butts to the front of the trailer and part with butts to the rear, the available load volume can be more effectively utilized. Lavoie (1980) reported the height at the butt of the front and rear facing piles for trees loaded butt to top in various bunk sizes. The implication of the results is that, for balsam fir and black spruce in eastern Canada, butt to top loading increases payload by more than 55 percent for full trees and by more than 80 percent for tree-length stems.

Catawba Timber Company in South Carolina encourages haulers to partially fill the rear bunk with random length wood and then load tree-length stems on top in the usual way (Anon, 1984c). It is estimated that this strategy can increase payload by approximately two cords or about 25 percent.

An additional advantage is that the two parts of the load can easily be separated and handled with conventional longwood unloading equipment.

Method

The method employed to accomplish the research objective included the following components:

1. An investigation of the constraints on timber hauling
2. Development of analytical techniques
3. Case studies of transportation at pulpmills
4. Analysis of options for increasing payload

Constraints on Timber Hauling

Constraints discussed in the literature review included transportation regulations, tree characteristics, system interactions and mechanical and safety considerations. In order to meet the research objctive, further information was needed on the legal and tree characteristics constraints.

A survey of transportation regulations in the South was made emphasizing weight, dimension and configuration restrictions. Commonality between laws in different states was sought so as to simplify later analyses.

Two important characteristics of southern pine trees which are relevant to transportation are stacking density and center of gravity location. An attempt was made to model the influence of tree characteristics on the weight of stems which can be contained in a given bunk area. It was hoped that the transition point between the volume limit and weight limit on payload could be determined. To predict the distribution of weight over a vehicle's axles it is necessary to know the location of the load center of gravity. Published equations for center of gravity and volume ratio prediction were used to develop simplifying assumptions about load center of gravity location.

Development of Analytical Techniques

Since there was very limited opportunity for real world experimentation, it was necessary to develop analytical models to evaluate options for increasing payload. In the first of these, the interaction between vehicle characteristics, tree properties, and weight and dimension regulations were modeled, so that the efficiencies of a variety of vehicle configurations and geometries could be compared over a range of product types and legal environments. Since the ulimate goal in increasing payload is to decrease costs, an economic model was developed to compare and rank alternatives.

Mill Case Studies

In order to obtain real world information on timber transportation three case studies were conducted at southern pulpmills. Scalehouse data were collected at two mills in order to investigate tare and gross weight variability. The potential savings from maximizing vehicle payloads were estimated for each location by truck and product type. These results were used to set priorities for which options should be analyzed. The contractual relationships between the parties involved in transportation were examined to determine who should initiate steps to increase payload and who is likely to benefit. System factors which impact the feasibility of solutions in both the harvesting and woodyard operations were identified.

Analysis of Options for Increasing Payload

Three general problem areas which can cause payloads to be restricted were recognized:

- The *Volume Problem*, where payload is limited by the maximum legal vehicle dimensions.
- The *Weight Problem*, where payload is limited by axle and gross weight restrictions.
- The *Control Problem*, where payload is limited by a loader operator's inability to accurately estimate the weight of individual loads.

For each problem area, a variety of solutions was examined. Potential solutions were of three types:

- Changes in operating procedures
- Modifications to existing equipment

- Design of new equipment

The results were summarized in the form of a trouble-shooting procedure for procurement managers and logging contractors.

Legal and Resource Constraints

Survey of Southern Transportation Regulations

A survey to collect information on the transportation regulations of 15 southern states was conducted in collaboration with the American Pulpwood Association. Information in the following categories was collected:

- weight and dimension restrictions
- penalties for overweight violations
- safety standards
- registration and licensing requirements
- vehicle inspection
- fuel tax and permit requirements
- operator licensing
- insurance requirements
- documentation requirements
- driving time limitations

The American Pulpwood Association provided a volunteer member in each state to whom survey forms were sent. The information was corroborated with the Bulletin Advisory Service published by American Trucking Associations, Inc. (1985). The completed survey forms were compiled keeping, as far as possible, the same format for each state. The resulting document will be published under separate cover since much of the information is not strictly relevant to this research. The information on dimension restrictions, weight restrictions and overweight penalties is summarized in Table 1, Table 2 and Table 3 respectively.

The Surface Transportation Assistance Act of 1982 required all states to adopt certain standards governing the length, width and weight of vehicles. These requirements applied particularly to the Interstate System and certain highways qualifying for federal aid. This led to most states having two sets of regulations, one for the Interstate and Designated Highway System, and another for other roads. On the Interstate System, in most cases restrictions on weight are more conservative than on other roads, but those on width and the range of permitted vehicle configurations are more liberal. Since log trucks always have to travel some secondary roads but can usually avoid the Interstate system, the summaries indicate the regulations for off-Interstate travel. The summaries also reflect any exceptions which have been made for hauling unprocessed forest products and, in particular, tree-length stems. They are inclusive of any enforcement tolerances and reflect the limits which are applicable with any permits which can be obtained for a nominal fee on a blanket basis.

The legal height limit is standard throughout most of the U.S. at 13.5 feet. Kentucky is the only exception to this in the South, with a limit of 12.5 feet on some roads. Only three southern states have adopted an unconditional width limit of 8.5 feet on all roads. Conditions on road and lane width mean that the effective limit on width for log trucks in all other states remains 8.0 feet.

Restrictions on vehicle length and load overhang are highly variable from state to state. Every state, with the exceptions of West Virginia and Kentucky whose laws would otherwise preclude tree-length hauling, has made an exception to accommodate this product form. With these two exceptions, overall vehicle plus load lengths of at least 70 feet are available for treelength hauling with

Table 1. Dimension Restrictions in Feet for Hauling Treelength Stems on State[1] Roads

			LENGTHS FOR TRACTOR-SEMITRAILERS			
STATE	HGT.	WIDTH	Semi-Trailer	Overall Combination Length	Overall Including Load	Load Overhang
Alabama	13.5	8.5	50	-	-	-
Arkansas	13.5	8.5	48	60	(85)[2]	25
Florida	13.5	8.5[3]	48	-	75[4]	-
Georgia	13.5	8.5[3]	48	60	75	-
Kentucky	12.5[5]	8.0	-	-	57.75[6]	-
Louisiana	13.5	8.0	50	65	(85)[2]	20
Maryland	13.5	8.0	48	-	70	-
Mississippi	13.5	8.5	50	-	-	28
N Carolina	13.5	8.0	-	55[7]	-	-
Oklahoma	13.5	8.5[3]	52	-	80[8]	-
S Carolina	13.5	8.0	48	60	80	-
Tennessee	13.5	8.0	47[9]	60	75	-
Texas	13.5	8.5	-	-	90	-
Virginia	13.5	8.0	48	60	80	-
W Virginia	13.5	8.0	-	55	-	6

FOOTNOTES:

[1] Roads other than Interstate and Designated Highways
[2] Not stated explicitly, but implied by other limits
[3] 8.0 feet if lanes less than 12 feet wide (GA & FL) or if road less than 20 feet (OK)
[4] Blanket overlength permit required
[5] 13.5 feet on designated roads
[6] 55 feet plus 5 percent tolerance
[7] 60 feet with annual permit
[8] Treelength log permit required
[9] As measured from point of attachment

Table 2. Weight Restrictions (lb) Inclusive of Tolerances for Hauling Timber on State[1] Roads

STATE	TIRE Wgt/ Inch	AXLE LIMITS Single	Tandem	Tridem	BRIDGE FORMULA Inner	Outer	MAX. GVW
Alabama	-	22,200	44,400	66,600	NO	NO	93,300[2]
Arkansas	-	20,000[3]	34,000	-	YES	YES[4]	80,000
Florida	605	22,000	44,000	66,000	NO	YES	80,000
Georgia	-	20,340	37,340[5]	-	NO	YES	80,000
Kentucky	600	20,000	34,000	50,000	NO	YES	80,000
Louisiana	650	22,000	37,000	45,000	NO	NO	88,000[7]
Maryland	-	20,000[8]	34,000[8]	-	YES	YES	80,000
Mississippi[6]	550	21,210	42,420	-	NO	NO	82,416
N Carolina[9]	-	20,000	38,000	58,000	NO	NO	79,800
Oklahoma	-	20,000	34,000	42,000	YES	YES	90,000[10]
S Carolina	-	22,000	39,600	-	NO[10]	NO[11]	80,600
Tennessee	-	20,000	34,000	-	NO	NO	80,000
Texas	650	20,000	34,000	42,000	YES	YES	80,000
Virginia	650	20,000	34,000	50,000	YES	YES	80,000
W Virginia	-	20,000	34,000	-	YES	NO	65,000[12]

FOOTNOTES:

1 Roads other than Interstate and Designated Highways
2 Requires 6 axles. 88,800 lb for 5 axles
3 12,000 lb on steering axle
4 If GVW greater than 73,280
5 34,000 lb if combination length exceeds 55 feet
6 For hauling forest products within 100 mls of woods. Includes loading and enforcement tolerances.
7 Requires triaxle trailer. Limit is 86,600 for tandem trailer with forest products permit.
8 Higher limit if GVW less than 73,000 lb
9 Must be in strict compliance with Bridge Formula after 1988 on Interstate and 1993 on state roads
10 Requires 6 axles spanning 60 foot bridge
11 Bridge Formula compliance required after 9/1/88.
12 73,500 pounds on certain highways.

Table 3. Schedules of Penalties for Violations of Weight Restrictions

	FINES (cents/lb) OVER SPECIFIED INTERVAL									
	AR	FL	GA	LA	MD	MS	NC[1]	SC[2]	TN[3]	VA
OVER GROSS										
1 - 1,000	2[4]	5	.08	2	5	1[4]	1	1	5	2
1,001 - 2,000	3	5	1.5	2	5	1	1	1	5	2
2,001 - 3,000	5	5	1.5	2	5	2	2	1	5	2
3,001 - 5,000	5	5	3.0	3	5	see	2	1	5	2
5,001 - 8,000	5	5	4.0	5	12	note	5	1	5	5
8,001 - 10,000	5	5	5.0	5	12	# 6	5	2	5	5
10,001 - 15,000	5	5	5.0	5[5]	12		5	3	5	5
over 15,000	5	5	5.0	5	12	11	5	5	5	5
OVER AXLE										
1 - 1,000	see	see[9]	.08	1	5	see	2	see	5	1
1,001 - 2,000	note	5	1.5	1	5	note	3	note	5	1
2,001 - 3,000	# 8	5	1.5	1	5	# 6	3	# 7	5	2
3,001 - 5,000		5	3.0	1.5	5		5		5	2
5,001 - 8,000		5	4.0	2.0	12		5		5	5
8,001 - 10,000		5	5.0	2.0	12		5		5	5
over 10,000		5	5.0	5[5]	12		5		5	5
Axle violations additive?	NO	YES	NO	YES	NO	YES	YES		NO	NO
Axle violation added to gross?	NO	NO	NO	NO[11]	NO	NO	YES		NO	NO
OTHER STATES	Schedules for WV and OK not on a per pound basis AL, KY & TX: fines at discretion of court of jurisdiction									

FOOTNOTES:

1 These rates half usual rates
2 Additional criminal fine $40-100
3 3% tolerance given. Court citation additional. Bridge violations $50
4 $10 minimum
5 Plus $100 for over 10,000 lb
6 Increases 1 cent per interval to 11 cents. Axle rate half of gross
7 $40-100 at court discretion
8 No schedule exists at present
9 $10 for 1 - 1,000 lb
10 If both gross & axle weights exceeded, both fines are calculated from gross schedule and the larger applies

overhangs of at least 20 feet. Excepting again West Virginia and Kentucky, all states allow an overall combination length of at least 60 feet. However, due to a rather irrational twist in Georgia's tandem weight limit, the consequences of exceeding a combination length of 55 feet in this state may be intolerable. Semitrailer lengths of up to 48 feet are allowed in all the states surveyed.

One of the requirements of the Surface Transportation Assistance Act was that for the National System of Interstate and Defense Highways, all states set limits of 20,000 pounds single axle, 34,000 pounds tandem axle, and 80,000 pounds maximum gross weight. In addition, the maximum gross weight and the gross weight on any group of axles must conform to the Federal Bridge Gross Weight Formula. The bridge formula is a means of controlling the bending moments which a truck can apply to a bridge. The maximum gross weight (W) allowed on any group of axles is given by:

$$W = 500\left(\frac{LN}{N-1} + 12N + 36\right)$$

where L is the spacing in feet between the extreme axles in the group and N is the number of axles in the group. The formula is modified to limit single axle weights to 20,000 pounds, total gross weight to 80,000 pounds, and total number of axles to not more than 7. An exception to the formula provided in Federal law is that two consecutive sets of tandem axles may carry a combined gross of 68,000 pounds if they span 36 feet rather than the 39 feet which is required by the formula. For convenience the formula is tabulated with permissible loads given to the nearest 500 pounds. Individual states may have a table in their law which differs slightly from Table 4 reflecting minor exceptions or differences in rounding. The terms *inner bridge* and *outer bridge* have emerged to describe the application of the formula to subsets of the vehicles axles (Figure 4). The *outer bridge* refers to the distance between the centers of the vehicle's first and last axles while the *inner bridge* refers to subgroups of axles.

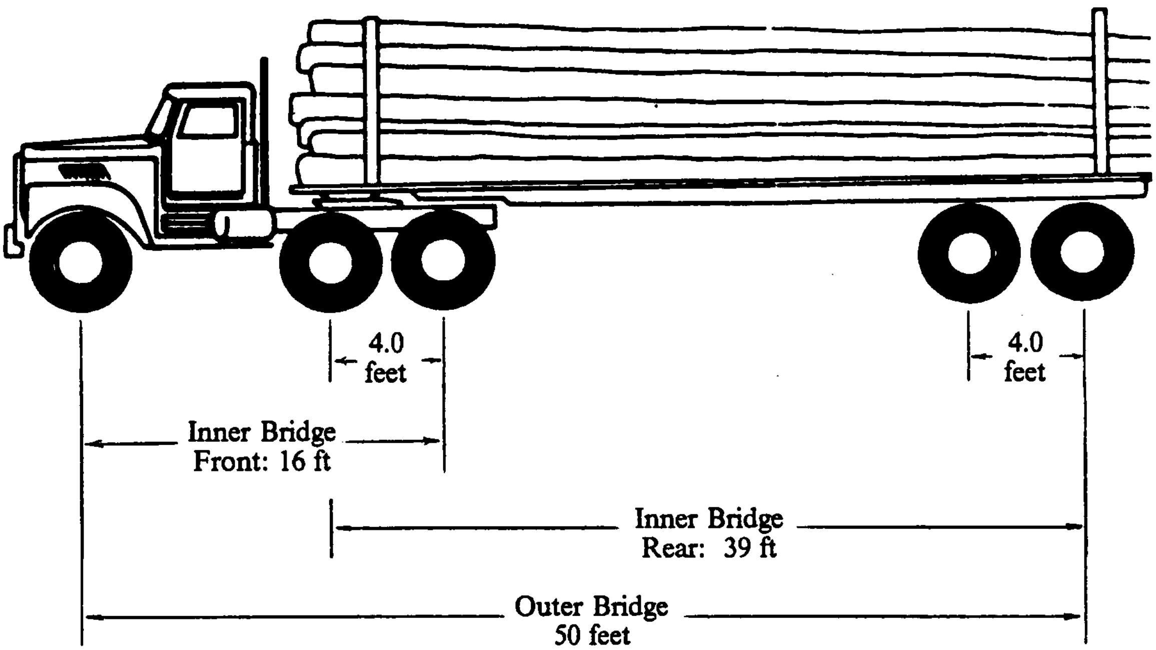
Again in reference to off-Interstate hauling of unprocessed forest products, of the 15 states surveyed, five opted to apply the bridge formula to all axle groups, three to only the *outer bridge*, one to only the *inner bridge*, and six states require no bridge formula compliance at all. However, this situation

Table 4. Permissible Loads Based on the Federal Bridge Gross Weight Formula (from U.S. Department of Transportation, 1982)

Distance in feet between the extremes of any group of 2 or more consecutive axles	Maximum load in pounds carried on any group of 2 or more consecutive axles [1]							
	2 axles	3 axles	4 axles	5 axles	6 axles	7 axles	8 axles	9 axles
4	34,000							
5	34,000							
6	34,000							
7	34,000							
8	34,000	34,000						
9	39,000	42,500						
10	40,000	43,500						
11		44,000						
12		45,000	50,000					
13		45,500	50,500					
14		46,500	51,500					
15		47,000	52,000					
16		48,000	52,500	58,000				
17		48,500	53,500	58,500				
18		49,500	54,000	59,000				
19		50,000	54,500	60,000				
20		51,000	55,500	60,500	66,000			
21		51,500	56,000	61,000	66,500			
22		52,500	56,500	61,500	67,000			
23		53,000	57,500	62,500	68,000			
24		54,000	58,000	63,000	68,500	74,000		
25		54,500	58,500	63,500	69,000	74,500		
26		55,500	59,500	64,000	69,500	75,000		
27		56,000	60,000	65,000	70,000	75,500		
28		57,000	60,500	65,500	71,000	76,500	82,000	
29		57,500	61,500	66,000	71,500	77,000	82,500	
30		58,500	62,000	66,500	72,000	77,500	83,000	
31		59,000	62,500	67,500	72,500	78,000	83,500	
32		60,000	63,500	68,000	73,000	78,500	84,500	90,000
33			64,000	68,500	74,000	79,000	85,000	90,500
34			64,500	69,000	74,500	80,000	85,500	91,000
35			65,500	70,000	75,000	80,500	86,000	91,500
36	Exception (see page 10)		66,000	70,500	75,500	81,000	86,500	92,000
37			66,500	71,000	76,000	81,500	87,000	93,000
38			67,500	72,000	77,000	82,000	87,500	93,500
39			68,000	72,500	77,500	82,500	88,500	94,000
40			68,500	73,000	78,000	83,500	89,000	94,500
41			69,500	73,500	78,500	84,000	89,500	95,000
42			70,000	74,000	79,000	84,500	90,000	95,500
43			70,500	75,000	80,000	85,000	90,500	96,000
44			71,500	75,500	80,500	85,500	91,000	96,500
45			72,000	76,000	81,000	86,000	91,500	97,500
46			72,500	76,500	81,500	87,000	92,500	98,000
47			73,500	77,500	82,000	87,500	93,000	98,500
48			74,000	78,000	83,000	88,000	93,500	99,000
49			74,500	78,500	83,500	88,500	94,000	99,500
50			75,500	79,000	84,000	89,000	94,500	100,000
51			76,000	80,000	84,500	89,500	95,000	100,500
52			76,500	80,500	85,000	90,500	95,500	101,000
53			77,500	81,000	86,000	91,000	96,500	102,000
54			78,000	81,500	86,500	91,500	97,000	102,500
55			78,500	82,500	87,000	92,000	97,500	103,000
56			79,500	83,000	87,500	92,500	98,000	103,500
57	Interstate Gross Weight Limit		80,000	83,500	88,000	93,000	98,500	104,000
58				84,000	89,000	94,000	99,000	104,500
59				85,000	89,500	94,500	99,500	105,000
60				85,500	90,000	95,000	100,500	105,500

[1] The permissible loads are computed to the nearest 500 pounds. The modification consists in limiting the maximum load on any single axle to 20,000 pounds.

[2] The following loaded vehicles must not operate over H15-44 bridges: 3-S2 (5 axles) with wheelbase less than 38 feet; 2-S1-2 (5 axle) with wheelbase less than 45 feet; 3-3 (6 axle) with wheelbase less than 45 feet; and 7-, 8-, and 9-axle vehicles regardless of wheelbase.



BRIDGE FORMULA RESTRICTIONS			
Axle Group	# of Axles	Distance	Bridge Limit
Steering Axle	1	0.00	20,000
Tractor Bogie	2	4.00	34,000
Trailer Bogie	2	4.00	34,000
Inner Bridge - Front	3	16.00	48,000
Inner Bridge - Rear	4	39.00	68,000
Outer Bridge	5	51.00	80,000

Figure 4. Example of the Federal Bridge Gross Weight Formula Applied to a 5-Axle Tractor Trailer.

is by no means static. In North Carolina, for example, after lobbying to be included in a grandfather clause, loggers were exempted from Bridge Formula compliance until 1993.

All states which have adopted inner bridge requirements also limit single and tandem axles to 20,000 and 34,000 pounds respectively. At the other extreme, Alabama has ignored axle spacing entirely, using simple multiples of its 22,200 pound single axle limit for tandem axle and triaxle sets. While no state has a single axle limit less than 20,000 pounds, steering axles may face a lower limit either by specific provision or as a result of limits on the weight allowed per inch of tire width.

Ten of the surveyed states set the maximum gross vehicle weight at or very close to 80,000 pounds. Among these, seven require that the *outer bridge* is in compliance with the Bridge Formula. Four states allow substantially higher gross vehicle weights, typically as part of a tolerance which is allowed on all weight limits. Oklahoma is unusual in this respect in that Bridge Formula compliance is required but the table of permissible limits is truncated at 90,000 pounds rather than 80,000 pounds.

The penalties for noncompliance with weight restrictions are even more diverse than the regulations themselves. Ten states use scales giving penalties per pound in excess of the legal limit. In four of these states separate axle weight violations are cumulative while in the remainder only the largest violation is charged. Only in North Carolina is an offender charged for both axle and gross weight violations. While rates for gross weight violations vary, the rate of five cents per pound occurs within the scales of most states.

To conclude this section, consider what restrictions an equipment manufacturer might adopt as design constraints for the production of a timber hauling vehicle with broad application across the South. The following set of constraints ignores the restrictions in West Virginia which, possibly because of the state's mountainous terrain, are out of line with the rest of the South. The length limits in Kentucky are also ignored. With these exceptions, a vehicle meeting the following requirements would be legal in every southern state:

Maximum Height	13.5 feet
Maximum Width	8.0 feet
Maximum Semitrailer length	48 feet
Maximum Combination Length	60 feet
Maximum Length Including Load	70 feet
Maximum Load Overhang	20 feet
Maximum Steering Axle Gross	12,000 pounds
Maximum Single Axle Gross (duals)	20,000 pounds
Maximum Tandem Axle Gross	34,000 pounds
Maximum Gross Combination Weight	80,000 pounds
Bridge Formula Compliance	All Axle Groups

For the purposes of this dissertation this set of conditions will be referred to as the *Uniform Southern Restrictions* and will be used as the base case in later analyses.

Tree Characteristics Relevant to Transportation

Weight Per Unit Bunk Area

The payload of a log truck is usually limited because adding one more piece of wood will cause the legal limit on either height or weight to be exceeded. Which of these factors is limiting depends largely on stand conditions. Clearly, if a vehicle operates primarily in stands where vehicle height is limiting, reducing vehicle tare weight has little value. The ability to predict when each of these conditions is limiting would be useful both in vehicle design and vehicle selection.

The maximum legal payload of a truck is equal to the difference between the legal GVW and the vehicle tare weight. The bunk area of the truck is constrained by the legal height and width limits. Bunk area becomes limiting when stand characteristics are such that the weight of trees which can be fit inside the bunk is less than the maximum legal payload. Thus, our interest is in predicting the weight of trees in a unit of area given the characteristics of the stand from which the trees are harvested. The analysis will be restricted to tree-length stems from pine plantations since this is where the problem of limited bunk area most frequently arises.

The starting point for the analysis is to consider how many stems can be loaded into a given bunk area, assuming that all butts are aligned in the same vertical plane. Lavoie (1980) noted that the available area on the trailer is not fully occupied because of spaces between the trees. The coefficient of effective occupancy (CO) was defined as:

$$CO = \frac{\text{area occupied by pile}}{\text{available loading area}}$$

Lavoie found CO to increase linearly with butt diameter (D in centimeters) and estimated the following coefficients in the relationship:

$$CO = 0.36 + 0.0146D.$$

One problem with this equation is the implication that CO exceeds one for butt diameters over 44 centimeters. An experiment was conducted to establish whether a similar relationship exists for loblolly pine stems. The data were collected from seventeen loads of plantation grown loblolly pine stems harvested from the coastal plain of North Carolina. For each load, the butt end diameter corresponding to the mean basal area was estimated from a sample of 10 randomly selected stems. The relatively small sample size was necessary in order to minimize the delay to the log trucks. The coefficient of occupancy was estimated by imposing a 10 X 10 grid over the butt end of the load and counting the number of grid intersections which coincided with occupied bunk area.

Five candidate models were proposed to explain the relationship between *CO* and butt diameter (see Table 5). Model I is the simple linear model proposed by Lavoie. In model II, the diameter squared term is included to allow the function to increase at a decreasing rate. Models III, IV and V are conditioned to prevent *CO* from exceeding one. Parameter estimates were obtained for models I through III using ordinary least squares regression, and for models IV and V using a nonlinear estimation technique.

Of the linear models, model III was the best by all selection criteria. Of the non-linear models, model IV was best by the MSE criterion. Model III is, in fact, a special case of model IV in which the b_2 coefficient is equal to negative one (1). Since b_2 in model IV was not significantly different from negative one (5% level of significance), model III was preferred. An undesirable feature of this model is that *CO* is negative for butt diameters less than 3 inches. The model should not be used to extrapolate below the lowest diameter in the data set, which was 5.5 inches.

The coefficient of occupancy equation can be rewritten to predict the number of stems which will fit in one square foot of bunk area:

$$\text{Stems/Sq.Ft.} = \frac{144\ CO}{\text{butt area per stem}}$$

$$= \frac{144\,(1 - 3.008/D)}{\pi D^2/4}$$

$$= 183.35/D^2 - 550.19/D^3. \qquad (5.1)$$

In order to estimate the weight of stems per square foot of bunk area, an estimate of green weight per stem is needed. Green weight prediction equations in the literature are most usually in the form:

$$\text{Green Weight} = b_0 + b_1 DBH^2 H.$$

Coefficients estimated for this equation by various researchers are given in Table 6. For plantation grown trees, the coefficients are very similar, indicating little regional variability. We will proceed

Table 5. Coefficient of Occupancy Regression Results

PARAMETER ESTIMATES	MODEL[1] I	II	III	IV	V
b_0	0.38470	.067719			
(s.e)	(.0654)	(.1767)			
b_1	.029167	.091156	-3.00084	-2.74440	-0.89740
(s.e.)	(.0059)	(.0329)	(.1329)	(.9283)	(.1587)
b_2		-.002835		-0.95867	-0.10559
(s.e.)		(.0015)		(.1547)	(.0187)
EVALUATION CRITERIA					
R^2	0.6135	0.6933	0.6978	0.6992	0.6780
$\bar{R}^2$	0.5877	0.6495	0.6575		
SSE	0.0691	0.0548	0.0540	0.0538	0.0576
MSE	.00461	.00392	.00338	.00358	.00384
PRESS	0.0882	0.0704	0.0606		

[1] Candidate Model Specifications:

MODEL I: $CO = b_0 + b_1 D$

MODEL II: $CO = b_0 + b_1 D + b_2 D^2$

MODEL III: $CO = 1 + \frac{b_1}{D}$

MODEL IV: $CO = 1 + b_1 D^{b_2}$

MODEL V: $CO = 1 + b_1 e^{b_2 D}$

where CO is the coefficient of occupancy and D is butt diameter.

Table 6. Green Weight Prediction Parameter Estimates for Loblolly Pine

MODEL: Green Weight (lbs) $= b_0 + b_1 DBH^2 H$					
Stand Type	Merch Limit	O.B./ I.B.	Region	Parameter Estimates b_0	b_1
Planted	0″	o.b.	VA Piedmont & Coastal Plain	- 2.342	.13258[2]
Planted	2″	o.b.	Interior West Gulf Coastal Plain	-13.263	.13820[4]
Planted	3″	o.b.	VA Piedmont & Coastal Plain	-18.588	.13336[2]
Planted	3″	o.b.	Interior West Gulf Coastal Plain	-26.832	.13885[4]
Planted	3″	o.b.	GA Piedmont	-17.262	.13819[1]
Planted	4″	o.b.	VA Piedmont & Coastal Plain	-45.021	.13403[2]
Planted	4″	o.b.	Interior West Gulf Coastal Plain	-61.328	.14080[4]
Planted	4″	o.b.	GA Piedmont	-48.903	.13905[1]
Natural	0″	o.b.	VA Piedmont & Coastal Plain	-18.452	.14439[3]
Natural	3″	o.b.	VA Piedmont & Coastal Plain	-33.883	.14439[3]
Natural	4″	o.b.	VA Piedmont & Coastal Plain	-64.227	.14439[3]

Sources:
[1] Burkhart and Clutter, 1971
[2] Burkhart, Parker, Strub and Oderwald, 1972
[3] Burkhart, Parker and Oderwald, 1972
[4] Hicks, Lenhart and Somberg, 1972

with the coefficients estimated by Burkhart, Parker, Strub and Oderwald (1972) for green weight to a three inch top in the Virginia Piedmont and Coastal Plain:

$$\text{Green Weight} = -18.588 + 0.13336\, DBH^2H. \tag{5.2}$$

It would be possible to estimate green weight per square foot from the product of equations 5.1 and 5.2 except that the first equation is in terms of butt diameter and the second in terms of DBH. This can be resolved by using Lanford and Cunia's (1971) equation for predicting groundline diameter (DGL) from DBH:

$$\text{DGL} = 0.909 + 1.15496\, DBH \tag{5.3}$$

Substituting 5.3 into 5.2 and multiplying by 5.1 gives:

$$\begin{aligned}\text{Weight/Sq.Ft.} = & -3{,}408.1/D^2 + 10{,}227/D^3 + 18.3304\, H - 88.329\, H/D \\ & + 115.695\, H/D^2 - 47.101\, H/D^3\end{aligned} \tag{5.4}$$

The response surface for this equation is shown as a contour map in Figure 5. This map could, in theory, be used to predict the break point between the GVW and bunk area limits on payload. Suppose a truck has a tare weight of 28,000 pounds and a legal gross weight of 80,000 pounds, giving a maximum legal payload of 52,000 pounds. If the truck has a bunk area of 65 square feet, then a stacking density of 800 pounds per square foot of end area would be needed for the legal payload to be fully utilized. For any combination of total height and butt diameter lying below the 800 pounds per square foot contour of Figure 5 the height limit would be reached before the GVW limit and vice-versa.

The predictions of the model must be viewed with extreme caution for several reasons. First, the standard error of prediction for this equation is unknown, but may be relatively large since three regression models are chained together to obtain the estimate. Consider, for example, a load of 8 inch dbh loblolly pine stems. The diameter at ground line predicted by equation 5.3 is 10.2 inches, but the 95% confidence interval for this prediction is 8.4 to 11.9 inches. The coefficient of occu-

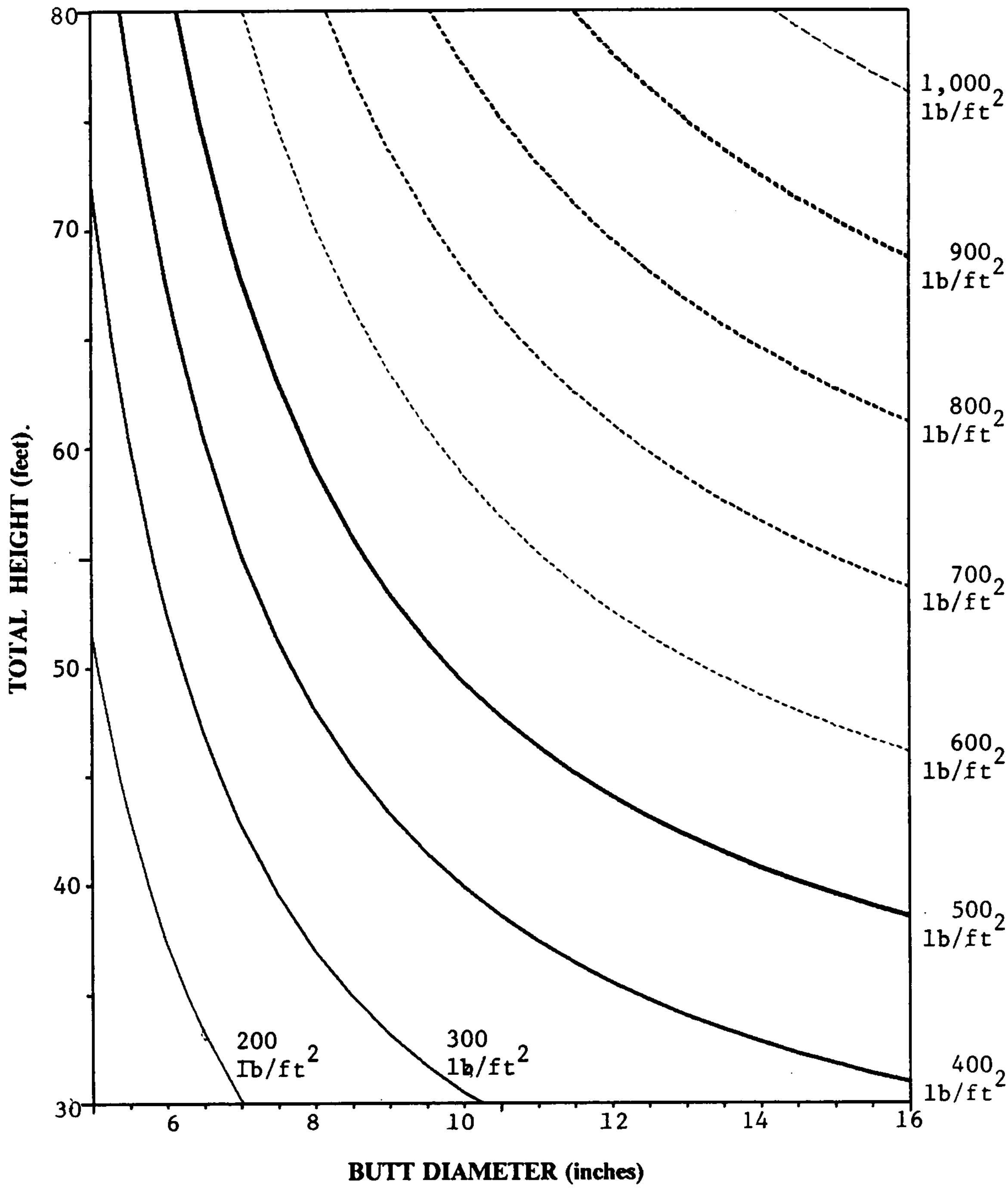


Figure 5. Response of Green Weight/Sq. Ft. of Bunk Area to Butt Diameter and Total Tree Height.

pancy predicted by equation 5.1 for a 10.2 inch DGL stem is 71 percent with a 95 percent confidence interval of 58 to 83 percent. With such wide confidence intervals in the model components, the model predictions cannot be expected to be highly reliable.

The assumption was made in the model that all butts are aligned in the vertical plane. In reality, this will not be so, and in some cases butts may be deliberately staggered to improve bunk occupancy. The model would, therefore, be expected to underestimate loads. Suppose, for example, a trailer is loaded with trees 10 inches in butt diameter, 50 feet in total length, and cut to a 3 inch top. According to equation 5.4, these characteristics would result in a load of 507 pounds per square foot of bunk area. If the inside dimensions of the bunks were 7.0 feet wide by 8.5 feet high, the predicted payload would be 30,200 pounds. If every other butt were positioned some distance, S, ahead of the rest, the effective diameter of these trees at the critical interface would be that diameter at the distance s from the butt. For S equal to 4.5 feet, the diameter of half of the trees at the interface would be dbh and a new estimate of the number of trees per unit area can be calculated. Under these somewhat contrived conditions, an 18 percent payload increase is predicted giving a total of 35,600 pounds.

In calculating the total trailer payload it was assumed that the end area of the load will be equal to the inside dimensions of the log bunk. This will not be the case if the tree butts are loaded a few feet in front of the front standards. The resulting flaring effect would allow the full legal width of 8 feet to be utilized and permit the load to drop below the height of the bolster. Taking these factors into account, the load of 10 inch butt diameter trees, staggered over 4.5 feet, would reach an estimated payload of 42,900 pounds.

It has been shown that the model for predicting the maximum payload in a given bunk area is unlikely to give reliable results. This may be due to insufficient data, measurement error, or the omission of important variables from the model. Probably the most valuable conclusion to be drawn is that a loader operator trying to estimate the weight of wood on a trailer faces a truly formidable task. This is a powerful argument in favor of allowing loggers a higher tolerance on legal gross weight.

While the utility of the model for predicting the precise conditions under which bunk area limits payload is limited, several inferences can be drawn from the modeling exercise:

1. Other things equal, as tree size decreases, the load per unit bunk area decreases at an increasing rate.

2. Load per unit area is highly sensitive to butt flare and can be increased greatly by staggering the butts of the stems.

3. Loading butts ahead of the log bunk generally increases load by increasing the available loading area.

Center of Gravity Prediction

The position of the center of gravity of a load of tree-length stems is dependent on the centers of gravity of the individual stems which make up the load. Lynch (1977) proposed the following model for estimating the center of gravity location of loblolly pine tree-length stems to a nominal two inch top diameter limit:

$$CG = b_0 + b_1 H ,$$

where CG is the distance from the tree butt to the center of gravity, and H is the total tree height. It may be more convenient to express center of gravity distance from the tree butt as a percentage of total stem length. This parameter will be referred to as center of gravity percent (CGP). Dividing Lynch's equation through by height gives:

$$CGP = CG/H = b_0/H + b_1.$$

Substituting Lynch's estimates for b_0 and b_1 leads to the conclusion that CGP decreases, but only slightly, with increasing tree height. In planted stands, for example, the predictions for 40 foot and 70 foot stems are 36.3% and 34.1% respectively. The corresponding figures for natural stand trees would be 36.6% and 35.7%.

The problem with this model is that it does not address the situation where the stem has been topped to some merchantable limit. A volume ratio equation developed by Cao and Burkhart (1980) can be used to derive an expression for the center of gravity of any log cut from a stem. The assumption must be made that green density is constant along the length of the stem. Page and Bois (1961) found green density of southern pine to increase only slightly towards the top of the tree. This would cause the equation based on uniform green density to underestimate CGP. The following generalized expression for estimating CGP for any log is derived in Appendix A:

$$CGP = \frac{\left[h_2 - \dfrac{b_2 \left[h_2^{(b_2+1)} - h_1^{(b_2+1)} \right]}{(b_2+1) \left[h_2^{b_2} - h_1^{b_2} \right]} \right]}{(h_2 - h_1)}$$

where h_1 and h_2 are distances measured from the stem tip which define the log of interest, and b_2 is a parameter of the volume ratio model.

It turns out that the predicted CGP depends only on the ratio of the distances from the stem tip to the large and small ends of the log. This relationship is shown graphically in Figure 6. The CGP predictions for untopped planted and natural stems of 29% and 31% respectively. These are somewhat lower than predicted by Lynch's model, even after the nominal two inch top in his data is taken into account. This discrepancy is consistent with the observed trend for density to increase slightly towards the top of the tree.

The prediction that CGP in planted stands will be less than in natural stands is made by both models. As more and more of the top of the tree is removed, the CGP for the remaining log approaches 50%. The increase is small within the usual range of merchantable top limits. Removing

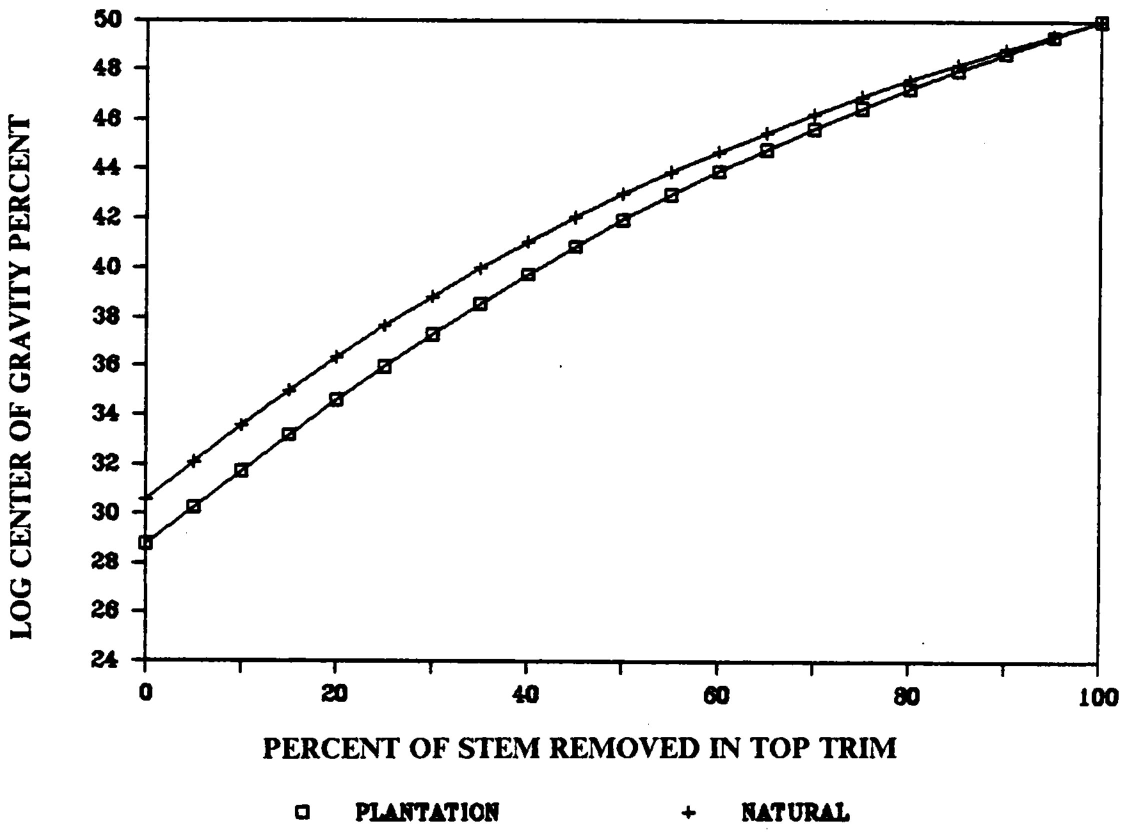


Figure 6. Relationship Between Center of Gravity Percent and Percentage of Stem Removed as Top

a 12 foot top from a 60 foot tree from a natural stand, for example, is predicted to increase CGP from 30.6% to 36.4%.

If the butt log is removed from a stem we should expect an increase in CGP because of the elimination of butt flare. The fact that the volume ratio derived model predicts no change in CGP is due to the fact that the underlying model does not have sufficient parameters to capture butt flare.

Now consider the location of the center of gravity of a load of tree-length stems under the following loading scenarios:

1. Centers of gravity aligned in the same vertical plane
2. Butts aligned in the same vertical plane
3. Randomly staggered

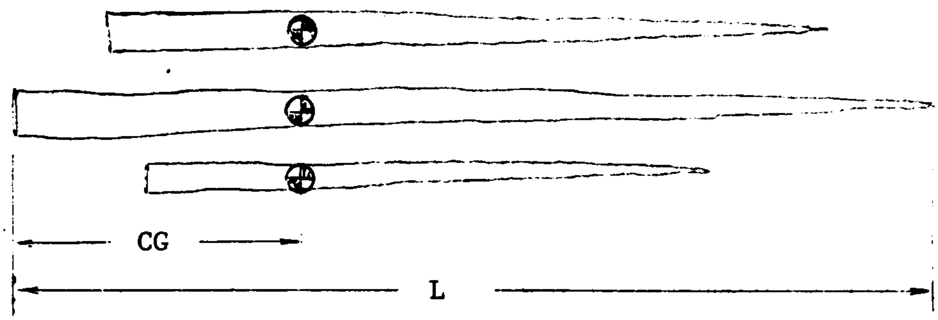
The three scenarios are illustrated in Figure 7. Assume that the CGP is one-third for every stem, and define the center of gravity percent for the load as:

$$\text{CGP(LOAD)} = \frac{\text{dist from front of load to C of G}}{\text{overall load length}} \times 100\ \%$$

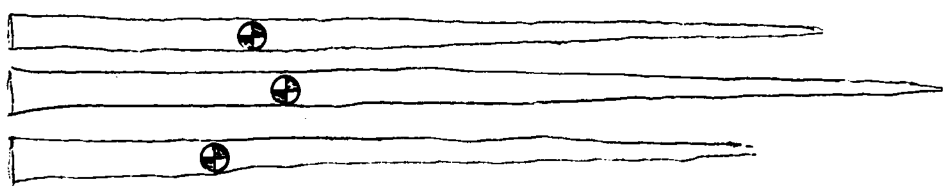
In scenario one, the front and rear of the load are defined by the top and butt of the longest stem. Since all stem centers of gravity are in the same position, CGP for the load is the same as CGP for each stem.

In the second scenario, The front and rear of the load are again defined by the butt and top of the longest stem. The center of gravity of all of the shorter stems will lie between the center of gravity and butt of the longest stem. The CGP for the load must, therefore, be less than CGP of the stems.

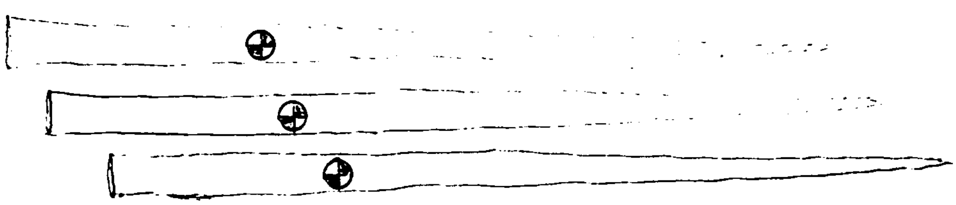
In the case where stems are randomly located, consider the special case where where all stems are of the same length, L. The load center of gravity location is the weighted average of all of the in-



I. Centers of Gravity Aligned: Load CGP = Stem CGP



II. Butts Aligned: Load CGP < Stem CGP



III. Random: Load CGP > Stem CGP

Figure 7. Impact of Loading Strategy on Load Center of Gravity Location

dividual center of gravity locations. Let the centers of gravity of the foremost and rearmost stems be some distance, X, from the load center of gravity. The distance from the foremost tree butt to the load center of gravity is {L/3 + X}. The overall load length is {L + 2X}. Therefore,

$$\text{CGP(Load)} = \frac{(L/3) + X}{L + 2X}$$

$$= \frac{1}{3} \times \frac{(L + 3X)}{(L + 2X)}$$

$$\text{Since, } \frac{(L + 3)}{(L + 2)} > 1 \quad \text{then} \quad \text{CGP(LOAD)} > \frac{1}{3}$$

Thus, the CGP of loads of randomly staggered stems will tend to be larger than that of the individual stems.

The center of gravity of a load of tree-length stems is determined not only by the centers of gravity of the individual stems, but also by the style in which the stems are loaded. In this case, modeling individual stem centers of gravity more precisely would seem to be of limited benefit to transportation problem solving. It may also explain why logging contractors have difficulty controlling the distribution of load over axles with the precision required in some states.

Though it does not seem possible to predict load center of gravity accurately by a simple procedure, the following rules of thumb may be useful in trailer design and, to a lesser extent in field operations:

1. For loads of tree-length stems with butts in the same direction, the load center of gravity will usually lie between 30 and 40 percent of the total load length from the butt end of the load (based on model predictions assuming less than one-third of the stem is removed in top trim).

2. This percentage will tend to be smaller for butt aligned stems of variable length.

3. This percentage will tend to be larger for larger top diameter limits, randomly staggered stems, and trees from natural stands.

Finally, just as the difficulty in predicting load per unit bunk area mitigates in favor of greater tolerance on gross weight limits, the difficulty in predicting the center of gravity of the load suggests that loggers might reasonably be allowed greater axle weight tolerances.

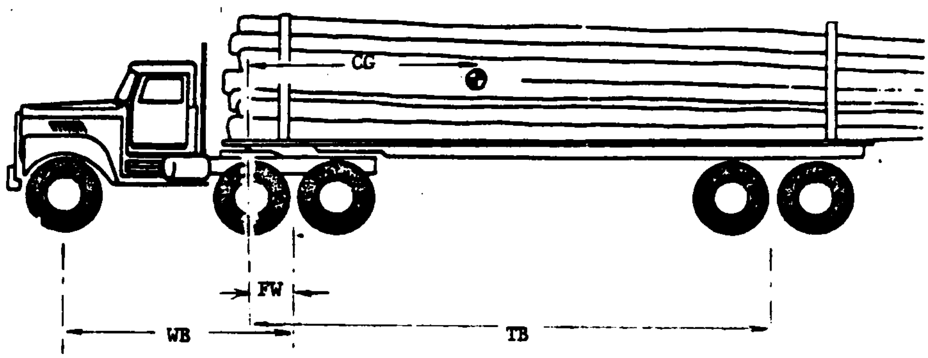
Development of Analytical Techniques

Evaluating Legal and Product Constraints on Vehicle Design

From the review of legal requirements for timber transportation and the analysis of pertinent tree characteristics, it is apparent that there are many dimensions to the problem of specifying or designing a log truck. So numerous are the constraints, that while making an adjustment to comply with one restriction there is a danger of unwittingly moving outside the boundaries of another. The purpose of this section is to develop a model which will facilitate the simultaneous consideration of legal and product constraints on vehicle design. The model will be developed for the tractor-semitrailer but the same principles could be applied to any vehicle configuration.

We begin by calculating the distribution of load over the axles. Consider the truck in Figure 8. Ignoring tare weight for the moment, the vehicle can be represented as two simply supported beams. The tractor beam is supported by the steering axle at one end and by the drive tandem at the other. For the purpose of calculating weight distribution, if the two axles in the tandem are

CRITICAL DIMENSIONS



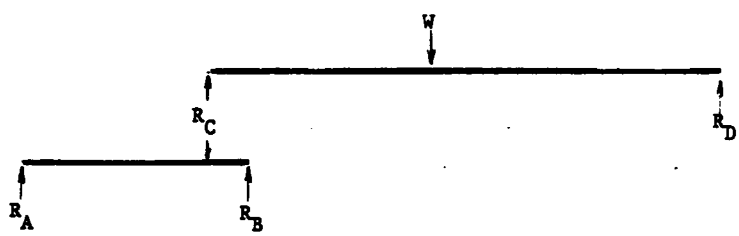
WB = Tractor wheelbase

FW = Fifth wheel offset

TB = Trailer base (kingpin to bogie center)

KP = Kingpin to load center of gravity

STATIC MODEL



WEIGHT ASSUMPTIONS

	Steering Axle	Drive Tandem	Trailer Tandem	Combination Total
Tare Weight	8,000	12,000	8,000	28,000
Legal Limit	20,000	38,000	38,000	80,000

Figure 8. Definitions and Assumptions for Tractor Trailer Load Distribution Model

equalized they can be replaced by a single support point midway between axle centers. The trailer kingpin acts as both the support point for the trailer beam and as the loading point on the trailer beam. The trailer beam is supported at the other end by the trailer's tandem axle and the weight of the trees can be assumed to act at their center of gravity.

Using the variable definitions from Figure 8 the kingpin load can be calculated as:

$$\text{Kingpin Load, } R_C = W\left(1 - \frac{CG}{TB}\right)$$

The distribution of the load over the three axle/tandem locations can now be calculated as:

$$\text{Steering axle load, } R_A = W\left\{\frac{FW}{WB}\left(1 - \frac{CG}{TB}\right)\right\}$$

$$\text{Drive Tandem Load, } R_B = W\left\{\left(1 - \frac{FW}{WB}\right)\left(1 - \frac{CG}{TB}\right)\right\}$$

$$\text{Trailer Tandem Load, } R_D = W\left\{\frac{CG}{TB}\right\}$$

To obtain the axle gross weights the axle tare weights are simply added to the right hand side of these equations.

Now suppose that there are legal limits on single axle, tandem axle and gross weights as shown in Figure 8 but no bridge formula requirements. For the truck to be loaded legally the following inequalities must hold:

$$\text{Steering Axle Gross, } G_A = W\left\{\frac{FW}{WB}\left(1 - \frac{CG}{TB}\right)\right\} + 8{,}000 \leq 20{,}000$$

$$\text{Drive Tandem Gross, } G_B = W\left\{\left(1 - \frac{FW}{WB}\right)\left(1 - \frac{CG}{TB}\right)\right\} + 12{,}000 \leq 38{,}000$$

$$\text{Trailer Tandem Gross, } G_D = W\left\{\frac{CG}{TB}\right\} + 8{,}000 \leq 38{,}000$$

$$\text{Gross Combination Weight, } GCW = W + 28{,}000 \leq 80{,}000$$

The inequalities can be rearranged to give the maximum legal payload (W_{max}) as a function of the load center of gravity location (CG) and other parameters which are constant for any particular vehicle. These relationships are plotted in Figure 9 using the weights from Figure 8 and assuming a trailer base of 30 feet and a fifth-wheel centered over the drive tandem.

Figure 9 shows the importance of load center of gravity location to payload maximization when axle weight limits are enforced. Legal payload is at its minimum when load center of gravity is directly above the kingpin because the entire load is supported by the tractor tandem. As the center of gravity moves toward the middle of the trailer, legal payload increases to the maximum value of 52,000 pounds and then declines as as the center of gravity moves toward the rear of the trailer. There is an area in the middle of the trailer, approximately 30 inches long in this example, over which the maximum payload can be reached. This flat area on the payload curve, which has been dubbed the *sweet spot*, has the following characteristics:

1. The size and location of the *sweet spot* depend on vehicle geometry, tare weight distribution and axle weight restrictions.

2. The wider the *sweet spot*, the easier it would be for a loader operator to place the actual load center of gravity within its boundaries.

3. The higher the *sweet spot* the greater the maximum legal payload for the rig.

Another interesting point about the graph in Figure 9 is that it can be used to evaluate the legal status of any given combination of load and center of gravity location. Any such combination will fall into one of the five zones marked on the graph:

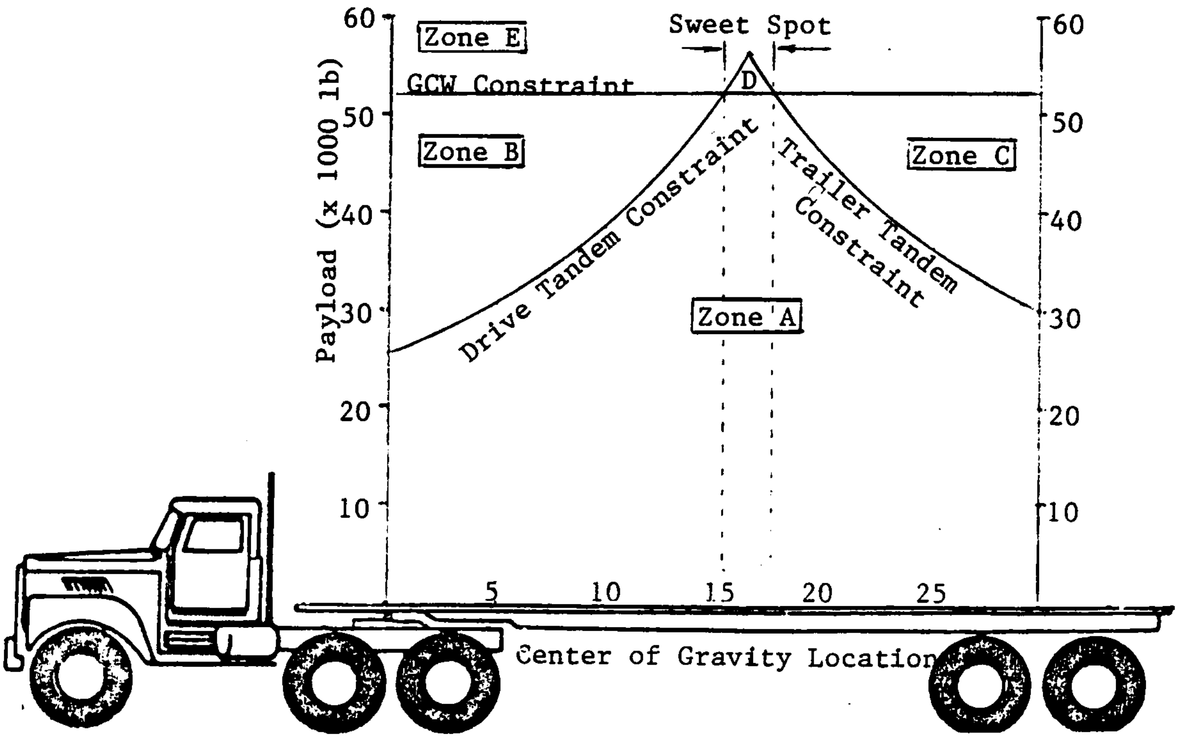


Figure 9. **Weight Constraints for Hypothetical Log Truck:** Assumes tare weight and legal restrictions from Figure 9 and a trailer base of 30 feet.

ZONE A: The entire area below the payload curve. In this zone the truck is within both axle and GCW limits.

ZONE B: The truck is within the GCW limit but exceeds the limit for the drive tandem.

ZONE C: The truck is within the GCW limit, but exceeds the limit for the trailer tandem.

ZONE D: The truck exceeds the GCW limit, but but does not exceed any axle limit.

ZONE E: The GCW limit and both tandem limits are exceeded.

To this point a relatively simple set of weight restrictions has been assumed. If Bridge Formula restrictions are added, the number of constraints increases from four to six. The mathematical representations of these constraints are given in Appendix 2. To generate graphs similar to Figure 9 more rapidly, including all Bridge Formula constraints, the analysis for tractor trailers with up to seven axles was transferred to a computerized spreadsheet. The input to the spreadsheet consists of the number of axles and their spacing, the fifth wheel and kingpin locations, and the tare weight distribution. The legal axle weight limits are looked up automatically from a Bridge Formula table included on the spreadsheet. At small intervals over the range of possible center of gravity positions, the legal payloads under each of the six constraints are compared to determine which constraint is binding. The legal payload values are then plotted against center of gravity.

The legal payload curve for the truck in Figure 10 was plotted assuming the *Uniform Southern Regulations* described earlier. The graph illustrates the problem of legally achieving the legal gross vehicle weight of 80,000 pounds without exceeding the axle weight limits. With the spreadsheet program it is possible to experiment with adjustments to vehicle geometry and see the effect on the legal payload curve almost instantaneously. The knowledge of which constraints are binding is useful in deciding what adjustment to vehicle geometry is appropriate. When experimenting with different configurations three goals should be considered:

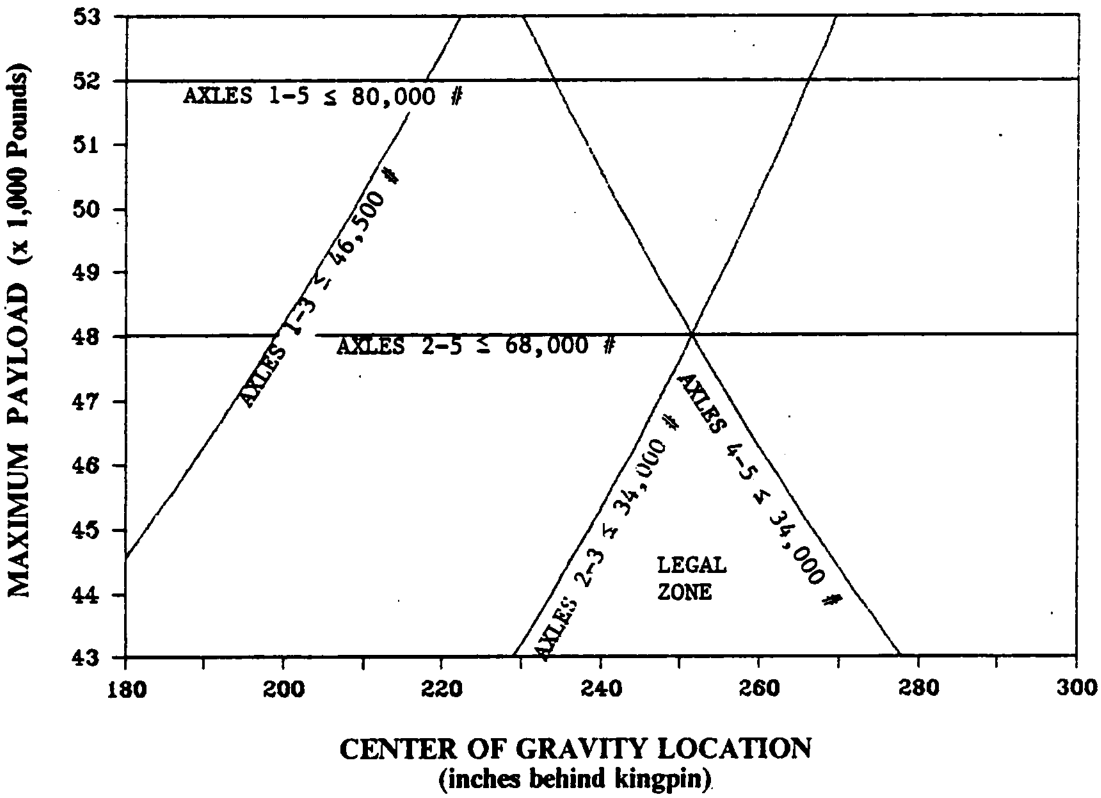


Figure 10. **Plot of Bridge Formula Constraints for 5-Axle Tractor Trailer:** Assumes tractor wheelbase of 14 feet, trailer base of 35 feet, and no fifth wheel offset.

1. To achieve maximum payload
2. To ensure that the *sweet spot* is sufficiently wide to allow for uncertainty in the actual center of gravity location
3. To ensure that the *sweet spot* coincides with the expected range of load center of gravity locations.

It is apparent that the specification of a log truck involves in part a problem of maximizing payload subject to a number of constraints. Such problems are often amenable to optimization techniques using, for example, linear programming or search algorithms. However, in this case no simple objective function exists since we want to maximize payload and *sweet spot* width. A second problem would be that the constraints are nonlinear. While techniques exist to circumvent both of these problems, it was felt that using the graphical search appproach described above was more appropriate since it is more easily understood and because the alternative, non-linear goal programming, is not readily available to most people involved in timber transportation.

Transportation Economics

The objective of modeling transportation economics was to determine what actions aimed at increasing payload are justified and under what conditions. The appropriate analysis for such decisions depends on who is making the decision and whose cash flows will be affected. It is worth considering, therefore, who the major players in the timber transportation industry are and how their relationships with each other are structured.

Most parties involved with timber hauling can be placed in one of the following categories:

1. Forest Products Companies (pulpmills, sawmills, etc.)

2. Timber Suppliers/Dealers
3. Logging Contractors
4. Trucking Contractors

All of these groups, with the exception of the trucking contractors, can be both vendors and purchasers of transportation services. The interrelationships between them are shown graphically in Figure 11. The division of responsibility for loading, transportation and unloading, and the basis of payment dictate who must make the necessary investment to increase payload and to whom the benefits will accrue. Some of the more common arrangements are discussed below.

A few forest products companies own their own log trucks which they use to move wood from company logging operations or outlying woodyards to a processing mill. In this situation, the company has every incentive to make whatever improvements it feels will reduce transportation costs since it controls all phases of the operation. More frequently, the forest products company contracts transportation services from the three other groups in the list. The contract may be for transportation only, or the transportation may be included in a timber harvesting or timber supply contract. The contractor may be paid on a *loaded-mile* basis or for each unit of weight or volume he delivers. The forest products company is usually responsible for unloading and, in some circumstances, for loading. However, loading is more usually the responsibility of the transportation contractor or a third party such as a logging contractor. The loaded-mile method of payment is common when the contractor is providing only transportation since in this case he does not have any control over payload. The problem with this method is that it provides no incentive to reduce vehicle tare weight. Where loading, transportation and unloading are performed by three separate parties some strategies for increasing payload may be difficult to implement.

The size of the truck fleet can also influence the economics of increasing payload. A logging contractor who provides his own trucking, for example, will not realize savings in fixed costs by increasing payload unless he can either increase the production from his logging system by a proportionate amount, or decrease the size of his truck fleet. This is a problem of indivisibility.

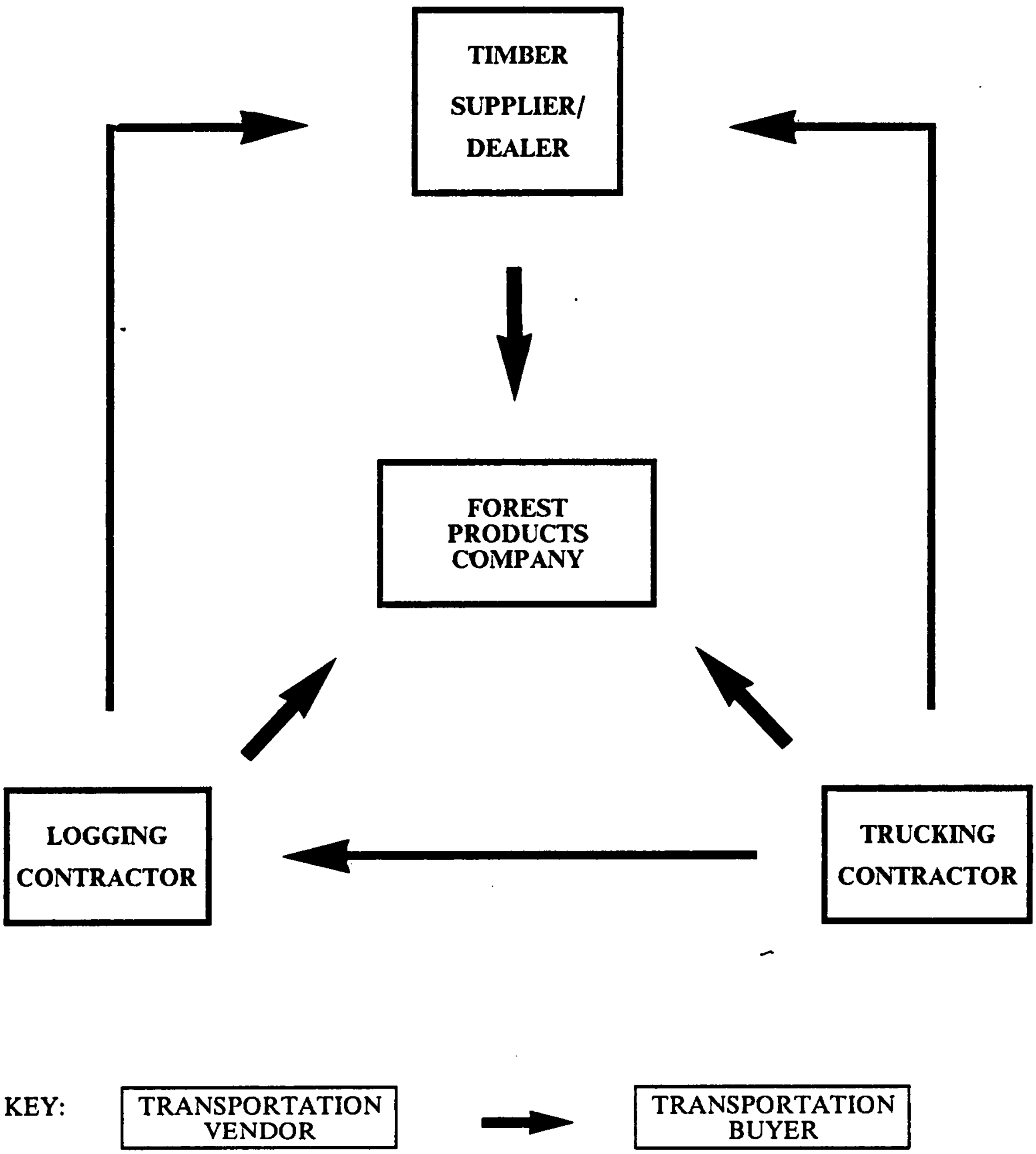


Figure 11. Structure of the Timber Transportation Industry: The arrows signify the sale of timber transportation services from one party to another.

The contractor cannot operate fractions of a truck and so the savings with increased payload will follow a step function. The function will approach a smooth curve for businesses owning a large number of trucks or for a hauling contractor who does not face a production quota.

Another indivisible quantity is the number of round trips a truck makes in a day. If the number of trips per year is calculated from the scheduled hours per year and the average cycle time, the result will most likely imply a non-integer number of trips per day. This can be justified by considering that cycle times will vary and truck drivers will adjust the length of their work day to compensate.

For the purpose of ranking options it seems justifiable to make the following assumptions:

1. The truck is not limited by system factors or quotas as to the volume it can haul in a year. Any additional payload, therefore, will result in increased production rather than a reduced number of trips.

2. The utilization of annual scheduled hours is not dependent on completing the same number of trips for each operating day.

However, when considering implementing these options, a truck owner should consider carefully whether these assumptions hold for his operation.

The rule used to evaluate payload increasing options was that the change in cash flows produced must have a positive net present value. In many situations, a set of base case assumptions was required in order to apply this rule. The assumptions listed in Table 7 were derived from the literature survey, information from equipment dealers and knowledge of timber transportation contract rates. The base case envisions purchasing a new tractor and two double bunk log trailers for cash and operating them over a total of 360,000 miles. Cash flows associated with the investment are divided into three groups: capital investments, time based cash flows, and mileage based cash flows. Different ownership groups will have different distributions of costs between these groups. An owner

Table 7. Base Case Assumptions for Net Present Value Calculations

OPERATING SCENARIO	
Tractor & Trailer Economic Life	300,000 miles
Average 1-Way Haul	40 miles
Operating Hours Per Year	2,000 hours
Travel Time Per Trip	2 hours
Standing Time Per Trip	40 minutes
CAPITAL INVESTMENT	
300 HP Tractor (Less Tires)	\$60,000
2 Double Bunk Log Trailers (Less Tires)	\$18,000
Salvage Ratio	10 percent
TIME BASED CASH FLOWS	
INCLUDES: Registration, Insurance, Property Taxes, Labor and Overheads	\$24,000 Per Year
MILEAGE BASED CASH FLOWS	
INCLUDES: Fuel, Lubrication, Supplies, Tires, Repairs and Maintenance	0.2030×1.01^{GVW}
(GVW here is average gross weight in thousands of pounds)	

operator, for example, might choose to buy second-hand equipment with lower capital investment but higher mileage related costs. Such differences should be taken into account when interpreting results. Mileage based cash flows were expressed as a function of GVW. According to Murphy (Pers. Comm.) studies conducted by the Cummins Engine Company found that increasing GVW by 1000 pounds produced a 0.9 to 1.0 percent increase in fuel consumption. Repair, maintenance and lubrication costs would also rise with increasing GVW. In the absence of any data on this relationship, total mileage related costs were assigned a base value of $0.45 per mile at 80,000 pounds GVW and assumed to rise or fall by one percent for every 1000 pound rise or fall in GVW.

For the purpose of setting up net present value calculations all cash flows were assumed to be real rather than nominal values. Because of imminent changes in the US Tax Code and wide fluctuations in the rate of inflation, all calculations were performed on a pre-tax basis in real (uninflated) dollars. In light of a survey of capital budgeting practices in the forest products industry (Cubbage and Redmond, 1985) which reported a 10 year average real discount rate of 10.9 percent, a 12 percent real after tax required rate of return was adopted.

Three different situations could commonly arise when examining the economics of payload increases. In the first situation, a logger who owns his own trucks is considering taking some action to increase payload. Here it is assumed that the logger receives, directly or indirectly through a cut and haul contract, a fixed revenue per ton-mile. To evaluate the decision, the net present value (NPV) of the trucking investment is calculated before and after the change is made. A sample NPV calculation is shown in Appencix C. If there is an increase in NPV the change should be adopted[4]. To simplify this process, critical values can be calculated for making decisions of certain types. Suppose we are interested in options for decreasing tare weight at the expense of additional initial capital investment. If the additional capital is calculated which, for a payload increase of 1,000 pounds, yields no change in the NPV, this critical ratio between payload increase and additional capital can be used to evaluate all decisions of this type.

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[4] This is equivalent to accepting the action if the NPV of the change in cash flows is positive.

In the second situation, the logger contracts hauling at a fixed rate per loaded mile. The relevant cash flows for the NPV analysis now are simply the costs associated with increasing payload and the value of the loaded miles saved. Suppose a logger who pays $2.30 per loaded mile is considering installing scales on his loader, which he estimates will increase his average payload by 1,000 pounds. The initial cash flow in this investment is the cost to purchase and install the scales. The annual savings are calculated from the difference in the number of loaded miles which must be paid for with and without the scales. If these cash flows give a NPV greater than zero the scales should be purchased.

The last situation is where a mill is considering taking some action to remove a facility constraint, thereby enabling its suppliers to increase their truck payloads. The critical questions here are how should the savings from increasing payload be calculated, and what fraction of these will accrue to the mill. Suppose, for example, that the mill is considering running a front-end loader so that some butt to top loads can be unloaded. The preferred way to estimate the savings from this move would be to ask procurement foresters how much lower they could negotiate contract rates where butt to top loading was allowed and over what annual volume would the lower rates apply. Failing this, it may be necessary to adopt an ad-hoc procedure of some kind. Begin by estimating the number of loaded-miles which would be saved and value them at the prevailing contract trucking rate. In the first year of operation the savings accruing to the company may be small, since it will take time for contract rates to adjust downward and contractors will have to sell some surplus trucks before they fully realize the available savings. Savings will increase in the second year and reach a maximum in year three. Under this scenario, we may estimate savings to the company in the first three years to be 25, 50 and 75 percent of total savings. The decision can then be based on the NPV of the investment calculated in the usual way.

Case Studies

Case studies were conducted at the woodyards of three southeastern pulpmills. The purpose was to collect information on real world constraints to timber transportation. Scalehouse data were collected at two of the mills to test hypotheses about supplier behavior. There follows a general description of each case after which the scalehouse data are discussed in detail.

Mill #1

The first mill visited was used as a pilot study so only a limited amount of data was recorded. The pulpmill was in the South Carolina piedmont, close to the border with North Carolina. For every log truck entering the mill over a 17 hour period the haul distance, gross and tare weights and details on the truck and load type were recorded.

Three truck configurations were used in roundwood deliveries; two axle trucks equipped to transport 5′ 3″ pulpwood loaded transversely in two bunks, three axle trucks loaded with random-length longwood, and three-axle tractors with two axle double I-beam semi-trailers. The loads transported by tractor trailers could usefully be divided into three groups; shortwood originating in company woodyards, tree-length originating in company woodyards and tree-length transported directly from woods operations. Only two loads of shortwood originated in the woods so these were excluded from the data set.

South Carolina's weight limits for forestry trucks on state roads are as follows:

Single Axle Weight	22,000 pounds
Tandem Axles Weight	44,000 pounds
Gross Vehicle Weight	80,600 pounds

All loads leaving company woodyards between 8:00 a.m. and 5:00 p.m. were weighed. The policy was to adjust the load if it was not between 79,000 lb and the legal limit of 80,600 lb.

Mill #2

The second mill was located in southeastern Tennessee close to the border with Georgia. No scalehouse data were collected at this mill. The mill furnish includes both pine and hardwood. Slightly more than half is produced by contract loggers with the remainder coming from dealers, gate purchases and sawmill residues. The company operates three outlying truck woodyards with transfer hauling contracted on a per cord basis. Trailers are loaded by the company but the contractor has the right to reject the load if he feels it is overweight or dangerous and is responsible for overweight tickets. Wood is also transfered from seven dealer woodyards.

The mill's scalehouse is computerized with vendor identification by plastic punch cards. The yard was converted to accept tree-length loads three years ago with the addition of a pivoting circular boom loader. This is a *one bite* machine with fixed radius. The grapple has an automatic closing safety feature which causes some problems in maneuvering around the load. The crane operator is directed by the truck driver through a telephone link. The crane is supplemented by a Prentice 810 knuckle-boom and a Letourneau stacker. The company will compensate for damage in unloading provided a minimum of 8 inches clearance between load and trailer is given. The slasher deck is a jack ladder type with circular saws at 5′ 3″ spacing. Butt to top loading is discouraged due to trees getting stuck in the unscrambling section of the slasher deck.

A great assortment of trucks and trailers deliver to this mill, due in part to the recent conversion to tree-length handling. Many trailers are converted Curry trailers with high tare weight. A small but increasing number of contractors are using pole trailers in order to reduce tare weight. One contractor operates an all fiberglass cab and pole trailer with a combined weight of less than 22,000 pounds.

For a substantial number of loads payload is limited by bunk area causing contractors to respond with a variety of equipment modifications. One has cut his trailers behind the landing gear and rewelded them to form an improvised drop-neck. Another contractor has cut out the center frame section and welded an I-beam to the lower flanges of the resulting halves. This allows increased grapple clearance as well as permitting the bunks to be let in flush with the original frame.

Tennessee's weight laws for state roads are as follows:

Single Axle Weight	20,000 lb + 500 lb tolerance
Tractor Steering Axle Weight	12,000 lb + 500 lb tolerance
Truck Steering Axle Weight	18,000 lb + 500 lb tolerance
Tandem Axle Weight	34,000 lb + 1000 lb tolerance
Gross Vehicle Weight	80,000 lb

Although the Federal Bridge Formula is applied only on Interstates in Tennessee, a substantial portion of the furnish comes from Georgia where the formula is applied to the *outer bridge* on all roads.

The company has adopted a GVW ceiling of 85,000 pounds. If a truck exceeds this limit the payload is calculated by subtracting the tare weight from 85,000 pounds. Loads are not unloaded if the driver is not wearing a hardhat. Safety equipment is on sale at cost in the scale house, including hardhats, red flags and red lights for night operation. The problem of keeping tail lights visible with tree-length loads is of major concern. Tennessee safety regulations for securing wood to trailers were recently rewritten. Every length of wood must be secured by two binders and tree-length stems (over 35 ft) must be secured by three. Chains or cables are allowed but nylon webbing is not.

On-board scales were provided to one contractor for evaluation. The control unit and fifth wheel load cells were mounted in the set-out tractor and each trailer was equipped with two load cells and the necessary wiring. The system gives readings for axle weights and GVW with accuracy reaching 0.25% on level ground if road tractor tare weight and fuel level are taken into account. Benefits include maximized payload, avoidance of fines and elimination of detours to avoid scales.

Mill #3

The third mill, located in central Georgia, has a furnish consisting entirely of pine. Approximately two-thirds of this arrives by truck in roundwood form with an average haul of approximately 44 miles. The majority of the roundwood is furnished by suppliers who operate logging crews and buy some of their own stumpage. The remainder is from suppliers who do not have their own logging crews and buy wood from third parties. The company utilizes only one satellite woodyard, where both the operation and wood transfer to the mill are contracted on a unit weight basis.

The woodyard scales are computerized with punched card vendor identification. The yard is centered around a flume which feeds the chipper via a jack ladder. Tree-length loads are handled by two Fulghum center pivot, fixed radius boom cranes. These have a capacity of 32,500 pounds, making unloading a two pass operation. The wood can be placed in inventory or loaded directly onto the slasher (one for each crane). The crane operators use a public address system to position the trucks but there is no audio link to allow drivers to assist in guiding the grapple. Additional tree-length handling and storage capacity is available using a CAT 988 front-end loader. Shortwood can be fed directly into the flume by paddling it off trucks and railcars. A shortwood inventory pile is also maintained using a grapple crane.

Both butt to top and double bunk loading are discouraged by the woodyard. Butt to top loading is permitted on a case by case basis, and only when small tree size severely reduces payload. The main problems with butt to top loads are perceived to be jack-strawing in unloading and inefficient use of the circular storage space. The technique of separating the load with cross logs had not been tried. While the CAT 988 would be well suited to dealing with butt to top loads, scheduling problems would arise since this machine is not normally operated continuously. It was also felt that butt to top loading had been abused in the past as a means to exceed legal weight limits. No great problems were envisioned with staggered butt loading, though the technique is not widely used at present.

The following weight limits are in effect for non Interstate roads in Georgia:

Single Axle Weight	20,340 lb
Tandem Axle wieght	37,340 lb
Gross Vehicle Weight	Max 80,000 lb

(Actual gross determined by bridge formula)

Although the maximum GVW is 80,000 pounds, some vehicles cannot achieve this legally since they are too short to meet the 51 foot *outer bridge* requirement. The tandem axle weight limit drops back to 34,000 pounds for vehicles longer than 55 feet, causing extreme difficulty in meeting the *outer bridge* requirement without exceeding this length. To discourage overloading the company has adopted a gross weight ceiling of 88,000 pounds.

Scalehouse Data

Scalehouse data were collected at mill #1 and mill #3. Table 8 shows the roundwood deliveries to each mill broken down by species mix, product form and vehicle type. The discussion will be limited to pine delivered by tractor trailer in tree-length or shortwood form since this accounts for the vast majority of the data set.

Comparisons Between Mills and Product Types

Table 9 shows the means and standard deviations of gross, tare and net weight for each mill by product type. The tree-length loads had, on average, lower gross weight, higher tare weight and hence lower net weight than loads of shortwood. The lower tare weight of shortwood vehicles is probably indicative of lower bunk weight. It also shows that the potential of using the inherent strength of tree-length to economize on trailer frame weight is largely unutilized.

The lower tree-length mean gross weight was accompanied by wider dispersion. Two hypotheses can be advanced to explain these observations:

1. Loader operators are less able to estimate the weight of tree-length loads, leading to a wider distribution of gross weights. Due to the wider distribution, a lower average tree-length gross weight must be maintained in order to avoid excessive overweight fines.

2. The problem of reaching the legal height limit before the legal weight limit is more frequently encountered with tree-length leading to a greater spread of gross weights and a lower mean.

Table 8. Breakdown of Truck Roundwood Deliveries at Mills #1 and #3

	MILL	
	#1	#3
SPECIES MIX		
PINE	94%	100%
HARDWOOD	6%	0%
PRODUCT FORM		
TREE LENGTH	61%	81%
SHORTWOOD	28%	17%
RANDOM-LENGTH LONGWOOD	11%	2%
VEHICLE TYPE		
TRACTOR TRAILER	89%	92%
STRAIGHT TRUCK	11%	4%
SAMPLE SIZE		
% OF ANNUAL TONS	0.4%	100%
NUMBER OF LOADS	179	42,570

Table 9. Comparisons of Gross, Tare and Net Weights by Product for Mills #1 & #3

			MILL	
			#1	#3
GROSS WEIGHT				
	TREE-LENGTH	MEAN	78,108[1]	74,632
		(Std. Dev.)	(6,410)	(5,621)
	SHORTWOOD	MEAN	79,149	77,741
		(Std. Dev.)	(3,767)	(5,225)
TARE WEIGHT				
	TREE-LENGTH	MEAN	27,846[1]	26,505
		(Std. Dev.)	(1,686)	(1,451)
	SHORTWOOD	MEAN	26,856	26,084
		(Std. Dev.)	(478)	(1,095)
NET WEIGHT				
	TREE-LENGTH	MEAN	50,262[1]	48,126
		(Std. Dev.)	(6,092)	(5,520)
	SHORTWOOD	MEAN	52,293	51,656
		(Std. Dev.)	(3,844)	(5,061)

[1] Excludes loads originating at company yards.

Table 10. **Impacts of Eliminating Overloading, Underloading and Excessively Heavy Vehicles**

		MILL	
		#1[1]	#3[2]
UNDERLOADING			
Ton-miles gained by eliminating underloading	TREE-LENGTH (% Change)	2,004,990 (4.4%)	4,722,400 (11.9%)
	SHORTWOOD (% Change)	417,640 (4.1%)	455,710 (6.3%)
OVERLOADING			
Ton-miles lost by eliminating overloading	TREE-LENGTH (% Change)	1,537,440 (3.4%)	304,165 (0.8%)
	SHORTWOOD (% Change)	145,310 (1.4%)	137,440 (1.9%)
OVERLOADING & UNDERLOADING			
Net change if all loads were at the legal gross limit	TREE-LENGTH (% Change)	466,550 (1.0%)	4,418,230 (11.1%)
	SHORTWOOD (% Change)	272,330 (2.7%)	318,370 (4.4%)
EXCESSIVE TARE WEIGHT			
Ton-miles gained if no vehicle's tare weight exceeds 27,000 lbs.	TREE-LENGTH (% Change)	1,009,150 (2.2%)	247,104 (0.6%)
	SHORTWOOD (% Change)	29,120 (0.3%)	15,930 (0.2%)

[1] Assumes 1 million tons annual delivery
[2] Assumes 44 mile average haul

The most striking aspect of the scalehouse data is the width of the distributions of gross weight, especially for loads of tree-length. Table 10 shows estimates of the total annual impact if deviations above and below the legal maximum GVW were totally eliminated. In the first section of the table, the additional ton-miles which would result if underloading could be entirely eliminated is shown. The potential gain is particularly large for mill #3, possibly because *outer bridge* requirements leave many of these tractor-trailers with a legal GVW which is less than the maximum of 80,000 pounds. In the second section of the table the ton-miles which would be lost if overloading were entirely eliminated are shown while the third section shows the net impact of eliminating overloading and underloading. In every case, eliminating both overloading and underloading would result in a substantial net gain in average payload. The fourth section of Table 10 shows estimates of the potential gain from eliminating excessively heavy vehicles from the fleet. Vehicles were considered to be excessively heavy if their tare weight was in excess of 27,000 pounds, allowing 16,000 pounds for a tractor and 11,000 pounds for a trailer. The figures suggest that mill #3 might focus attention first on increasing average GVW while decreasing tare weight would be the first area of concern for mill #1.

Consider a situation where all loads arrive at the mill at or very close to the maximum legal GVW and no vehicles have a tare weight in excess of 27,000 pounds. Contract timber hauling rates depend on a variety of factors but typically are in the range $1.90 to $2.50 per loaded mile. Assuming $2.30 as the value of a loaded mile, crude estimates of the gross annual savings from moving to this situation are $153,000 and $431,000 for mills one and three respectively. Additional benefits would be the elimination of overweight fines and improved public relations. These figures should be considered as upper limits since the degree of movement toward this hypothetical situation would depend on the cost effectiveness of the measures which will be examined later. The contribution of tree-length to potential savings was much greater than that of shortwood for both mills. The relative importance of increasing GVW versus decreasing tare weight varies from mill to mill and from contractor to contractor.

Primary versus Secondary Hauling

In the data set from mill #1 it was possible to identify which loads came directly from the woods (primary hauls) and which had been transferred from outlying woodyards (secondary hauls). The gross weights of tree-length loads being transferred from outlying woodyards averaged almost 3,000 pounds heavier than those coming directly from the woods. The two groups showed similar exposure to overweight fines because the gross weight distribution of woods loads was much wider. Two factors contributed to the superior performance of loads from the woodyards. First, the ability to weigh loads at the outlying woodyards meant that deviations from the legal gross weight limit could be kept to a minimum. Second, where tree size would have limited payload, the technique was used of partially filling the rear bunk with random length wood before loading the tree-length stems. The mean tare weights for the two tree-length groups were almost identical. It would seem reasonable that the vehicles pulling from the outlying woodyards would need to be less rugged than those which have to travel rough woods roads. There may therefore be an opportunity to reduce the tare weight of the secondary haul trucks.

Variability Over Time

It has been suggested that some contractors tend to overload trucks early in the morning and late at night. If this is true, then it would account for some of the variability in gross weight. When the data for mill #3 were split into those loads arriving in the day (8:00 a.m. to 5:00 p.m.) and those arriving at other times, it was found that the daytime loads had a mean GVW 1,056 pounds lighter than those delivered at other times. Further, the percentage of loads exceeding 80,000 pounds decreases from 22 to 15 percent in the daytime. It should be emphasized that even at night the average gross of 75,768 pounds was still relatively low and well below the legal maximum. The extent to which this technique is used varies among contractors and wood types. The percentage of contractors whose gross increased by more than 1,000 pounds from the daytime mean was 80 percent for shortwood haulers but only 19 percent for tree-length haulers. This observation is consistent with the hypothesis that tree-length loads are frequently restricted by the height limit rather than the limit on gross weight.

A second possible source of variability in gross weight is seasonal variation due to changes in moisture content. According to Koch (1972) studies of moisture content of southern pines with changing seasons have been inconclusive. Those studies which did find seasonal differences found moisture contents higher in midwinter than in early summer. Plots of monthly means from the mill #3 data set revealed no obvious seasonal trends. This is not to say there was no seasonal variation in moisture content, only that if any such variation existed it was masked by other influences on mean gross weight.

Variability Between Contractors

The data set from mill #3 lent itself well to making comparisons between suppliers since a large number of observations was available for each supplier. After deleting suppliers of less than 50 loads per year, there remained 32 tree-length and 10 shortwood suppliers. The means and standard deviations of gross, tare and net weights were calculated for each supplier. The tree-length suppliers' average gross weights for the year ranged from 69,044 to 79,147 pounds. It is interesting to note that no supplier's average gross weight exceeded the legal maximum of 80,000 pounds even though approximately 15 percent of all loads exceeded this limit. In Figure 12 each supplier's mean gross weight is plotted against the percentage of loads exceeding 80,000 pounds. The summary of this data in Table 11 shows that shortwood contractors overloaded their trucks more frequently than did tree-length contractors. The data also suggest that contractors adopt a range of trade-off positions between maximizing gross weight and limiting exposure to overweight fines. Or, in other words, the data do not support the notion that all contractors load up to the point when the mar-

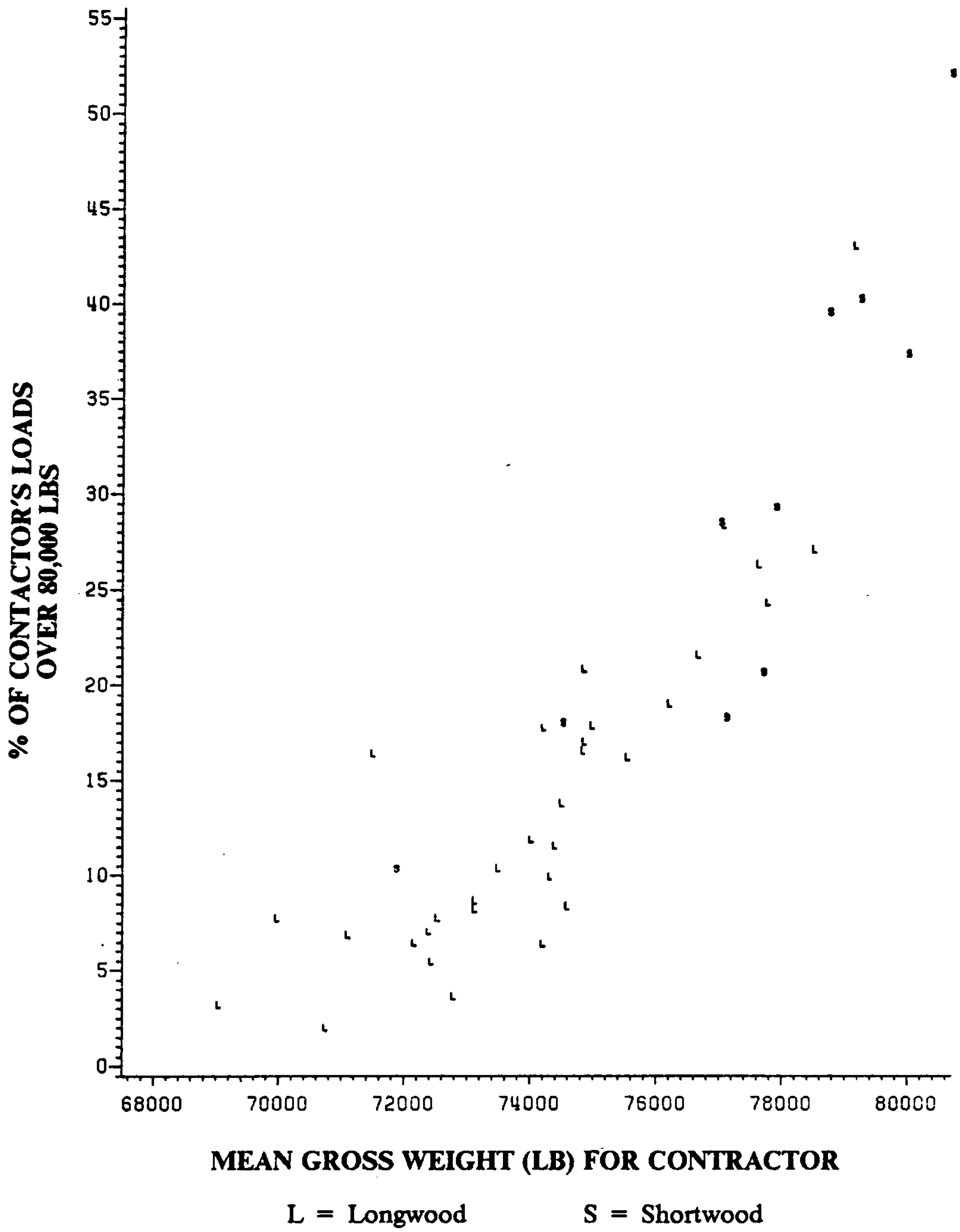


Figure 12. Percent of Loads Exceeding 80,000 lb vs. Contractor Mean Gross Weight

Table 11. Comparison of Overloading Frequency Between Tree-length and Shortwood Suppliers

PERCENT OF SUPPLIERS' LOADS EXCEEDING 80,000 LB	NUMBER OF SUPPLIERS IN CLASS	
	SHORTWOOD	TREE-LENGTH
0 - 15 %	1	18
15 - 30 %	5	13
> 30 %	4	1
TOTAL	10	32

ginal revenue from extra payload is equal to the marginal cost from overweight fines and operating costs.

Seven suppliers produced both tree-length and shortwood. All of these delivered overloaded shortwood loads much more frequently than tree-length loads. This suggests that a large percentage of the severely underloaded tree-length loads result from reaching the load height limit rather than from an effort to avoid overweight fines.

Pole versus Frame Trailers

The mill #3 data set also provided an opportunity to compare the use of pole and frame trailers. Over a six month period two contractors, one with pole and the other with frame trailers, were operating on the same tract in stands with similar characteristics. Comparative summary statistics for this period are presented in Table 12. Even though the pole trailer combinations weighed 3,471 pounds less, their average payload was only 462 pounds greater than that of the frame trailer combinations. The reduced tare weight did, however, result in considerably less exposure to overweight fines. There are two plausible explanations for these results; the contractor with pole trailers may be more averse to overweight fines, or the pole trailers may have had a smaller bunk area. Whatever the explanation, it is clear that the translation of decreased tare weight to pound for pound increases in payload cannot be taken for granted.

Table 12. Comparison Between Contractors using Pole Trailers and Frame Trailers

	A CONTRACTOR USING POLE TRAILERS	B CONTRACTOR USING FRAME TRAILERS
NUMBER OF LOADS	1,186	1,882
MEAN TARE WEIGHT	23,670	27,141
MEAN GROSS WEIGHT (Std. Dev. of GROSS)	74,259 (4,089)	78,192 (3,123)
MEAN NET WEIGHT (Std. Dev. of NET)	50,589 (4,144)	51,051 (3,226)
PERCENTAGE OF LOADS EXCEEDING:		
76,000 lb	32.5	81.8
78,000 lb	16.0	62.2
80,000 lb	7.3	25.3
82,000 lb	2.8	6.0
84,000 lb	1.4	1.3

Summary

The populations of tractor-trailer loads of roundwood entering the mills studied were characterized by wide distributions of gross weight. A rational goal for a socially responsible forest products company would be to encourage a simultaneous increase in gross weight and a decrease in gross weight variability, so that ultimately all loads would cross the scales at or very close to the maximum legal GVW. The attainment of this goal would result in an increase in average payload, reduction of overweight fines, and potential economic gains. There is evidence to suggest that with tree-length wood underloading often results from reaching the legal height limit. All three of the mills studied restricted the use of loading strategies which could alleviate this problem. Both underloading and overloading can also result from inability of loader operators to accurately estimate gross weight. It is also evident that some contractors overload deliberately on occasion, particularly early in the morning.

In the mills studied, tractor-trailers hauling tree-length would be a good group to target with efforts to increase payload. They delivered the greatest volume and, compared to tractor-trailers hauling shortwood, had lower gross weights with wider dispersion and a greater potential for tare weight reduction.

The Volume Problem

The problem of a vehicle reaching the legal height limit before the GVW or axle weight limits is most prevalent for tree-length loads cut from stands of small trees. Figure 13 shows the revenue which would be needed to generate a 12 percent internal rate of return for a range of GVW's under the assumptions listed in Table 7. In this figure it was assumed that all other elements in the trucking investment were unchanged. Usually an increase in GVW cannot be achieved without some expense. The change could, for example, require additional capital outlays, decrease the expected equipment life, increase repair and maintenance costs, or increase loading or unloading time. Suppose we are considering some change which is expected to increase GVW by an average of 2,000 pounds, and the revenue per ton-mile is $0.09. Such a change will have a net present value greater than zero provided that:

- the additional capital requirement does not exceed $9,300,
- the life of the equipment is not reduced by more than 55,000 miles,
- annual operating costs do not increase by more than $2,682,
- or trip cycle time does not increase by more than 12 minutes.

Two approaches can be taken to solving the volume problem. The first is to attempt to load more wood inside the same bunk area by adopting alternative loading strategies. The second is to increase

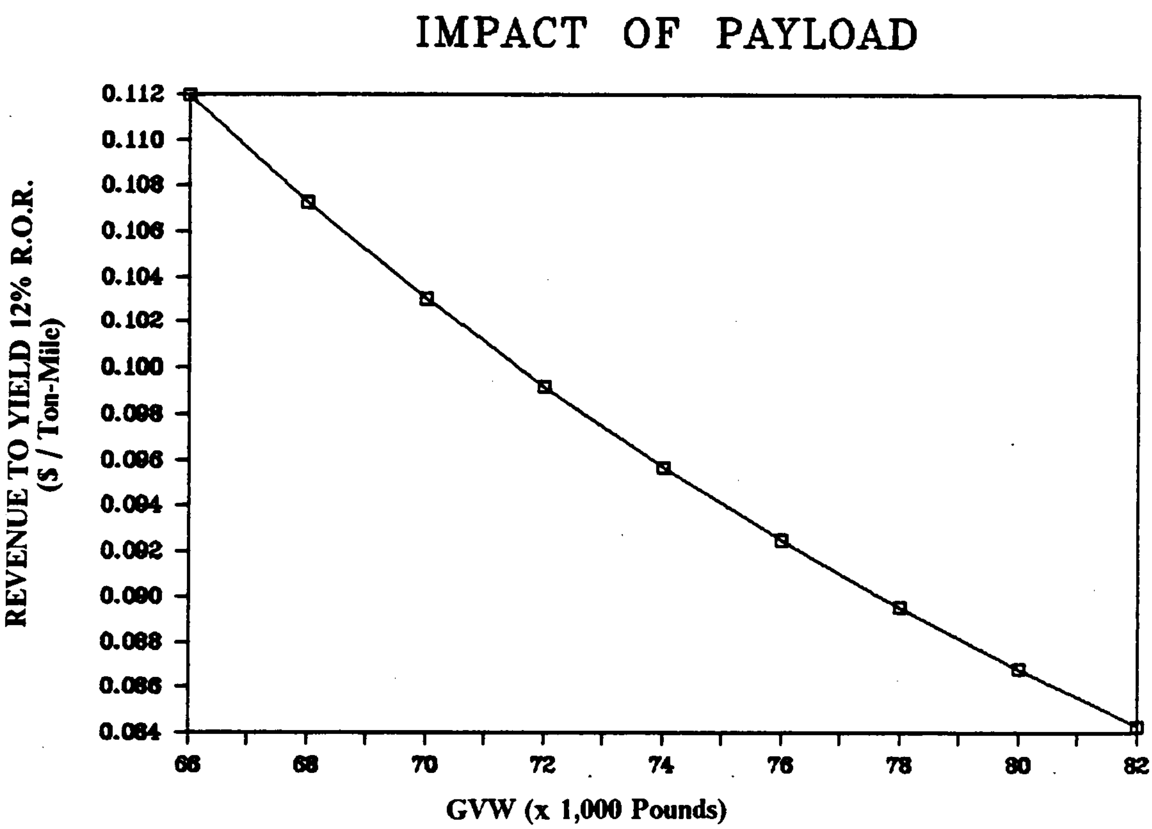


Figure 13. Impact of Payload on Revenue Needed to Generate 12% Return: In addition to the base case assumptions, it was assumed that the tractor trailer has a tare weight of 27,000 pounds.

bunk area by modifying or replacing equipment. These approaches are discussed below in terms of potential gains, appropriate applications, and barriers to implementation.

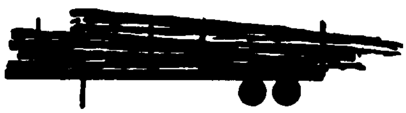
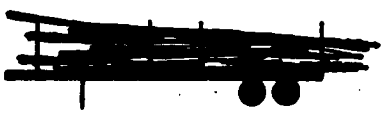
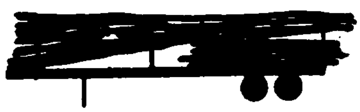
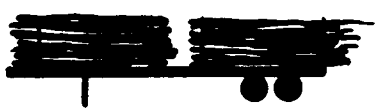
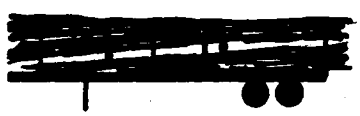
Alternative Loading Strategies

Five alternative loading strategies were identified which could increase bunk occupancy over conventional loading. A trial was conducted in which the same stems were loaded on a trailer using the conventional and three of the alternative loading strategies. The loaded trailer was weighed each time so that the increase in payload over conventional loading could be calculated. The increase in payload from the two strategies which were not included in this trial were estimated by company personnel where the strategies were in common use. The estimates of the gains from each loading strategy are shown in Table 13. In addition to the data on the quantitative benefits, qualitative information on the problems of implementing each strategy was collected from loggers and woodyard personnel. The five strategies are discussed below in order of increasing payload gain.

The technique of dropping the top one-quarter to one-third of the load back to the second pair of standards is used by Union Camp's company logging operations in Georgia for clearcut stems of 50 feet or less in length. Besides the increase in bunk occupancy, this strategy has the effect of improving axle weight distribution by transferring weight from the tractor tandems to the trailer tandems. The net effect is to move the load center of gravity two to three feet to the rear. The technique has no effect on loader productivity and unloading will be unaffected provided the load can still be kept as a single unit. Possible problems would be if the woodyard requires butt alignment to facilitate reclaim from inventory or because of slasher design.

The strategy of staggering butts, used by Weyerhaeuser Company in North Carolina, is essentially the same as the method above except that alternate grapple loads are staggered. It was being used

Table 13. Potential Payload Increases from Alternative Loading Strategies

LOADING STRATEGY	PLACE OBSERVED	ESTIMATED GAIN[1]
TOP LAYER STEPPED BACK TO SECOND STANDARD 	UNION CAMP GEORGIA	13-15%[2]
BUTTS STAGGERED 	WEYER-HAEUSER N. CAROLINA	18%[3]
COMBINED RANDOM LENGTH AND LONGWOOD 	CATAWBA TIMBER CO. S. CAROLINA	20-25%[2]
DOUBLE BUNK RANDOM LENGTH 	VARIOUS	30%[3]
BUTT TO TOP 	VARIOUS	35%[3]

[1] Assumes that weight restrictions are not limiting
[2] Estimated by company personnel
[3] Estimated by loading trial

with tree-length pine thinnings as short as 35 feet in length. The distance over which the butts are staggered can be varied according to the additional payload needed. As with all of the alternative loading strategies, weight is shifted from the tractor to the trailer tandems. Loading and unloading productivities are essentially unaffected but again there would be problems if woodyard constraints dictate butt alignment.

On hauls from woodyards to the mill, Catawba Timber Company in South Carolina frequently loads the rear trailer bunk one-third to one-half of the height of the standards with random-length longwood and then loads tree-length stems in the conventional manner. Productivity at the loading end of the operation will be reduced if the random-length wood must be produced especially for this purpose. Unloading productivity is reduced for cranes which would normally unload a truck in a one-pass operation. Other advantages are that a much larger space is created between the treelength stems and the trailer frame in which to maneuver the unloading grapple, and that tail light visibility is improved. Mill woodyards which routinely receive both treelength and random length material should experience no difficulty in implementing this system. However, woodyards with fixed radius circular boom cranes will lose storage capacity by handling random-length wood.

The technique of loading two bunks of random-length longwood is not normally used specifically to increase payload since it sacrifices all of the efficiencies of tree-length handling. It could be useful where a mechanical slasher is already present at the loading site.

Butt to top loading offers the greatest increase in payload but also presents the greatest barriers to implementation. The 35 percent estimated increase in payload is much lower than the 80 percent increase that can be inferred from the work of Lavoie (1980) in Canada. The difference may result from the fact that the trees in the loading trial were only roughly delimbed. It must be emphasized that only with the very smallest of trees would even a 35 percent increase in payload be possible without exceeding the legal GVW. The weight transferred to the trailer tandems is greater than for other alternatives, but this can be controlled by varying the percentage of stems loaded in each direction. The load can be split into two distinct piles with butts at either end of the trailer, or the oppositely oriented stems can be intermingled. Loader productivity will be reduced if the loader has to turn half of the stems. This can be avoided by skidding trees onto the deck from two directions. Butt to top loading is easier if the tractor is not attached to the trailer because this allows stems to be drag loaded from both directions. Unloading is simplest if the load can be treated as a single package and the stems allowed to remain switched. Common objections to this include *jackstrawing* in the unloading and reclaim operations, inefficient use of circular storage systems, and hangups in the slasher deck and conveyers from having butts pointing in both directions. All of these can be eliminated if the butts are switched back around in the same direction during unloading. This is often accomplished by separating the oppositely loaded piles with two logs laid crosswise. A front-end loader can easily pick off the top pile, disposing of this while the truck turns around. A variation is to park the truck on a ramp for unloading so that the underside of the top pile is level. These same techniques can be used with an overhead grapple if the cross logs are large enough.

A concern voiced by one procurement manager was that when loggers are allowed to use alternative loading strategies they take advantage of them to exceed legal weight limits. This demonstrates the need for mills to adopt comprehensive programs which deal simultaneously with overloading and underloading. Interviews with procurement and woodyard personnel suggest that frequently the reasons why mills do not allow alternative loading techniques are institutional rather than technical or economical. Woodyards are normally set up within corporations as cost centers and, as such, have no incentive to trade woodyard efficiencies off against transportation efficiencies. In such a situation one procurement group estimated the annual opportunity cost of forbidding butt to top loading and challenged the woodyard management to demonstrate that the cost of adapting to these loads would be greater than the savings. Butt to top loading was subsequently allowed on a limited basis.

Alternative Equipment Designs

By law, a loaded vehicle cannot normally have a cross-sectional area which exceeds 13.5 feet in height and 8.0 feet in width. Efforts to increase tree-length payloads by equipment modification must, therefore, increase the proportion of this profile which is occupied by wood. A typical road truck has a fifth-wheel height of 48 to 50 inches. The main beams of a log trailer have a depth of 8 to 10 inches at the neck and a bolster height of at least 6 inches. Thus, 5 to 5.5 feet of the available height is occupied by equipment rather than wood. The standards of the trailer are commonly made from 5 or 6 inch pipe, eliminating one foot from the legal horizontal dimension. Of the maximum legal cross-sectional area of 108 square feet, a typical log bunk will make available an inside area of only 56 to 60 square feet.

One way to increase bunk area is to use a drop- or goose-neck trailer. This design is essentially a lowboy trailer with log bunks. Existing trailers can be converted to this design or the drop-neck trailer can be purchased new. A disadvantage of the drop-neck design is that the ability to transport cut products, such as sawlogs and plywood logs, is lost. This problem could be overcome by designing a removable false bolster to fit in the second bunk at the same height as the bolster of the front bunk.

A second way of increasing inside bunk area is to fabricate tapered standards, using rectangular tubing rather than pipe. This design also has the advantage of saving weight and will be discussed further in the next chapter. The state of the art in high volume log-trailers was built and designed by Evans Manufacturing Company in 1985 of South Carolina in conjunction with Weyerhaeuser Company. Using a combination of the drop neck, tapered standards, and low profile tires, an inside bunk area of 72 square feet was achieved, an increase of between 20 and 30 percent over conventional models. Further, the tare weight was kept down to 10,800 pounds which compares favorably with the lighter conventional trailers.

Mills can contribute to maximizing bunk area by keeping the clearance they demand between the load and trailer frame to a minimum. To do this they must also ensure that their unloading system does not frequently cause damage to trailer frames.

The question arises of which is the appropriate strategy; alternative loading patterns or modified equipment designs. From the logger's point of view, alternative loading patterns would usually be preferable since there is no capital investment required and the flexibility of hauling cut products is retained. From the point of view of the mill, the decision depends on the magnitude of the underloading problem and the expense involved in facilitating alternative loading strategies. However, with trailers costing $10,000 to $12,000 each, the economics would seem to favor the implementation of alternative loading strategies.

The Weight Problem

A vehicle's payload may be limited by legal weight limits in two ways. Most obviously, the vehicle's payload cannot exceed the difference between its tare weight and the maximum legal GVW. In this case the only way to increase payload is to reduce vehicle tare weight. Payload can also be restricted because the load cannot be distributed over the vehicle's axles as required by law. Such cases require a change in axle configuration either through equipment modification or replacement.

Tare Weight Reduction

In many situations, tare weight reductions could be effected at virtually no cost if the decision maker were more aware of the economic impact of tare weight when making purchase decisions. Consider a company which contracts hauling on a per-mile basis. Figure 14 shows the effect of tare weight on transportation cost per ton on a 40 mile haul at a contract rate of $2.30 per loaded mile. When one large forest products company weighed the truck tractors of contractors hauling from its logging operations it found a 3,000 pound range in tare weight. If these tare weight differences translated directly to differences in payload, there would be a six percent difference in haul cost between the

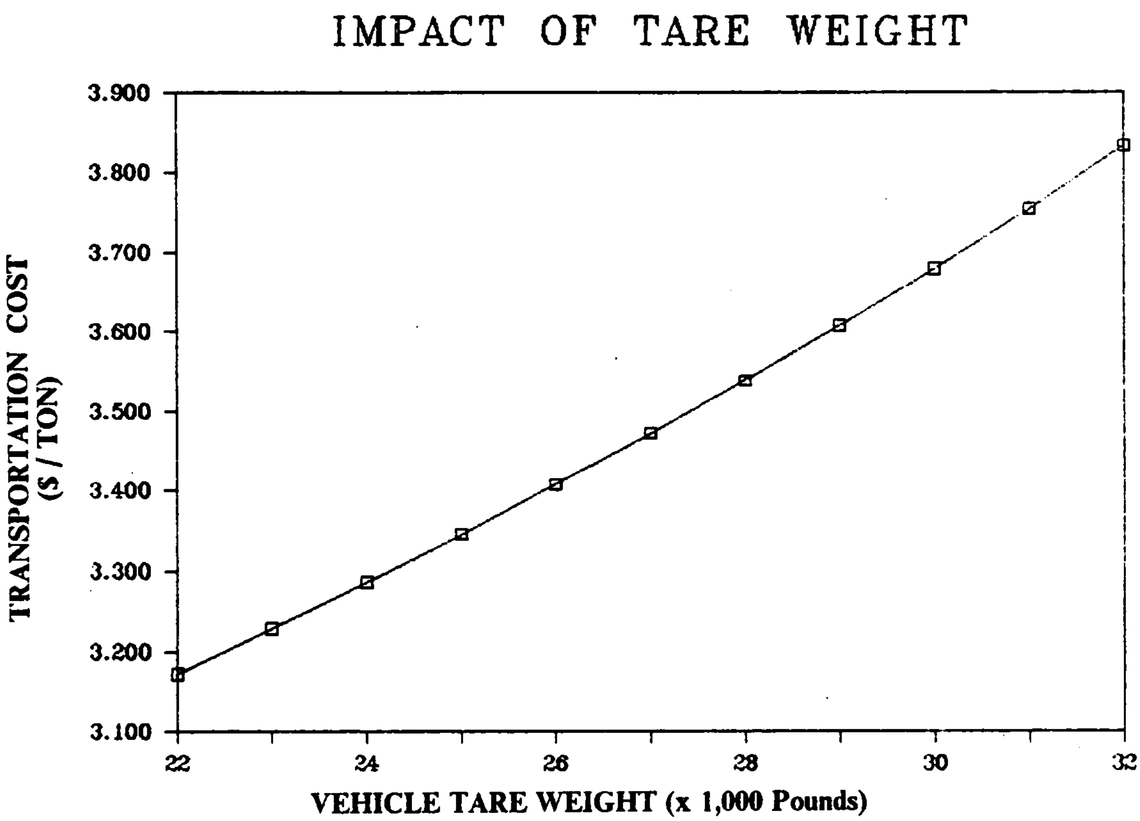


Figure 14. Influence of Tare Weight on Transportation Cost for Contract Hauling: Assumes a 40 mile haul, a contract rate of $2.30/ton-mile and 80,000 lb GVW.

heaviest and lightest tractor. In a set-out trailer system, if trailers are loaded to be legal when hauled by the heaviest tractor the impact of not discriminating between tractors of different weights would be even greater since all other tractors would then be underloaded. This problem could be approached in one of several ways. Wherever possible, paying for contract hauling on a per-mile basis should be avoided. Where this type of contract is used, tare weight should be a factor in contractor selection, or rates should be adjusted to reflect tare weight differences.

The economics of tare weight reduction are somewhat different from the point of view of the truck owner. Reducing tare weight will frequently involve additional capital expense or increased operating cost due to the use of less robust components. Under the base-case assumptions with a revenue of $0.09 per ton-mile, an action which reduces tare weight by 2,000 pounds would have a net present value greater than zero provided that:

- the additional capital required does not exceed $11,400,
- the life of the equipment is not reduced by more than 50,000 miles, or
- annual operating costs are not increased by more than $2,700.

These critical decision values apply only if the reduced tare weight translates pound for pound to increased payload. For this reason, it must be certain that payload will not be limited by other factors.

Tare weight reductions in truck tractors can be achieved through careful selection of components and the elimination of unnecessary equipment. Keeping in mind that, other things being equal, every pound added to the tractor's tare weight decreases its net present value by about $5 should be a useful aid for tractor specification. In the course of the project, the following suggestions for reducing tractor tare weight were collected from equipment manufacturers and transportation managers:

- Specify lightweight materials such as fiberglass for the cab and aluminum for the chassis rails.

- Eliminate superfluous and cosmetic equipment such as sleeper cabs.
- Estimate fuel tank needs carefully and do not install excess capacity.
- Radial tires are lighter than bias-plies and low-profile tires are lighter still.

In the interest of safety, some components should not be compromised. In particular, weight should not be trimmed by failing to install a sturdy cab guard.

Tare weight reductions may be possible by making small changes to the system in which the truck operates. An alternative to specifying tractors with heavy duty components to withstand rough woods roads would be to forward trailers out to surfaced roads with a set-out truck. Rocky Creek Logging Company of Alabama takes this idea one step further. On long hauls, heavy *woods tractors* bring loaded trailers to outlying woodyards or staging areas. These tractors are designed for low-speed fuel economy and do not haul more than 15 miles. The trailers are taken the remaining distance to the mill by *line haulers* which are lightweight and designed for maximum fuel economy at 50 miles per hour.

Tare weight reductions in trailers are possible through the selection of the most appropriate trailer type and by applying some engineering finesse to trailer design. Pole trailers weigh 3,000 to 6,000 pounds less than double-bunk frame trailers. However, pole trailers cannot carry log-length products and their use is limited to trees which are long and stiff enough to provide the required spacing between the tractor and trailer bogies. A possibility for future research would be to bind small trees together to form unitized loads which could overcome this problem.

Log trailers are usually sold on price and durability with scant consideration given to minimizing weight. Table 14 shows the weight of a typical modern double-bunk log trailer broken down to its constituent parts. The largest contribution to weight comes from the running gear, which offers little opportunity for weight reduction except by reducing rated capacity. The usual 7 or 8 leaf springs can be replaced with lighter 3 leaf springs of the same capacity but some manufacturers claim that this compromises safety. Air-ride suspensions would actually be heavier than conven-

Table 14. Weight Breakdown for a Typical Modern Double-Bunk Log Trailer

ITEM	MATERIAL	QUANTITY	WEIGHT
RUNNING GEAR	Includes: Springs, Axles, Wheels Rims, Brake Drums & Tires	-	4,000 LB
MAIN FRAME	18" WF @ 35 LB/FT	80 FT	2,800 LB
CROSSMEMBERS	12" WF @ 14 LB/FT	35 FT	490 LB
STANDARDS	5" SCHEDULE 80 PIPE @ 21 LB/FT	64 FT	1,330 LB
BOLSTERS	8" x 6" x 3/8" RECTANGULAR TUBE @ 33 LB/FT	32 FT	1,060 LB
LANDING GEAR		ONE	350 LB
FIFTH WHEEL PLATE	40" x 40" x 3/8" PLATE	ONE	170 LB
BUMPER		ONE	150 LB
MISCELLANEOUS			250 LB
TOTAL			10,600 LB

tional steel sprung suspensions but may offer potential for reducing the trailer frame weight since they provide a smoother ride. Modern axles, which have solid spindles friction welded into tubular shafts, are considerably lighter than older designs. Steel spoke wheels are lighter than conventional designs but some argue that with only five bolts they are more difficult to keep true. Although aluminum hubs are available, they are very maintenance sensitive and would save only 50 pounds per trailer. Low profile radial tires can be used to save weight and increase bunk area.

The second largest contribution to trailer weight is from the main trailer frame beams. Weight can be shaved from these by custom fabrication. Fontaine Truck Equipment Company of Alabama, for example, fabricate their own beams rather than using standard wide-flange beams. These beams are 22″ deep with 4″ x 3/4″ flanges. The web is 3/16″ thick with stiffening at frequent intervals. This beam weighs 33.4 pounds per foot and has a section modulus of 73.8 in^3 compared to 57.9 in^3 for a standard 18 inch wide-flange beam weighing 35 pounds per foot. Another advantage of these custom beams is that high tensile (grade 65) steel is used which is not available for stock beams.

The third major component of trailer weight is the log bunks. Critical loading of the standards occurs during the loading and unloading operations and causes maximum loading at the point of attachment to the bolster. A typical standard made from 5 inch Schedule 80 pipe has a section modulus of 7.4 in^3. The same or greater bending moment could be resisted by high tensile 5 inch square tubing with 1/4 inch wall thickness and a section modulus of 7.1 in^3. Eight foot standards made from this material and tapered down to one inch at the top, would weigh 122 pounds each, saving 350 pounds on total trailer weight. According to the economic model, this change would have a positive net present value provided it added no more than $998.00 to the price of each trailer.

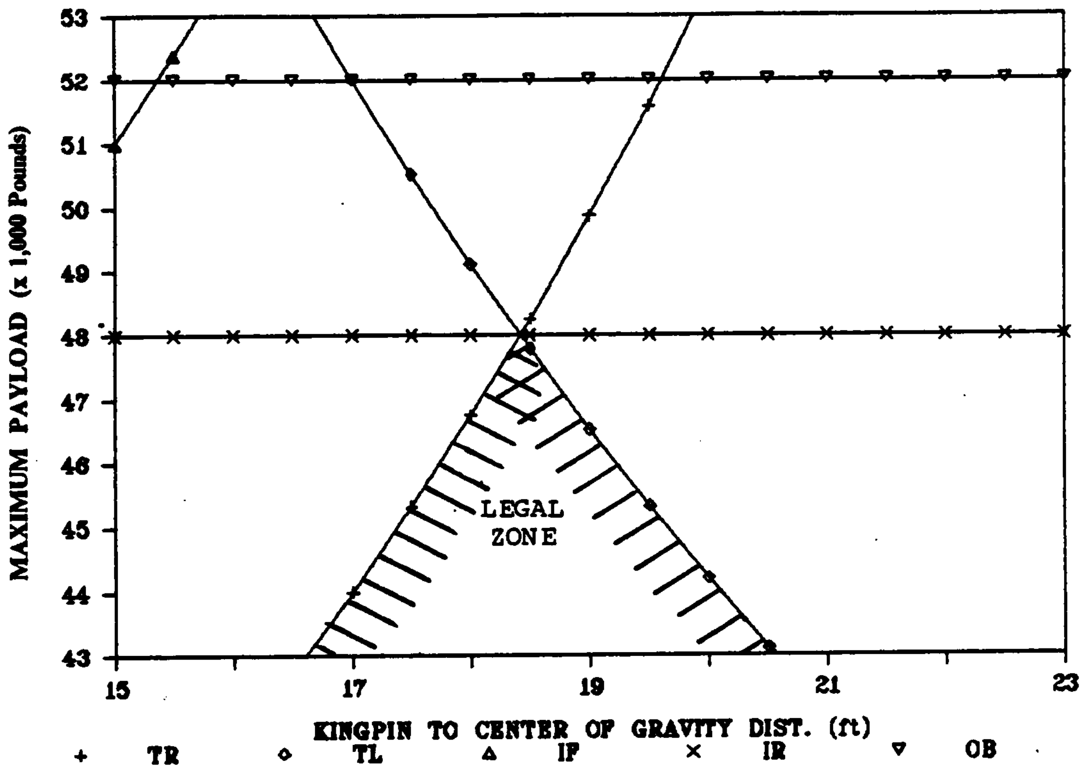
The state-of-the-art in lightweight trailer design is an experimental aluminum double-bunk log trailer designed by Union Camp's Frank Pickle in Savannah, Georgia. The trailer has a frame of 12 inch aluminum I-beams weighing 14.3 pounds per foot. The 8″ x 8″ bolsters were fabricated from 3/4 inch aluminum plate and the standards from 6.5 inch diameter, 3/4 inch wall aluminum tubing at 15.9 pounds per foot. The trailer has a tare weight of 7,800 pounds compared to 12,800 pounds for the trailers it is meant to replace, a savings of 5,000 pounds. After 20,000 miles, the only failure has been a standard which was broken by the unloading crane at the mill. It was estimated by a manufacturer experienced in aluminum trailer construction, that this design would cost approximately $18,000 to produce commercially, or about $6,000 to $8,000 more than a steel trailer. If the tare weight reduction is taken to be 5,000 pounds, the investment will have a positive net present value provided operating costs are not dramatically increased. However, steel trailers are available weighing only 3,000 pounds more for approximately $7,000 less. In a set-out trailer system requiring at least two trailers per tractor, the weight savings of 3,000 pounds at a capital cost of $14,000 is marginal under the assumptions of the economic model and leaves very little room for possible increases in repair and maintenance costs.

Optimizing Axle Configurations

The problem of achieving the required distribution of load over a vehicle's axles has been exacerbated by the introduction of the Federal Bridge Formula. As we noted earlier, eight southern states already require that the *outer bridge* complies with the formula and six states require *inner bridge* compliance.

Consider again the tractor-trailer in Figure 5. The plot of the Bridge Formula payload constraints in Figure 15 illustrates the load distribution problem for this configuration. Given sufficient spacing between axles one and five, this configuration has a legal GVW of 80,000 pounds and hence a maximum payload of 52,000 pounds. However, since each tandem is allowed only 34,000 pounds, and their combined empty weight is 20,000 pounds, the tandem axle constraints limit payload to 48,000 pounds. Even this payload is only legal if the load center of gravity is exactly 18.4 feet behind the kingpin. If, for example, we could be sure of estimating the load center of gravity location

BRIDGE FORMULA PAYLOAD CONSTRAINTS



ASSUMPTIONS			
Tractor Wheelbase	14.5 ft	Overall Length	55.0 ft
Trailer Length	40.0 ft	Fifth Wheel Offset	0.0 ft

AXLE GROUP	# OF AXLES	DISTANCE	BRIDGE LIMIT	TARE
Steering Axle (SA)	1	0.00	20,000	8,000
Tractor Bogie (TR)	2	4.00	34,000	12,000
Trailer Bogie (TL)	2	4.00	34,000	8,000
Inner Bridge - Front (IF)	3	16.50	48,500	20,000
Inner Bridge - Rear (IR)	4	38.00	68,000	20,000
Outer Bridge (OB)	5	50.50	80,000	28,000

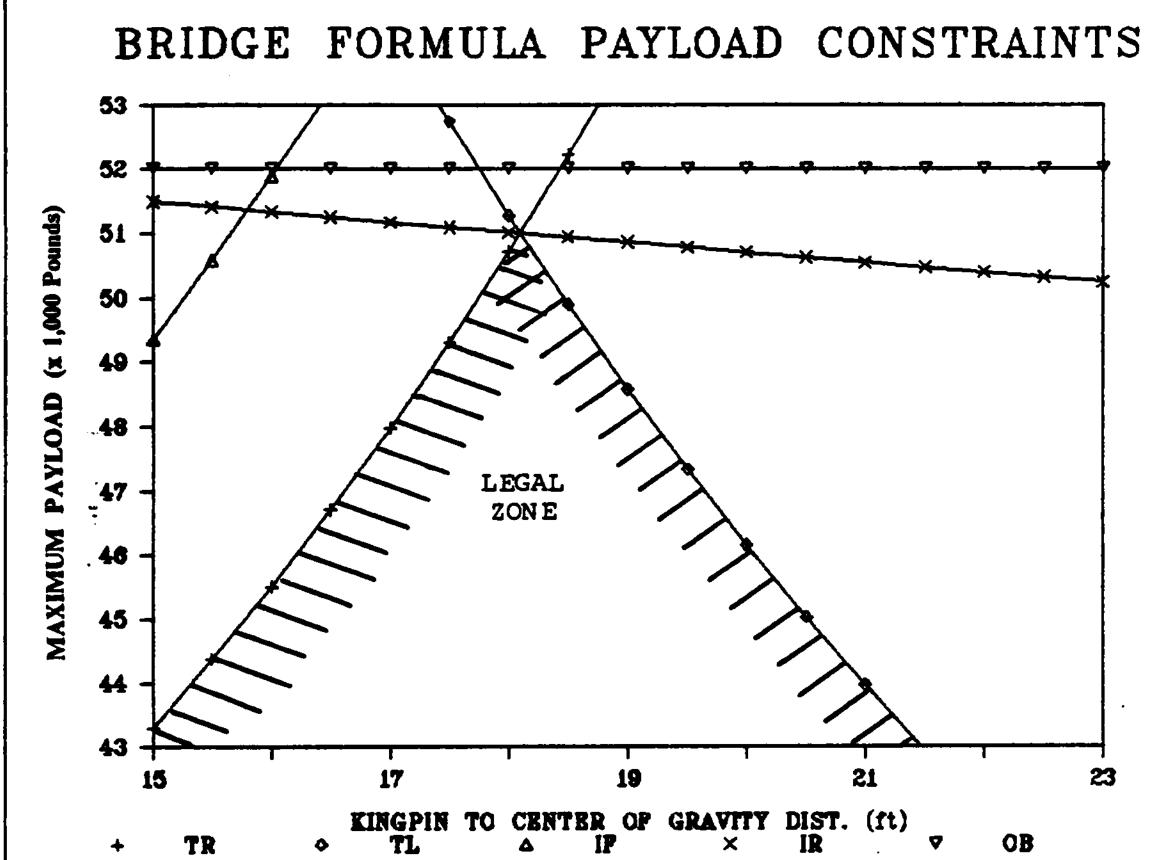
Figure 15. Payload Constraints for a Typical Tandem Tractor and Tandem Trailer

to within only two feet of its actual location, then payload would have to be cut back to 43,000 pounds to ensure full legal compliance.

One way to alleviate this problem is to set the tractor fifth wheel ahead of the tandem center so as to transfer weight to the steering axle. Figure 16 shows that using an 18 inch offset transfers approximately 3,000 pounds to the steering axle giving a payload of 51,000 pounds. To be legal at this payload, the load center of gravity must be located in precisely the correct place. Also, most truck drivers do not like to carry this much weight on the steering axle since it makes steering difficult and could be dangerous in a blowout situation. However, a smaller fifth wheel offset can be used to improve on the other configurations discussed here.

A solution to weight distribution under the Bridge Formula which is becoming increasingly common on the Interstates is to spread the trailer axles nine or more feet apart to increase the limit for the trailer bogie to 39,000 pounds. It can be seen from Figure 17 that the payload of this configuration is now limited by the rear *inner bridge* constraint (axles two through five). In this example the trailer length was increased to 45 feet but even so the rear *inner bridge* limit was not raised sufficiently to allow the maximum legal payload. Another problem is that the load center of gravity must now be positioned at least 20.5 feet behind the kingpin, which would be difficult with tree-length stems less than 60 feet in length. Operational difficulties with the spread tandem configuration are that it may be difficult to turn on logging roads and tire wear may be excessive.

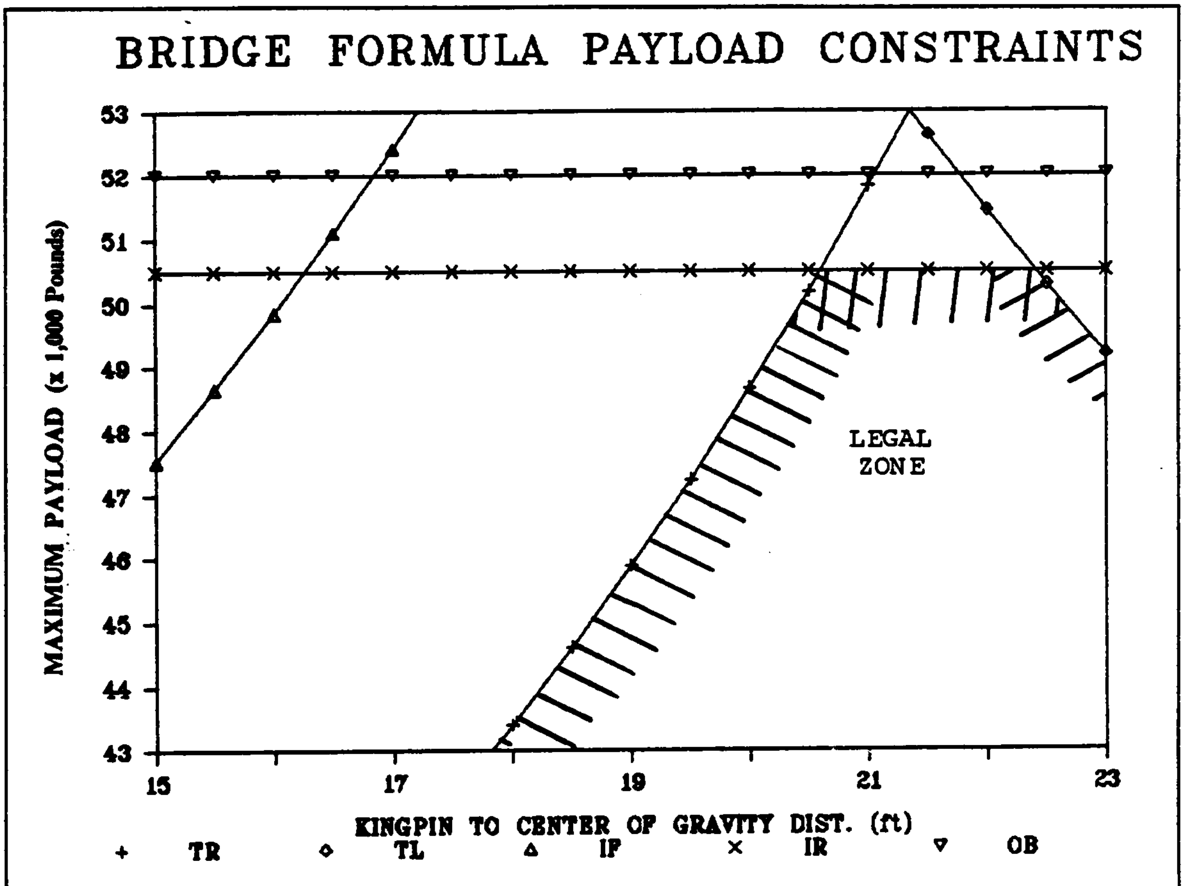
The next alternative is to increase the number of axles under the vehicle. Since each additional axle increases tare weight by 1,500 to 2,000 pounds, configurations with more than 6 axles do not make much sense in states where GVW is limited to 80,000 pounds. Figure 18 shows how the payload constraints are modified by using a triaxle trailer, assuming the extra axle adds 1,500 pounds to tare weight. With a payload of 50,500 pounds and a sweet spot width of almost 3 feet, this is the best configuration considered thus far. The trailer is not excessively long and the sweet spot is in a reasonable position relative to the kingpin. If this configuration were adopted the challenge would be to minimize the weight penalty of the third axle. One way to do this is to mount only single wheels



ASSUMPTIONS			
Tractor Wheelbase	14.5 ft	Overall Length	55.0 ft
Trailer Length	41.5 ft	Fifth Wheel Offset	1.5 ft

AXLE GROUP	# OF AXLES	DISTANCE	BRIDGE LIMIT	TARE
Steering Axle (SA)	1	0.00	20,000	8,414
Tractor Bogie (TR)	2	4.00	34,000	11,586
Trailer Bogie (TL)	2	4.00	34,000	8,000
Inner Bridge - Front (IF)	3	16.50	48,500	20,000
Inner Bridge - Rear (IR)	4	38.00	68,000	19,586
Outer Bridge (OB)	5	50.50	80,000	28,000

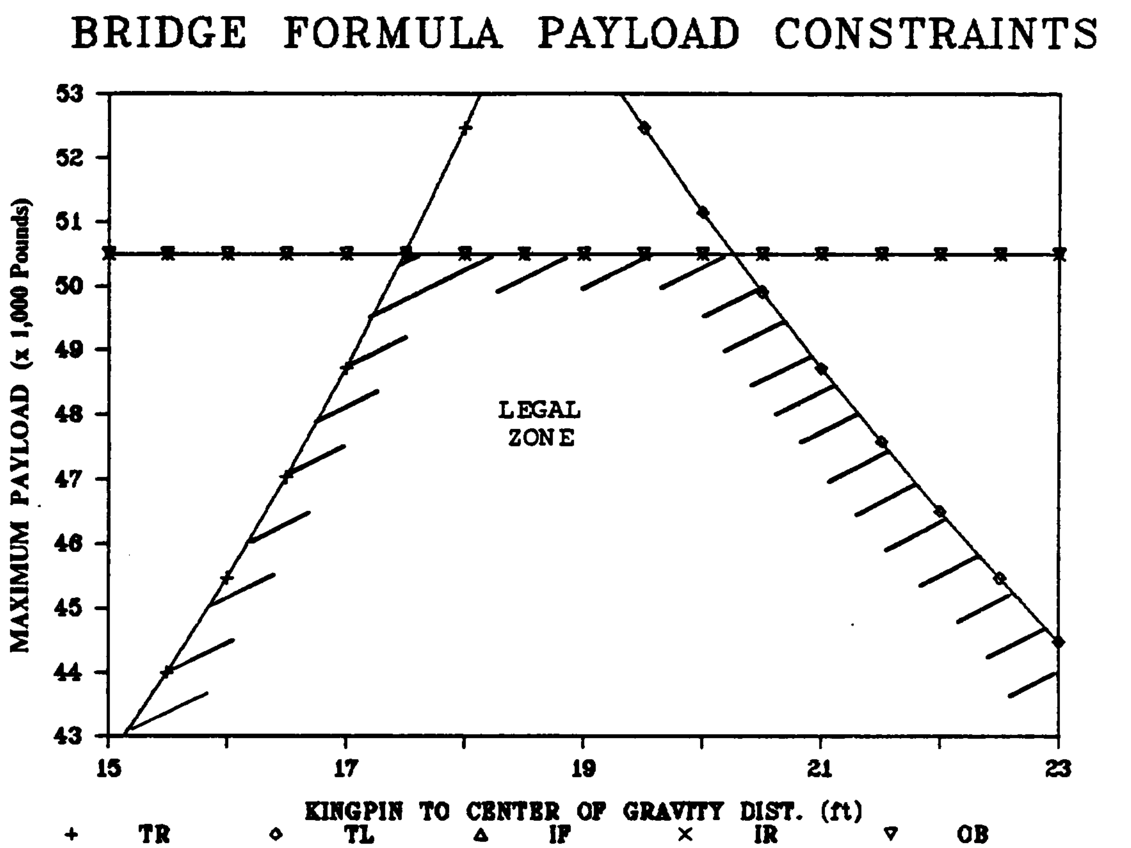
Figure 16. Payload Constraints for Tandem Tractor & Tandem Trailer With Fifth Wheel Offset



ASSUMPTIONS			
Tractor Wheelbase	13.5 ft	Overall Length	59.0 ft
Trailer Length	45.0 ft	Fifth Wheel Offset	0.0 ft

AXLE GROUP	# OF AXLES	DISTANCE	BRIDGE LIMIT	TARE
Steering Axle (SA)	1	0.00	20,000	8,000
Tractor Bogie (TR)	2	4.00	34,000	12,000
Trailer Bogie (TL)	2	9.00	39,000	8,000
Inner Bridge - Front (IF)	3	15.50	48,000	20,000
Inner Bridge - Rear (IR)	4	43.00	70,500	20,000
Outer Bridge (OB)	5	54.50	80,000	28,000

Figure 17. Payload Constraints for Tandem Tractor & Spread Tandem Trailer



ASSUMPTIONS			
Tractor Wheelbase	14.5 ft	Overall Length	54.5 ft
Trailer Length	39.5 ft	Fifth Wheel Offset	0.0 ft

AXLE GROUP	# OF AXLES	DISTANCE	BRIDGE LIMIT	TARE
Steering Axle (SA)	1	0.00	20,000	8,000
Tractor Bogie (TR)	2	4.00	34,000	12,000
Trailer Bogie (TL)	3	9.00	42,500	9,500
Inner Bridge - Front (IF)	3	16.50	48,500	20,000
Inner Bridge - Rear (IR)	5	37.50	72,000	21,500
Outer Bridge (OB)	6	50.00	80,000	29,500

Figure 18. Payload Constraints for Tandem Tractor & Triaxle Trailer

on the third axle and have it carry only one fifth of the bogie weight. This unequal loading can be achieved either with an air-ride suspension or by using asymmetric equalizer arms. Another approach would be to mount single wide tires, rated at 7,500 pounds or more, on all three trailer axles. This configuration is very common in parts of Europe and warrants further investigation.

A more radical version of the tandem tractor and triaxle trailer could be based on a configuration proposed by Wilson (1980) shown in Figure 19. Advantages include increased bunk area at the butt end of the trees, good load distribution and the elimination of overhanging tops at the rear. A useful modification might be to use a cab-over-engine tractor with a long wheelbase so as to eliminate the need for the tops to hang over the cab.

In some parts of the U.S., straight trucks pulling full trailers are commonly used for hauling timber. This configuration has the advantage that the axles are relatively evenly spaced, as is required by the Bridge Formula. However, with so many woodyards already converted to tree-length handling, it seems unlikely that this configuration will become commonplace in the South.

So far we have concentrated on adapting truck configurations to meet the difficult requirements of the Federal Bridge Formula. Another common approach has been to lobby to have state regulations modified to meet the difficult requirements of the forest products industry. Several approaches are possible, and each is accompanied by a different set of justifying arguments. The most common is to request that the tandem limit be increased because of the difficulty in locating the centers of gravity of loads of trees loaded in the woods. Increasing the tandem axle limit effectively increases the *sweet spot* width in Figure 15, but payload is still limited by the rear *inner bridge* limit. Thus, the next argument is that all inner bridge restrictions should be lifted since very long log trailers are difficult to maneuver on woods and rural roads. A different strategy is to accept all of the requirements of the Federal Bridge Formula but request that the 80,000 pound ceiling be raised to compensate for the weight of the extra axles which are needed for compliance. This argument actually makes a lot of sense since if the Bridge Formula does what it is meant to do, there is no logical reason for truncating it arbitrarily at 80,000 pounds.

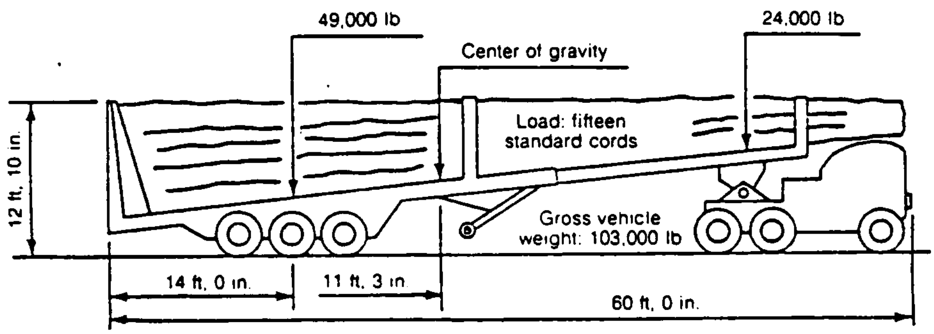


Figure 19. Tandem Tractor and Triaxle Trailer Proposed by Wilson (1980)

The Control Problem

In the mill case studies it was noted that there is a high degree of variability in GVW, particularly for tractor-trailer loads of tree-length stems. In some cases this is the result of physical constraints such as inability to reach the maximum legal GVW with small trees. Differences between vehicles may exist if *outer bridge* requirements give varying legal GVW. However, a considerable amount of variability is due to the inability of loader operators to control GVW precisely. We can envision a process where the loader operator, consciously or subconsciously, loads a trailer until he estimates some target GVW has been reached. The actual GVW could lie several thousand pounds to either side of the target, depending on the operator's estimating skill. Further variability will result if the target is adjusted to match fluctuations in the risk of being weighed by enforcement officials.

Companies which utilize timber as a raw material have an interest in seeing the GVW's of trucks arriving at their mills kept within a fairly narrow range; not so low as to be inefficient nor so high as to be unsafe or damage relations with the public or state transportation officials. The producers who supply wood to these companies also have a target range which is as high as possible without incurring excessive overweight fines. In this chapter, the use of existing and additional sources of information to improve control over GVW will be examined.

Control Using Scalehouse Data

Historically, payments for loads of wood were based on calculations of volume from stick measurements. Traditional stick scaling has gradually been replaced in most mills by weight scaling which requires less labor and is more accurate. Recently, some mills have computerized their scalehouses so that information on each load is fed directly into the computer. This change has been motivated by the need to streamline payment procedures and provide timely information on wood flows. A by-product of this innovation is the existence of a database from which a wealth of information to improve GVW control can be extracted at very low cost. To demonstrate some possible uses of this database a scenario using the data from case study mill #3 was developed.

The first step in exploiting the scalehouse database is to develop a set of target ranges and goals for GVW. These should define what ranges of GVW are acceptable and set goals for the percentage of vehicles within each range. Different target ranges will be required for different vehicle and, possibly, product types. A possible target and goal system for tree-length pine is shown in Table 15. In developing such a system it may be prudent to involve the state's Department of Transportation so that they become sensitized to the problems of hauling timber and are made aware that the objective is to decrease overloading as well as underloading. By demonstrating concern for the problem of overweight vehicles it may also be possible to reduce the attention paid by the Weight Enforcement Division to vehicles delivering to the mill. Notice that the *acceptable* range has a midpoint of 79,500 pounds rather than 80,000 pounds so as not to give the impression of encouraging loggers to overload. Similarly, larger percentages of the loads in the underloading categories were considered tolerable than in the overloading categories. Ultimately it would be desirable for all loads to be in the *acceptable* range, but goals should be set within the realm of what is considered achievable. If the goals in Table 15 were attained, there would be a 4,500 pound increase in the average payload for loads of treelength, as well as a considerable decrease in overloading.

Table 15. Example System of Target GVW Ranges and Goals for Tree-Length Pine at Mill #3

CURRENT G.V.W. DISTRIBUTION		
G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	
		0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	48.1	********************
Moderately Underloaded (75,000 - 78,000 lb)	21.5	*********
Acceptable Range (78,000 - 81,000 lb)	20.2	********
Moderately Overloaded (81,000 - 84,000 lb)	6.9	***
Severely Overloaded (more than 84,000 lb)	3.4	*
Average GVW	74,800 lb	

G.V.W. DISTRIBUTION GOALS		
G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	
		0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	5% Max	**
Moderately Underloaded (75,000 - 78,000 lb)	10% Max	****
Acceptable Range (78,000 - 81,000 lb)	80% Min	**********************************
Moderately Overloaded (81,000 - 84,000 lb)	4% Max	**
Severely Overloaded (more than 84,000 lb)	1% Max	*
Average GVW	79,300 lb[1]	

[1] Average based on range midpoints weighted by goal percentages.

The scalehouse database can be used to facilitate progress from the current GVW distribution to the target. The computer can be programmed to produce a report for each vendor which shows his performance and compares it to that of his competitors. This could be generated on a periodic basis and included with the settlement check. Procurement foresters could also use these reports to work with contractors to improve their performance and to target chronic overloaders. The challenge in designing this report is to motivate the wood supplier to increase payloads by eliminating underloading rather than by overloading more frequently. Comparative information on net weight was not included since this might encourage increasing payload irrespective of whether this increased overloading. The first report, at least, should be accompanied by a careful explanation of its purpose and how it should be interpreted. Better still, the report could be distributed at first on a trial basis through the procurement foresters or contract logging administrators. This would provide the opportunity to discuss the causes of underloading and solicit ideas on how the report could be designed to be more useful. To demonstrate possible uses for the scalehouse data base, Tables 16, 17 and 18 show sample reports for three of the vendors delivering to mill #3.

The first report (Table 16) is an example of a good GVW distribution, showing that the goals we set are probably attainable. This distribution is characterized by an average GVW which is close to the legal limit and by very little underloading or overloading. This operation is run by a logger who owns one logging side and does his own hauling. He is well respected by the pulpmill procurement foresters and considered to be a good businessman. During the sample period the crew was operating in the Piedmont, 50 miles north of the pulpmill. In this area there is no chip-n-saw market and the local sawmill has a 14 inch minimum butt diameter limit which is strictly adhered to. This combination of tract type and market conditions meant that there was no difficulty in attaining full payloads of tree-length pulpwood. The tight GVW distribution was accomplished with the aid of on-board scales.

The report for vendor B in Table 17 shows a GVW distribution which is centered close to the legal maximum but is too spread out. This vendor is a dealer whose loads are harvested by up to four different contractors. Some of these tended to underload while others frequently overloaded, re-

Table 16. Loading Performance Report For Vendor A

Loading Performance Report	Vendor # A	Period: September 1985
YOUR G.V.W. DISTRIBUTION		
G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	2.5	*
Moderately Underloaded (75,000 - 78,000 lb)	28.0	***********
Acceptable Range (78,000 - 81,000 lb)	61.9	*************************
Moderately Overloaded (81,000 - 84,000 lb)	5.9	**
Severely Overloaded (more than 84,000 lb)	1.7	*
Your Average GVW	78,850 lb	
MILL G.V.W. DISTRIBUTION		
G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	48.1	*******************
Moderately Underloaded (75,000 - 78,000 lb)	21.5	*********
Acceptable Range (78,000 - 81,000 lb)	20.2	********
Moderately Overloaded (81,000 - 84,000 lb)	6.9	***
Severely Overloaded (more than 84,000 lb)	3.4	*
Mill Average GVW	74,800 lb	
TARE WEIGHT COMPARISON		
AVERAGE TARE WEIGHT FOR VEHICLE TYPE		26,540 lb
YOUR AVERAGE TARE WEIGHT THIS PERIOD		27,338 lb

Table 17. Loading Performance Report For Vendor B

Loading Performance Report	Vendor # B	Period: September 1985

YOUR G.V.W. DISTRIBUTION

G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	11.6	*****
Moderately Underloaded (75,000 - 78,000 lb)	17.7	*******
Acceptable Range (78,000 - 81,000 lb)	29.9	************
Moderately Overloaded (81,000 - 84,000 lb)	25.0	**********
Severely Overloaded (more than 84,000 lb)	15.8	******
Your Average GVW	80,130 lb	

MILL G.V.W. DISTRIBUTION

G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	48.1	*******************
Moderately Underloaded (75,000 - 78,000 lb)	21.5	*********
Acceptable Range (78,000 - 81,000 lb)	20.2	********
Moderately Overloaded (81,000 - 84,000 lb)	6.9	***
Severely Overloaded (more than 84,000 lb)	3.4	*
Mill Average GVW	74,800 lb	

TARE WEIGHT COMPARISON

AVERAGE TARE WEIGHT FOR VEHICLE TYPE	26,540 lb
YOUR AVERAGE TARE WEIGHT THIS PERIOD	27,921 lb

sulting in a very wide GVW distribution. It would be difficult in this case for the company owning the pulpmill to effect any improvement in the lower side of the GVW distribution since they have no direct contractual relationship with the parties responsible for loading. Some control can be exercised over the overloading side of the distribution through a penalty system. Two of the case study mills employed GVW ceilings, above which they would not pay for wood delivered. Other mills in the South penalize overloading by reducing the vendor's quota for the following week. The problem with both systems is that the logger is penalized on a load by load basis instead of for poor performance over a period of time. The result can be that instead of aiming to load each load at the legal limit, loggers may load as heavily as they possibly can without reaching the point at which sanctions are applied. A better system might be to penalize overloading on a periodic basis. At the end of each month the logger could have his quota reduced for exceeding target values for the moderately and severely overloaded GVW ranges. This would discourage overloading while recognizing that, even with the best intentions, some loads will inevitably exceed the legal limit.

The last report (Table 18) exemplifies the chronic underloading problem. This dealer used a contract logger for tree-length harvesting who was considered to be quite low on the scale of professionalism. The wood was harvested on the Coastal Plain from an area 50 miles to the south of the pulpmill. In this area there is a very competitive market for chip-n-saw material down to a 10 inch butt diameter. The remaining pulpwood consists of only small trees making full payloads difficult to attain. This is a good example of a situation where allowing butt to top loading would improve trucking efficiency.

The most useful aspect of generating performance reports may be simply heightening awareness of the importance of loading control. A loader operator who has been given goals for GVW values is likely to be more conscientious and take more interest in each scale ticket that the truck drivers bring back from the mill. Beyond this, closely monitoring loading performance is a necessary step in evaluating options for increasing payload.

Table 18. Loading Performance Report For Vendor C

Loading Performance Report	Vendor # C	Period: September 1985

YOUR G.V.W. DISTRIBUTION

G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	86.1	***********************************
Moderately Underloaded (75,000 - 78,000 lb)	11.1	****
Acceptable Range (78,000 - 81,000 lb)	2.8	*
Moderately Overloaded (81,000 - 84,000 lb)	0.0	
Severely Overloaded (more than 84,000 lb)	0.0	
Your Average GVW	70,500 lb	

MILL G.V.W. DISTRIBUTION

G.V.W. RANGE	PERCENTAGE OF LOADS IN RANGE	0% 20% 40% 60% 80%
Severely Underloaded (less than 75,000 lb)	48.1	********************
Moderately Underloaded (75,000 - 78,000 lb)	21.5	*********
Acceptable Range (78,000 - 81,000 lb)	20.2	********
Moderately Overloaded (81,000 - 84,000 lb)	6.9	***
Severely Overloaded (more than 84,000 lb)	3.4	*
Mill Average GVW	74,800 lb	

TARE WEIGHT COMPARISON

AVERAGE TARE WEIGHT FOR VEHICLE TYPE	26,540 lb
YOUR AVERAGE TARE WEIGHT THIS PERIOD	27,210 lb

Control Using Weighing Devices

It has already been pointed out that some of the variability in GVW is attributable to the loader operator's inability to precisely estimate the weight of wood on a trailer. Thus, any device which can improve the quality of this estimate should reduce GVW variability. Since load weighing devices are the subject of a separate research project here, they will not be covered in detail. However, this report would be incomplete without an overview of the subject and an examination of the factors affecting the economics of such devices.

Load weighing devices can be mounted on the truck, on the loader, or independent of both truck and loader. The simplest on-board truck device is a plumb-bob which measures deflection of the suspension springs. Since this has practically zero capital cost, savings need only compensate for the time involved in calibration and inspection to justify its use. The next level of sophistication is to use an air pressure gauge to estimate axle loads on vehicles equipped with air suspensions. Since very few log trucks in the South currently use air suspensions this option is not usually available to the logging industry. However, if air suspensions are being considered for some other reason, such as the ability to lift a trailer off its landing gear, then the ability to inexpensively weigh loads may be an important factor in the decision. Electronic scales are the most common on-board weighing device and are finding increasing application in southern logging. Mechanically induced stresses in load cells are measured electronically and converted to some measure of vehicle or axle weight. On tractor-trailers, one load cell is usually located between the center spring hanger and frame on each side of the trailer bogie and two more are mounted between the fifth wheel and tractor frame. With this layout, a digital indicator in the cab can give readings for axle weights and GVW. If a set-out trailer system is used, the fifth wheel load cells and indicator can be mounted in the set-out truck in order to reduce the capital cost of the system.

Loader based weighing systems were first used in front-end loaders. These use pressure transducers to measure the pressure in the lift cylinders. The indicator has an addition function to keep track of the accumulated weight in the load. Recently, attempts have been made to adapt this technology to knuckle-boom loaders. In order to get consistently accurate results, the stick boom and main boom must always be in the same position for weighing and the load center of gravity must be a constant distance from the grapple.

Independent weighing systems commonly use the electronic load cell technology packaged in transportable platforms. Difficulties in using these in logging applications arise because they require a hard level surface in order to be accurate.

All load weighing devices have one benefit in common; they give an improved estimate of GVW or axle weights over the loader operator's visual estimate. A loader operator may, for example, be able to visually estimate GVW to within 3,000 pounds for 90 percent of loads. With on-board electronic scales the estimate may be within 1,000 pounds for 90 percent of the loads. Thus, it is important to know by how much a weighing device will reduce the variance of weight estimates over the visual alternative. In making such a comparison, the loader operator's skill at visual estimation should first be developed to the highest possible degree by asking him to estimate the weight of each load and then comparing his estimates to the scalehouse tickets. It may be possible to improve these estimates by, for example, counting the number of trees which go into each load. A possible way of improving axle weight distribution would be to mark the *sweet spot* on the trailer. The loader operator could then find the approximate balance point of a grapple load of trees and align it with the mark to give the optimum weight distribution. Only when the minimum variance for visual estimation has been achieved can a fair comparison with with a mechanical estimation method be made.

The greatest difficulty in evaluating a weighing device lies in determining the economic impact of reducing the variance of weight estimates. Suppose for the moment that loggers adopt a target GVW which maximizes their profit. This target would be at the point where the marginal revenue from increasing payload is equal to the marginal cost of additional overweight fines and operating expenses. Reducing the variance of actual GVW's around the target would allow the target to be increased by reducing the marginal cost of overweight fines. In reality, loggers do not have sufficient information to maximize profit by equating marginal costs and revenues. Instead, they attempt to maximize profit by employing a variety of strategies. A logger may choose to always shoot for the maximum legal payload, in which case the direct benefit of scales will be to reduce overweight fines. Alternatively, he may decide that a certain number of overweight fines per month is acceptable, in which case scales will allow him to increase his average GVW while paying out the same amount in overweight fines. Using scales can also result in a complete change of strategy. Without scales a logger may deliberately overload and operate his trucks at night or make detours on secondary roads. Such evasive techniques are associated with longer delays, unnecessary mileage and inconvenience for the truck driver. Under these circumstances the logger may decide to install scales and operate at the legal limit even if this decreases his average payload and has no impact on his overweight fines costs.

The cost of a load weighing device can include several elements in addition to the capital and operating costs of the device itself. Using the device will slow down loading if adjustments to the load must be made. If the loader is not fully utilized, as is often the case in southern logging operations, there could still be an economic impact due to delays to trucks. If the loader does approach full utilization, then delays to all upstream phases of the operation must be considered.

From this discussion it should be apparent that there is more to the decision of whether to invest in scales than simply trading capital costs off against increased payload or decreased fines. The following guidelines are written for the logger who provides his own trucking:

1. Examine the current distribution of GVW's and check that all prospects for improvement have been exhausted before considering an investment in scales.

2. Using an estimate of the accuracy of the candidate weighing device, and taking into account any probable change in strategy, estimate what the new GVW distribution is likely to look like. Do not make the mistake of assuming that loads which were light because of the height limit will be changed by the acquisition of scales.

3. Calculate the change in average payload and determine the associated change in cash flows. If the operation's productivity is limited by the trucking phase, an increase in the average GVW will result in an increase in the volume delivered to the mill, and hence an increase in revenue. More commonly, some other phase will limit productivity, and increasing payload will result in a decrease in the number of trips and hence a reduction in trucking variable costs. If using the scales is expected to affect loader productivity, estimate the impact on system productivity.

4. From the current and projected GVW distributions, estimate the change in the annual bill for overweight fines.

5. The net change in annual cash flows is estimated from the sum of the following elements:

   - Revenue from increased production
   - Savings from reduced variable costs
   - Change in overweight fines
   - Repair and maintenance of scales

6. Use the capital cost of the scales and the estimated change in annual cash flows to calculate the investment decision criterion of your choice. Before making a final decision, consider any possible changes which were were not quantified in the analysis. Operating at a constant payload may, for example, facilitate production planning and system balancing.

Even if a logger comes to the conclusion that scales are not a good investment, the decision should be re-evaluated periodically. Actions by the state, such as increasing overweight fines, changing axle weight distribution requirements or boosting weight limit enforcement efforts, will make investment in scales more attractive. Similarly, mills taking sanctions against chronic overloaders will influence the decision.

Summary and Conclusions

The objective of this research project was to investigate the potential for decreasing timber transportation costs in the South through increasing payload. Three general problem areas which can cause payloads to be restricted were recognized:

- The *Volume Problem*, where payload is limited by the maximum legal vehicle dimensions.
- The *Weight Problem*, where payload is limited by axle and gross weight restrictions.
- The *Control Problem*, where payload is limited by a loader operator's inability to accurately estimate the weight of individual loads.

The approach to solving these problems contained three distinct elements: a theoretical analysis, a series of case studies, and the development of practical solutions.

The theoretical portion of the study began with a survey and analysis of transportation regulations in 15 southern states. Considerable disparities between the regulations in different states were found which make it difficult to develop generalized recommendations for the region. In order to meet legal requirements across the South[5] a transportation system would have to satisfy the following list of conditions:

Maximum Height	13.5 feet
Maximum Width	8.0 feet
Maximum Semitrailer length	48 feet
Maximum Combination Length	60 feet
Maximum Length Including Load	70 feet
Maximum Load Overhang	20 feet
Maximum Steering Axle Gross	12,000 pounds
Maximum Single Axle Gross (duals)	20,000 pounds
Maximum Tandem Axle Gross	34,000 pounds
Maximum Gross Combination Weight	80,000 pounds
Bridge Formula Compliance	All Axle Groups

A model was developed to predict the weight of tree-length stems that can be loaded into a trailer bunk of specified size. The objective was to predict the conditions under which bunk area becomes the constraining factor on payload. The weight of trees per unit bunk area was found to fall off dramatically with decreasing butt diameter and total height. Load per unit area is also sensitive to butt flare and can be increased by staggering the butts of the stems. The model was not thought to be very reliable and was therefore of limited practical use. However, the difficulty of predicting the weight of wood on a trailer, even under laboratory conditions, provides the logging community with a strong argument for tolerances on gross weight.

The location of the load center of gravity of tree-length stems is important because of its influence on how the load is distributed over the vehicle's axles. Mathematical models were used to investigate the factors which affect center of gravity location. For loads of tree-length stems with butts in the same direction, the distance from the butts to the load center of gravity is typically between 30

[5] West Virginia and Kentucky have some additional requirements.

and 40 percent of the total load length. load. This percentage will be smaller the more variable are the lengths of the stems in the load. The percentage will be larger if the diameter at which the trees are topped is larger; if the butts of the stems are not aligned; or if the trees are from natural stands. The centers of gravity of loads of timber were found to be difficult to predict by any simple method which could be applied in the woods. This mitigates in favor of greater axle weight tolerances for loggers.

A method was developed for evaluating the impact of Federal Bridge Formula axle weight constraints on the payloads of tractor trailers with varying dimensions and axle configurations. Mathematical relationships were derived between the legal weight for each axle group, the weight of the load, the load center of gravity location, and the dimensions and weight of the vehicle. Plotting these constraints on a graph of payload against center of gravity location provided a useful means of comparing different vehicle designs. This technique was used for comparing the characteristics of different axle configurations under the Bridge Formula constraints. It was found that where the Bridge Formula is fully enforced, a tandem axle tractor and triaxle trailer may be the best configuration for hauling tree-length wood.

Since increasing payload is only desirable so far as it decreases the cost of transportation, an economic framework was developed with which different options could be compared. The appropriate economic analysis depends on who must take the action to increase payload and who reaps the benefits, so the creation of a rigid economic model was avoided. Instead, the nature of the contractual relationships between parties involved in timber transportation was examined, and a set of base-case assumptions for cash flows in a trucking investment was developed. In addition to the examination of specific options for increasing payload, the base-case assumptions were used to develop rules of thumb for use in making decisions which affect truck payload. It was estimated, for example, that every pound eliminated from the tare weight of a tractor-trailer is worth a capital expenditure of approximately $5.

Case studies were conducted at woodyards of three pulpmills to obtain information on real world constraints to timber transportation and to collect scalehouse data. The tractor-trailers entering these mills had widely varying gross weights. From the point of view of the mill, it would be best if all loads crossed the scales at, or close to, the legal limit. Moving toward this goal by eliminating overloading and underloading would result in a net increase in average payload, improved public relations, reduced overweight fines, and potential economic gains. Two of the mills had already taken steps to reduce overloading by setting ceilings on GVW, above which they gave no credit for wood delivered. One reason for the prevalence of underloading was identified as reluctance of mills to accept trees loaded in ways other than butts aligned and forward, which increase the volume of wood per unit of bunk area.

Scalehouse data also showed that the tare weights of tractor-trailers are quite variable, indicating some potential for increasing payload in the long term by eliminating excessively heavy equipment. The greatest weight reductions may be possible in trucks hauling from outlying woodyards to mills since these need not be designed to withstand the abuse of rough woods roads. It was found that reductions in tare weight do not necessarily translate pound for pound to increases in payload. Tare weight reductions are only useful if the vehicle is consistently able to attain the maximum legal GVW.

Solutions to the problems of payload maximization can usefully be summarized along the lines of actions to be taken by the logger and those to be taken by the mill. The following strategy is recommended for the logger:

1. Look at your scalehouse receipts for the past several months. The majority of loads should be within one to two thousand pounds of the legal GVW. If they are not, you need to find out why.

2. If there is a considerable amount of underloading, is it because your loader operator cannot get any more wood on the trailer, or is he is not too good at estimating GVW?

3. If the problem seems to be that you reach the height limit before maximum GVW, try different loading techniques, such as staggering the butts or loading butt to top. If such loads are against the rules at the mill you deliver to, challenge the rules or consider delivering somewhere else. Loggers who harvest thinnings or operate in particularly small wood should consider the long term option of changing to drop-neck trailers.

4. If your loader operator is seriously underloading for fear of getting overweight tickets, you need to improve his ability at estimating load weight. The least expensive way to do this is through training. Have him estimate the GVW of every load and write it down. Get him to compare his estimate with the true value as soon as the information becomes available, and set goals for the proportion of loads in different GVW ranges. Counting the trees in each load may prove more accurate than visual estimation, especially in fairly uniform timber. This could be achieved by attaching a counter to one of the control levers in the loader. It would also help to standardize equipment in the truck fleet so that the loader operator does not need to take variations in tare weight into account. If all of these measures fail, consider purchasing on-board scales for your trucks.

5. When all of your weight tickets are at or close to the legal limit, it is time to consider long term measures for reducing the tare weight of your transportation fleet. Various heroic measures are described in this document, but the major gains are to be made simply by being weight conscious when you are shopping for equipment. If you contract your hauling, use tractor weight as one of the factors in selecting contractors.

In a competitive market, the industries which buy wood will benefit in the long term from improvements in the efficiency of transportation made by their suppliers. There are also great gains to be made in public relations by discouraging overloading and encouraging safe transportation practices. The following suggestions may benefit these industries:

1. Begin by looking at the distribution of GVW's for trucks supplying the mill. Like the logging contractor, your aim should be for all loads to be at or close to the legal limit. Set goals for improvements in the GVW distribution, and schedules for achieving these goals.

2. Generate the GVW distributions for all of your regular suppliers and work with them individually to attain your goals. Consider, supplying them with performance reports on a regular basis to increase their awareness of the problem and encourage a spirit of competition.

3. If underloading is a serious problem, estimate what savings would result if it could be eliminated. Weigh these against the cost of removing facility constraints such as banning butt to top loading or requiring very large clearances between the load and the trailer frame.

4. Impose sanctions against chronic overloaders. Rather than using penalties for each overweight load, consider using a system where a supplier is penalized for exceeding monthly goals. Work with other companies to adopt regional standards and penalties for overloading.

5. Work with industry groups to lobby against regulations which do not recognize the peculiarities of hauling timber. In particular, it can be argued that regulations requiring precise positioning of the load center of gravity discriminate against loggers.

Several questions were left unanswered in this project which warrant further research. Because the scalehouse data were not collected under controlled conditions, it was impossible to determine how much of the variability in GVW was attributable to errors in estimation and how much to other factors. Hard data is needed on the quality of loader operators' visual estimates of GVW. This is essential for making the decision on whether or not to purchase on-board scales and would be extremely useful when arguing for weight tolerances for loggers. In order to eliminate other sources of variability, the operator's estimate of each load's GVW must be recorded and compared to the true value. This project could be extended to document the variability of estimates made by non-visual means, such as tree counting or electronic scales.

The recommendations made here for loggers and mills to improve transportation efficiency are as yet untested. The mill case studies could be extended to look at loading performance before and after the implementation of these recommendations. In particular, it would be useful to test the concept of generating regular performance reports from computerized scalehouse databases.

Bibliography

American Pulpwood Association. 1981. Southern guide to Federal and State trucking regulations. American Pulpwood Association Report 81-A-5, Washington, D.C., 101 p.

American Pulpwood Association. 1982a. 1982 Wood fiber forecast for the south. American Pulpwood Association Report 82-A-11, Washington, D.C., 10 p.

American Pulpwood Association. 1982b. Safety in woodlands transportation. American Pulpwood Association Report 82-A-5, Washington, D.C., 16 p.

American Pulpwood Association. 1984. 1984 Wood fiber forecast for the south. American Pulpwood Association Report 84-A-9, Washington, D.C., 10 p.

American Trucking Association. 1985. Bulletin Advisory Service. American Trucking Associations, Inc. Washington, D.C.

Anonymous. 1984a. Forest products trailer review. Southern Loggin' Times, July 1984. p 14-17.

Anonymous. 1984b. Class of '85. Timber Harvesting, November 1984. p 8-9.

Anonymous. 1984c. Proper load balance means extra cords. Timber Harvesting, November 1984. p 39.

Baas, P.H. and J.A. Stulen. 1985. Safety in log transport - an investigation into load securing devices and methods. Logging Industry Research Association. Project Report No.23, 61p.

Baumgras, J.E. 1975. How to avoid axle-weight overloads on tandem-axle log trucks. Northern Logger and Timber Procesor, September 1975. p 14-15.

Bixler, D. 1985. Personal communication. Fontaine Truck Equipment Company, Haleyville, Alabama.

Burkhart, H.E. 1977. Cubic-foot volume of loblolly pine to any merchantable top limit. Southern Journal of Applied Forestry. Vol.1, No.2 p 7-9.

Burkhart, H.E. and J.E. Clutter. 1971. Green and dry weight yiels for old-field loblolly pine in the Georgia Piedmont. Georgia Forest Research Council Report No. 22 - Series 4.

Burkhart, H.E., R.C. Parker and R.G. Oderwald. 1972. Yields for natural stands of loblolly pine. Publication FWS-2-72, Div of For & Wildlife Res. VPI&SU, Blacksburg, VA.

Burkhart, H.E., R.C. Parker M.R. Strub and R.G. Oderwald. 1972. Yields for old-field loblolly pine plantations. Publication FWS-3-72, Div of For & Wildlife Res. VPI&SU, Blacksburg, VA.

Cao, Q.V. and H.E. Burkhart. Cubic-foot volume of loblolly pine to any height limit. Southern Journal of Applied Forestry. Vol.4,No.4 p 166-168.

Cubbage, F.W. and C.H. Redmond. 1985. Capital budgeting practices in the forest products industry. Forest Prod. J. 35(9):55-60.

Della-Moretta, L. and L.E. Hanna. 1978. Trailer tractrix equations and computer algorithm for curve widening. USDA For. Serv. Equipment Development Center, San Dimas, Cal. ED&T 2526, 30p.

Dykstra, D.P. and J.J. Garland. 1977. Log hauling on public roads in oregon - an analysis of the possible effects of changes in allowable hauling weights. Forest Engineering Department, Oregon State University. 21p.

Dykstra, D.P. and J.J. Garland. 1978. Log trucking in Oregon - a survey. Transactions of the ASAE, Vol 21 No.4 p628-632.

Ford, E.C. 1976. Predictors of tree weights and centers of gravity for various Appalachian hardwoods. Masters Thesis, VPI&SU, Blacksburg, Va.

Garland, J.J. and D.P. Dykstra. 1978. Log truckers finding payloads reduced by revised weight law. Forest Industries, April 1978.

Garner, G.J. 1978. Wind tunnel tests of devices for reducing the aerodynamic drag of log trucks. Forest Engineering Institute of Canada, TR-27 25p.

Gordon, R.D. 1980. Log truck axle layouts (an economic comparison of 5-axle and 6-axle layouts). Logging Industry Research Association, Project Report No. 10. 23p.

Hicks, D.R., J.D. Lenhart and S.I. Somberg. 1972. Merchantable gree weights for loblolly pine trees in old-field plantations in the Interior West Gulf coastal Plain. Texas forestry Paper No.16. S.F. Austin State Univ., Texas.

Izlar, B. 1980. Federal and state trucking regulations confuse wood transportation outlook. Pulp and Paper, June 1980. p79-81.

Izlar, B. 1983. Review of market and transportation requirements and future trends. *In* Harvesting the South's Small Trees. FPRS Conference, April 1983. Proceedings 7340. FPRS, Wisconsin. p89-96.

Koch, P. 1972. The utilization of southern pines. USDA Forest Service Agricultural Handbook No.420 Vol.2 pp 734.

Koger, J. C. 1981. Transportation methods and costs for sawlogs, pulpwood bolts and longwood. Tennessee Valley Authority. Division of Land and Forest Resources. Norris, Tenn. Technical Note B44.

Lanford, B.L. and T. Cunia. 1971. Relationships among diameter measurements for seven species in the South. American Pulpwood Association. Harvesting Research Project. 85p.

Lavoie, J.-M. 1979. The transportation of tree lengths by truck trains. Forest Engineering Research Institute of Canada, Technical Report No. TR-33, 57p.

Lavoie, J.-M. 1980. The transport of full trees from the stump area to the mill woodyard. Forest Engineering Research Institute of Canada, Technical Report No. TR-44, 36p.

Lavoie, J.-M. 1981. Securing systems for truck loads of tree lengths. Forest Engineering Research Institute of Canada, Technical Note No. TN-41, 13p.

Leister, R.L. and B. von Segen. 1979. Analysis of tree length hauling. Truck Regulation Committee, Arkansas Forestry Association, August 1979. 16p.

Lynch, T.B. 1977. Prediction equations for centers of gravity and moments of inertia of loblolly pine stems and for loblolly pine stump diameter. VPI&SU Masters Thesis. 63p.

Martin, J.A. and A.B. Valia. 1979. Woodyard conversion to treelength log handling takes careful planning. Pulp and Paper, June 1979. p96-98.

Matney, T.G. and A.D. Sullivan. 1979. Inside- and outside-bark taper equations for old-field loblolly pine trees in the central Gulf Coastal plain. Miss. Ag. and Forestry Expt. Station. Technical Bulletin 101. 25p.

Murphy, L. 1986. Cummins Engine Company. Personal communication.

Page, R.H. and P.J. Bois. 1961. Buying and selling southern yellow pine saw logs by weight. Georgia Forest Research Council. Report No.7, May 1961.

Schultz, P.W., D.A. Klokkenga and D.B. Stattenfield. 1970. Vehicle mission simulation. Soc. of Automotive Engineers. No. 700567. 8 p.

Shaffer, R. M. 1984. Virginia log truck survey. American Pulpwood Association Technical Release 84-R-96, Washington, D.C., 11 p.

Smith, D. G. 1981. Computer aided comparison of 5, 6, and 7 axle log trucks for long distance highway hauling. Forest Engineering and Research Institute of Canada, Pointe Claire, Quebec. Technical Report No. TR-49. 56 p.

Smith, D.G. and P. P. Tse. 1977. Logging trucks: comparison of productivity and costs. Forest Engineering and Research Institute of Canada, Pointe Claire, Quebec. Technical Report No. TR-18. 43 p.

Steinhilb, H.M. and J.R. Erickson. 1970. Weights and centers of gravity for quaking aspen trees and boles. USDA For. Serv. Research Paper NC-91, 4 p.

Steinhilb, H.M. and J.R. Erickson. 1972. Weights and centers of gravity for red pine, white spruce and balsam fir. USDA For. Serv. Research Paper NC-75, 7 p.

Stuart, W.B. Harvesting cost analysis workshop. VPI&SU, Blacksburg, Va. 140 p.

Stuhlen, J.A. 1984. Securing loads on logging trucks. Logging Induxtry Research Association, Vol. 9 No.2, 4 p.

Thill, M. 1984. Computer looks at weight distribution. Fleet Equipment, August 1984. p52-53.

Thomson, E. 1984. Unloading logging's marred image. Timber Harvesting, Aug. 1984. p 32-33.

United States Department of Transportation. 1976. Federal Motor Carrier Safety Regulations. Federal Highway Administation, Bureau of Motor Carrier Safety, Washington, DC.

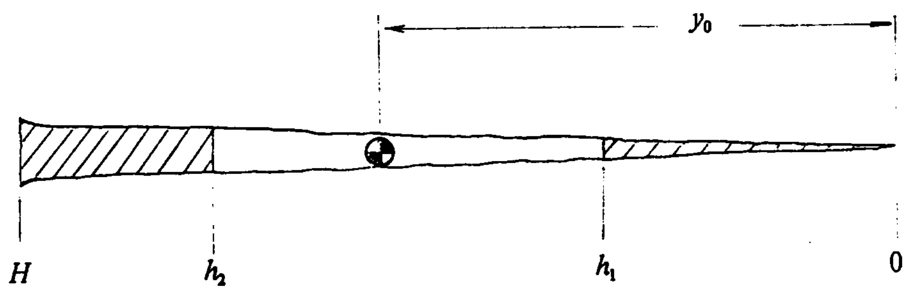
Watson, W.F. and T.G. Matney. 1981. The impact of Mississippi's weight laws on the cost of manufactured forest products and stumpage prices. Tree Talk Magazine, Miss. For. Assoc. 3:6-10.

Watson, W.F. and T.G. Matney. 1984. Predicting axle loads on trucks hauling tree length logs. Miss. State University. Review draft. 14 p.

Weaver, G.H., R.A. Kluender, W.F. Watson, W. Reynolds and R.K. Matthes. 1981. 1979 Pulpwood producer census SW and SE Technical Divisions of the American Pulpwood Association. Miss. State University. 11 p.

Wilson, F.G. 1980. Truck transport of longwood call for new equipment and regulations. Pulp and Paper, June 1980. p 99-103.

Appendix A. Derivation of a Generalized Center of Gravity Equation



Definitions:

H	= total tree height
h_1, h_2	= distances measured from the tip of the stem defining a log
t	= a distance mesured from the stem tip
d_t	= stem diameter at distance t from the stem tip
y_0	= distance from stem tip to center of gravity of log h_1-h_2
V	= total tree volume

v_0 = volume above some point t

v_1 = volume below some point t

Volume Ratio Model, (Cao & Burkhart, 1980):

$$R = \frac{v_1}{V} = 1 + b_1(t^{b_2}/H^{b_3})$$

$$\rightarrow \quad v_0 = V\left[- b_1(t^{b_2}/H^{b_3})\right]$$

We can also define v_0 by integrating x-sectional area:

$$v_0 = \int_0^t 0.00545 \ d_t^2 \quad \delta t$$

Therefore,

$$\int_0^t 0.00545 \ d_t^2 \quad \delta t = V\left[- b_1(t^{b_2}/H^{b_3})\right]$$

$$0.00545 \ d_t^2 = V\left[- b_1 b_2(t^{(b_2 - 1)}/H^{b_3})\right]$$

Assuming constant density, ρ, the moment, M, for the log $h_1 - h_2$ about the stem tip is given by:

$$M = \rho \int_{h_1}^{h_2} t \times 0.00545 \, d^2{}_t \quad \delta t$$

$$= \rho V \int_{h_1}^{h_2} t \times \left[- b_1 b_2(P^{(b_2 - 1)}/H^{b_3})\right] \quad \delta t$$

$$= \rho V \int_{h_1}^{h_2} \left[- b_1 b_2(P^{b_2}/H^{b_3})\right] \quad \delta t$$

$$= \frac{\rho V \, (- b_1 b_2)(h_2^{(b_2 + 1)} - h_1^{(b_2 + 1)})}{(b_2 + 1)H^{b_3}} \qquad (1)$$

The weight, W, of log $h_1 - h_2$ is given by:

$$W = \frac{-\rho V b_1\left[h_2^{b_2} - h_1^{b_2}\right]}{H^{b_3}} \tag{2}$$

Since $y_0 = M/W$, dividing equation (1) by (2) gives:

$$y_0 = \left[\frac{b_2\left[h_2^{(b_2+1)} - h_1^{(b_2+1)}\right]}{(b_2 + 1)\left[h_2^{b_2} - h_1^{b_2}\right]}\right]$$

And, $CGP = (h_2 - y_0)/(h_2 - h_1)$, therefore,

$$CGP = \frac{\left[h_2 - \frac{b_2\left[h_2^{(b_2+1)} - h_1^{(b_2+1)}\right]}{(b_2 + 1)\left[h_2^{b_2} - h_1^{b_2}\right]}\right]}{(h_2 - h_1)}$$

Appendix B. Bridge Formula Weight Constraints for Tractor Trailers

Definitions:

G_A , T_A and B_A	Gross, Tare and Bridge Formula limit for steering axle
G_B , T_B and B_B	Gross, Tare and Bridge Formula limit for tractor bogie
G_C , T_C and B_C	Gross, Tare and Bridge Formula limit for trailer bogie
B_F	Front inner bridge limit
B_R	Rear inner bridge limit
B_O	Outer bridge limit
W	Payload
CG	Distance from kingpin to load center of gravity
FW	Distance from tractor bogie center to fifth wheel center
WB	Distance from steering axle to tractor bogie center
TB	Distance from kingpin to trailer bogie center

Steering Axle Constraint: $W\left\{\frac{FW}{WB}\left(1-\frac{CG}{TB}\right)\right\} + T_A \leq B_A$

Tractor Bogie Constraint: $W\left\{\left(1-\frac{FW}{WB}\right)\left(1-\frac{CG}{TB}\right)\right\} + T_B \leq B_B$

Trailer Bogie Constraint: $W\left\{\frac{CG}{TB}\right\} + T_C \leq B_C$

Front Inner Bridge Constraint: $W\left\{1-\frac{CG}{TB}\right\} + T_A + T_B \leq B_F$

Rear Inner Bridge Constraint: $W\left\{1-\frac{FW}{WB}\left(1-\frac{CG}{TB}\right)\right\} + T_B + T_C \leq B_R$

Outer Bridge Constraint: $W + T_A + T_B + T_C \leq B_O$

Appendix C. Sample NPV Calculation for a Trucking Investment

EFFECT ON NPV OF INCREASING GVW FROM 78,000 TO 80,000 LB.

INPUT:

EQUIPMENT LIFE	360,000 MLS	CAPITAL INVESTMENT	78,000
1-WAY HAUL	40 MLS	SALVAGE RATIO	10%
OPERATING HRS/YR	2,000 HRS	TIME BASED COSTS	24,000
TRAVEL TIME/TRIP	2.00 HRS	DISCOUNT RATE	12%
STANDING TIME/TRIP	0.67 HRS	TARE WEIGHT	27,000

OUTPUT:

TRIPS/YEAR	750	EQUIP LIFE YRS	6
MLS/YEAR	60000	ASSUME REV/TON-MILE =	$0.09

CASE 1: GVW = 78,000 POUNDS

PAYLOAD = (78,000 - 27,000) / 2,000 = 25.5 TONS
ANNUAL REVENUE = 25.5 * 30,000 * .09 = $68,850

YEAR	CAPITAL COST	FIXED COSTS	VARIABLE COSTS	REVENUE	NET	PRESENT VALUE
0	(78,000)	0	0	0	(78,000)	(78,000)
1	0	(24,000)	(26,468)	68,850	18,382	16,414
2	0	(24,000)	(26,468)	68,850	18,382	14,654
3	0	(24,000)	(26,468)	68,850	18,382	13,085
4	0	(24,000)	(26,468)	68,850	18,382	11,682
5	0	(24,000)	(26,468)	68,850	18,382	10,430
6	7,800	(24,000)	(26,468)	68,850	26,182	13,264
					NET PRESENT VALUE	1,529

CASE 2: GVW = 80,000 POUNDS

PAYLOAD = (80,000 - 27,000) / 2,000 = 26.5 TONS
ANNUAL REVENUE = 26.5 * 30,000 * .09 = $71,550

YEAR	CAPITAL COST	FIXED COSTS	VARIABLE COSTS	REVENUE	NET	PRESENT VALUE
0	(78,000)	0	0	0	(78,000)	(78,000)
1	0	(24,000)	(27,000)	71,550	20,550	18,349
2	0	(24,000)	(27,000)	71,550	20,550	16,383
3	0	(24,000)	(27,000)	71,550	20,550	14,628
4	0	(24,000)	(27,000)	71,550	20,550	13,060
5	0	(24,000)	(27,000)	71,550	20,550	11,660
6	7,800	(24,000)	(27,000)	71,550	28,350	14,362
					NET PRESENT VALUE	10,442

THE INCREASE IN GVW (AND HENCE PAYLOAD) RESULTS IN A $8,913 INCREASE IN NPV

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