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CONSTRUCTIVE USE OF PERFORMANCE MEASURES FOR IMPROVED VEHICLE SAFETY AND PRODUCTIVITY – CANADIAN EXPERIENCE

John Woodrooffe Roaduser Research; Norm Burns Saskatchewan Highways and Transportation, Doug Johnson, John Palmer and David Smith and New Brunswick Department of Transportation

ABSTRACT

Heavy vehicle stability and control performance measures are commonly used as an objective tool for the development of heavy vehicle size and weight policy. In some jurisdictions, the use of performance measures has expanded to help support screening protocols for non-conforming vehicles under special permit systems. Special permit systems allow for the acceptance of vehicles not covered by standard size and weight policy. A given vehicle may be designed for overweight or over dimension applications to improve transport efficiency or to transport indivisible loads usually on specified routes

The performance measures are used to determine if the vehicle can adhere to certain performance criteria defining acceptable vehicle safety performance. The concept of a “special permit” means that the vehicle is non-conforming but possesses acceptable dynamic performance characteristics. While under a special permit, the vehicle is “on probation” meaning the permit can be revoked for reasons of non-compliance with the terms and conditions of the permit or policy.

The revocable nature of this system instills an incentive for carriers to take extra care in maintenance and operational matters and to protect the market advantage realized from the unique character of the vehicle. There is a willingness on the part of the transporter to work more closely with the regulators to ensure that potential risk can be reduced through the adoption of mutually agreed proactive safety strategies.

This paper examines the special permit systems currently in use in the provinces of New Brunswick and Saskatchewan and contains an example illustrating the safety benefits and innovations that have emerged form the special permit systems.

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THE PROVINCE OF SASKATCHEWAN'S TRANSPORTATION PARTNERSHIP PROGRAM

BACKGROUND

In 1977, Saskatchewan became the first jurisdiction in North America to use commercial vehicle weight and dimension policy as an economic development tool. The initial policy enabled industry to use commercial motor vehicles with weights and/or dimensions that exceeded legal limits on condition that the motoring public and taxpayers were not adversely affected by industrial traffic. This policy reduced industrial truck transportation costs by about $50 million annually. It also reduced Canadian rail rates on potash by providing a truck connection to the U.S. rail system. Except for incremental road and bridge costs, all of the benefits from the policy accrued to the private sector.

The economic and financial environment in Saskatchewan changed dramatically after 1977. Ongoing budget reductions and increased demands on the highway system from grain traffic and other commodities have led the department to restructure its organization and review the initial 1977 Bulk Commodity Policy. This process led to the development of the Transportation Partnership Policy.

PARTNERSHIP PROGRAM OBJECTIVES

In 1994, Saskatchewan Highways and Transportation announced a vision for moving Saskatchewan's freight transportation system into the 21st century. This new direction is intended to ensure that the highway system is safe, reliable, efficient, environmentally sound, and financed by a combination of public and private sector funds.

The cornerstone of this initiative is in forging partnerships with private sector companies to reduce truck transportation costs. The savings generated from these partnerships enable the company to be more competitive and provide new revenue for making improvements to the specific highways used by their vehicles. The objectives of the Transportation Partnership Policy are to:

1. support economic development in Saskatchewan
2. provide additional revenue for road improvements on specific routes used by a particular transport company
3. promote the use of more efficient road friendly vehicle technology; and
4. ensure that the taxpayer and motoring public are not adversely affected by industrial traffic.

IMPLEMENTATION PROCESS

The new policy provides a mechanism that enables the Department to work with private industry to custom design truck haul systems within the province that meets the objectives. New vehicle configurations are identified that will reduce trucking costs by optimizing the vehicle with the highway system as well as the material handling facilities. All new vehicles are evaluated from a safety performance, road and bridge infrastructure, and haul savings perspective. The Transportation Association of Canada (TAC) performance measures described in this paper are used to pre-screen vehicle alternatives. If the vehicle concept represents a major departure from existing vehicles, field demonstration projects are undertaken to confirm the analysis prior to full implementation. If the study results are favorable, the Department enters into a comprehensive transportation partnership agreement with the industry that contains:

- vehicle configurations including weights and dimensions
- vehicle standards and specifications
- haul routes
- vehicle operating and maintenance procedures
- driver qualifications
- truck haul savings to be used for road improvements; and
- highway improvement projects

After the agreement is signed the Department issues permits to the client that enables them to operate vehicles within the terms and conditions of the agreement. The Department conducts safety and financial audits to ensure compliance.

Truck haul savings are determined by taking the difference in transportation costs associated with using vehicles that comply with regulation weights and dimensions and the cost of using overweight and/or over-dimension vehicles. All incremental road and bridge costs associated with using the overweight vehicles and any incremental costs to the client are deducted from truck haul savings. Of the residual, the client retains 50% and the other 50% are used for road improvement projects. The road contributions do not revert to the consolidated fund of the province but are deposited in separate accounts that disperse the money for the highway improvement projects that have been mutually agreed to by the Department and the client.

PROGRAM BENIFITS

In the Province of Saskatchewan, the road network consists of 26,100 km of roads and highways. The annual budget for the Department has been in order of $170 million per year. The plan is to increase the funding for this network to approximately $250 million per year.

The 5-year objective for the partnership program is to generate an additional $15 - 20 million per year for highway improvements. As of December 1, 1997, the Department had negotiated 9 partnership agreements that collectively generate approximately $4.4 million per year. An additional 12 agreements are in the negotiation stages. **Figure 1** show some of the vehicles that operate pursuant to the agreements as well as an indication of the truck haul savings associated with each one.

THE PROVINCE OF NEW BRUNSWICK NON-CONFORMING VEHICLE PROGRAM

New Brunswick has recently developed a new procedure that considers vehicle safety, performance, the influence of road and bridge life, road geometrics and traffic considerations. The procedure is based on the following principles:

(1) Any request from industry for use of a non-conforming vehicle, on all of or part of the highway system, will be considered and evaluated using sound engineering principles and analysis.

(1) If the theoretical engineering analysis proves that the vehicle can be operated safely, a pilot project using one or more vehicles will be carried out for up to one year to test the theoretical analysis and ensure that there are no serious unforeseen problems.

(2) If the pilot project proves that the theoretical analysis was correct and no further safety issues were raised during the pilot project, then a "non-conforming" permit will be issued.

(3) The theoretical analysis will be comprised of the following components:
- Vehicle Safety Performance and Stability Assessment
- Load Security Assessment
- Bridge and Road Loading Impact Assessment
- Route Geometry and Traffic Assessment

(4) Weight considerations are not to exceed those in the current New Brunswick weight regulations.

(5) Other vehicle safety enhancements may be mandated for trial during the pilot project and beyond.

(6) All costs of pilot vehicles are the responsibility of the operator.

NEW BRUNSWICK CASE STUDY

The particular case described in this paper involves a 26.5 meter 8 axle "B" Train designed to transport large rolls of tissue paper between two cities on a continuous year round basis. The vehicle exceeded the provincial overall length limit of 25 meters.

The case study vehicle is an 8-axle B-train with an overall length of 26.42 meters (1.42 meters longer than current regulations permit). The loaded gross vehicle weight of the vehicle was expected to be 46,500 kg. The current maximum gross vehicle weight for an 8-axle B-train in New Brunswick is 62,500 kg. The original vehicle proposed by the applicant was a 7-axle B-train, however analysis indicated that an 8-axle unit was significantly superior.

The vehicle has been designed to transport 10 large paper rolls (5 in each trailer). The rolls are 261.6 cm (103 inches) high. The width and weight of the roll can vary but nominal values are; width 213.4 cm (84 inches) and weight 2,500kg (5,500 lbs.).

The benefits as outlined in the request associated with this proposal were as follows:

- Savings in transportation costs estimated to exceed $260,000 annually.
- Reduction in annual truck volumes from current procedures of 1,286 loads or 27%.

ASSESSMENT OF DYNAMIC PERFORMANCE

Using the procedures developed in the RTAC Heavy Vehicle Weights and Dimensions study report (1) and other measures, the following vehicle performance attributes were examined using the University of Michigan Transportation Research Institute (UMTRI) Yaw/Roll program:

- roll stability
- load transfer ratio
- rearward amplification
- low speed offtracking
- high-speed steady-state offtracking
- high speed dynamic offtracking
- friction demand

STEADY-STATE ROLLOVER

Heavy trucks can withstand limited lateral acceleration in a curve before rolling over. This rollover limit is expressed in terms of the lateral acceleration, and is given as a proportion of gravitational acceleration (g). Total rollover occurs when all the wheels on one side of the combination vehicle (on the inside of the turn) lift off the road surface, as shown in **Figure 2**.

REARWARD AMPLIFICATION

When articulated vehicles undergo rapid steering, the steering effect at the trailer is magnified. This results in increased side force, or lateral acceleration, acting on the rear trailer. This in turn increases the likelihood of the trailer rolling over under some circumstances.

Rearward amplification is defined as the ratio of the lateral acceleration at COG of the rearmost unit to that at the hauling unit in a dynamic maneuver of a particular frequency. As shown in **Figure 3**, steering from side to side produces more lateral movement at the rear unit than at the hauling unit.

LOAD TRANSFER RATIO

Load transfer ratio is defined as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient maneuver. Where vehicle units are roll-coupled - as in B-doubles - the load transfer ratio is computed for all axles on the vehicle. When the vehicle units are not roll-coupled, as with truck-pony configurations, they are evaluated as separate units. When the load transfer ratio reaches a value of 1, rollover is about to occur. The LTR is the ultimate measure of rollover stability.

HIGH SPEED STEADY-STATE OFFTRACKING

High-speed offtracking is defined as the extent to which the rearmost tires of the vehicle track outboard of the tires of the hauling unit in a steady-turn at highway speed. High-speed offtracking relates closely to road width requirements for the travel of combination vehicles and is an important part of the total swept width of the combination vehicle (that is, the extent to which the lateral excursions of the rear of the vehicle exceed those of the hauling unit in normal operation).

HIGH-SPEED DYNAMIC OFFTRACKING

High speed dynamic offtracking is a measure of the lateral excursion of the rear of the vehicle with reference to the path taken by the front of the vehicle during a dynamic maneuver. This expresses the amount of additional road space used by the vehicle combination in an avoidance maneuver.

High-speed dynamic offtracking is computed for the lane-change maneuver at a speed of 90 km/h. In each case, the vehicle was made to follow a path so that the lateral displacement of the vehicle's path remained constant.

LOW-SPEED OFFTRACKING

Low-speed offtracking represents a measure of the swept path of the vehicle and its lateral road space requirement when turning at intersections or when turning into loading areas. The offtracking of the vehicle depends on axle position, trailer tongue length and hitch location.

FRICTION DEMAND

Friction demand is the non-tractive friction levels between the tires and the road surface at the steer axle of the truck. It is a measure of the shear force between the tires and the road that results from the vehicle negotiating a curve in the road. As the aligning moment of an axle group increases, this measure becomes more significant. Friction demand at the steer axle and drive axles is evaluated at high and low speed. The RTAC measures focus only on low speed friction demand of the drive axles. From experience, Roaduser Research has found it to be more practical to examine the additional low-speed friction demand at the steer axle and high-speed friction demand at the drive axles.

RESULTS

Table 1 contains the results of the assessment of dynamic performance. In general, the vehicle demonstrated very good dynamic behavior.

Table 1. Assessment of dynamic performance.

Performance Measures	**TAC Max. Values**	**Candidate Vehicle**	**Grade**
Static roll threshold by axle group	-	-	-
• Drive axles	-	0.425	Very good
• Lead trailer axles	-	0.422	Very good
• Pup trailer axles	-	0.330	Marginal
Net static roll threshold (est.)	-	0.370	Good
Load transfer ratio	0.60	0.375	Pass
Rearward amplification	2.00	1.35	Pass
Low speed offtracking	6.00 m	5.63 m	Pass
High speed offtracking	0.46 m	0.40 m	Pass
High speed dynamic offtracking	0.80 m	0.22 m	Pass
High speed friction demand (drive axles)	-	0.121	-
Low speed friction demand	-	-	-
• Steer axle	-	0.213	-
• Drive axles	0.10	0.028	Pass

Note: There are no uniform national targets for rollover threshold. The targets vary with risk exposure and jurisdiction.

The 7-axle B-Train passed the RTAC performance measures, however the vehicle does exhibit non-uniform roll resistance at the center axle group supporting both trailers. It was found that significant improvements in roll stability could be realized by converting the vehicle to an 8 axle B-Train. This is done by replacing the tandem axle group, at the junction between the lead and pup trailers, with a close spread tridem.

BRIDGE CAPACITY AND LIVE LOADING ANALYSIS

New Brunswick has developed an extensive bridge assessment model, which bridge engineering officials from provinces in the Eastern Task Force have endorsed. The following is a brief summary of how this model was developed and how it is used.

The majority of regulating authorities in Canada use the present CSA S6-88 Code for the design of highway bridges. The load model that is used by most highway authorities is the CS-600 truck model as shown in **Figure 4**, where 600 represents the GVW in kilo-Newtons. The CS-600 model is also often used for evaluating existing bridges and was chosen to simulate a B-Train configuration with a maximum GVW of 62,500 kg. It must be noted that the physical model for designing bridges may not resemble a "real" vehicle but is chosen to represent force effects in bridges that result from real vehicles.

Truck weight and dimension regulations should be formulated such that the force effects of the entire spectrum of vehicles are at best equal to or less than those produced by the design vehicle, including any administrative tolerances. It follows that the force effects from the vehicles when ratioed to the CS-600 model effects, must be less than or equal to 1.00. Conversely, the force effects of the design model must be greater than the corresponding force effects for the real vehicles; that is, CS-600 divided by the real force effects must be greater or equal than 1.00. This will then give a satisfactory safety index for bridges designed using the current code and model.

A major assessment of vehicles in the New Brunswick Motor Vehicle Regulation has been done based upon the methodology noted above. The methodology used compared bending moment and shear (over a range of span lengths) resulting from the current Canadian design truck model; with those resulting from the vehicles conforming to the N. B. Regulations. The actual vehicles consisted of various weights and spacings of single, tandem and tridem axle groups. This was done for simple span bridges with span lengths between 3 meters and 40 meters. The results are also be applicable to the central regions, or positive moment regions, of continuous span bridges with span lengths that are approximately 70 % longer than the simple span length.

An example of the comparison of the moment effects resulting from a short tridem-semi trailer truck with three different configurations is shown in **Figure 5**. A graphical representation of the comparison is shown in **Figure 6**. This same comparison would also be made for shear force effects in bridges.

When comparisons of various vehicles are made in this manner, it is evident that the allowable gross vehicle weights and individual axle weights depend upon interaxle spacings and overall vehicle base length. Generally, vehicles with smaller base lengths will be allowed smaller GVW and in some cases, smaller individual axle loads.

It is important to note that this comparison is the best-case scenario because it applies only to bridges designed and constructed to recent bridge codes. Existing bridges may be evaluated for non-permit vehicular traffic using the CS600 model with Clause 12 of the CSA Standard S6 - 88 Design of Highway Bridges. The CS600 model must be treated as a real truck with the associated load factors when using Clause 12, if the model is to be used as a representation of non-permit traffic. The correlation of non-permit vehicular traffic to the design model must be established by the Regulatory Authority by comparing moment and shear effects, as shown in the preceding example.

Bridges must be assessed for strength on an individual basis in order to determine the live load capacity as compared to the model. When this model (CS600) is used to evaluate existing bridges for non-permit vehicular traffic, the ratio of the capacity of the bridge to the applied factored forces caused by the CS600 model is often less than 1.00. This implies that such a bridge may not be capable of safely resisting loads that are in excess of the model, and may only be capable of safely carrying a fraction of the weights that are represented by the model. Since the inventory of bridges, may only be capable of safely resisting a portion of the CS600 model, it follows that force effects are greater than the design and evaluation model are not acceptable (from a standpoint of public safety and structural damage to existing bridge infrastructure).

The Structures Branch of the New Brunswick Department of Transportation analyzed the affects of the 26.5 m B-train and found it to be well within the bridge capacity guidelines for the intended route.

ROAD LIFE ASSESSMENT

The Equivalent Standard Axle Loads (ESAL's) (4) are calculated to quantify the impact that a vehicle will have on the roads. The ESAL's per vehicle are based on standard axle loads of:

- 8,200 kg single
- 14,500 kg tandem
- 19,100 kg tridem

The relationship used is a s follows:

$$\text{ESAL} = \left(\frac{\text{Design Axle Loads}}{\text{Standard Axle Load}} \right)^{3.8}$$

The original request considered a 7 axle B-Train with anticipated axle loads of:

- steer axle 4,620 kg
- drive axles 12,857 kg
- center tandem 17,583 kg
- last tandem 10,559 kg

The total ESAL's for the 7-axle B-train are 3.13 ESAL's per vehicle or 0.31 ESAL's per roll of paper.

As an alternative, if an 8 axle B-train were used where a center tridem axle replaced the center tandem. The center tridem axle load reflects the increased tare weight attributed to the additional axle. The anticipated axle loads of the 8- axle B-train are as follows:

- steer axle 4,620 kg
- drive axles 12,857 kg
- center tridem 18,436 kg
- last tandem 10,559 kg

The ESAL's per vehicle for the 8 axle B-Train are reduced by 41% to 1.92 ESAL's or 0.19 ESAL's per roll compared with the 7 axle B-Train.

OPERATIONS

The Transport Company, Sunbury Transport was hauling the paper rolls in 16.15 m (53 foot) vans. A total of 8 rolls can be loaded into these trailers but because of variations in roll diameter and loading procedures, the majority of trips (70%) are made with only 7 rolls. In essence, the current 53 foot trailer moves 7.3 rolls per trip.

The proposed B-trains transport 10 rolls per trip. The company expects to transport 34,783 rolls per year between the two cities. If current equipment is to be used, 4765 trips will be required. By using the proposed B-train, 3,479 trips will be required thereby reducing the number of return trips per year by 1,286, representing a 27% reduction in truck traffic for this particular haul, as mentioned earlier. This reduction of 1,286 truck movements is considered significant in the reduction of accident exposure and in truck traffic.

SPECIAL SAFETY ISSUES

LOAD SECURITY

The paper rolls are loaded into the vans standing on end. There is lateral free space between the rolls and the wall of the van amounting to 39 cm (15 inches). Each roll has a nominal diameter of 213 cm (84 inches). When loaded in a straight line, the rolls occupy 10.65 m, which exceeds the interior space available within the trailers as shown in **Figure 7**.

This situation requires that the rolls are offset from side to side, to create sufficient space for all 5 rolls to be loaded into each trailer as shown in **Figure 8**.

Because there are an odd number of rolls in each trailer, the lateral offset loading pattern will result in a shift of the mass center of the vehicle laterally from the centerline. The lateral shift will result in reduced vehicle roll stability. The problem can be made worse if the lead trailer is loaded identically to the rear trailer, as shown in **Figure 9**, so that there are 4 rolls along one side of the vehicle and 6 rolls on the other side.

Such a loading situation will make the vehicle more susceptible to rollover on the side containing the extra rolls. To reduce this risk, a specific loading pattern was mandated eliminating any lateral imbalance as shown in **Figure 10**. The two rolls positioned in the center of the trailer required dunnage to prevent shifting. The consequence of improper loading is sufficiently serious to make it an ongoing condition for permit operation.

The rolls are protected on all surfaces by plastic wrap. Any snow or ice present on the floor of the vehicle can lead reduced friction resulting in shifting of the rolls. In addition, the wooden floors of truck vans result in poor frictional coefficients between the floor and the cargo. Rubber flooring mats designed to improve the friction between the floor and the payload were mandated. Because the rolls are tall, strapping was mandated between the top of the rolls and security rails along the walls of the trailer. The compliance criteria imposed required that the rolls be restrained against longitudinal deceleration of 0.6 g for 5 seconds.

OTHER SAFETY PRECAUTIONS

The special pilot project to operate a longer (26.5) than normal (25m) B-Train, provided an opportunity to evaluate special safety precautions that would enhance the visibility and the overall safety of the vehicle as it traveled between the two cities. The following enhancements were put in place:
<u>Two Additional rear top mounted red brake/tail/signal lights</u> on the rear of the second trailer. Two 4" light emitting diode (LED) signal lights were mounted on each side at the top outer corners of the rear doors. An additional LED signal light was mounted on the rear of the trailer at frame height. These lights are in addition to the normal brake/tail/signals already on the stock trailer.

It is expected that the top mounted brake/tail/signal lights will be less likely to pack with snow. Because of the high location of the lights, it is also expected that in congested or urban traffic, several cars behind the B-train will have clear line of sight so as to be pre-warned of turns or braking. Conventional trailers signal lights are often "hidden" by the vehicles directly behind the trailer. Additional amber clearance lights have been installed on the top center of rear trailer and along the side of the trailers, to improve side visibility.

Reflective Tape Markings are also required as per the conspicuity specification now in place.

A Special Sign was required to be placed on the rear of the trailer indicating to the public that the length of this unit was 26.5 meters. It is expected that this sign will warn those who intend to pass, that this is a long vehicle. The sign shows a side-on image of the B-train with a 26.5 m dimension marker.

Splash-Spray suppressing devices have been required for this unit. Over all wheels except the steering axle, special fenders were fitted with plastic brushes to shed water.

Rear Under-ride protection is required as per New Brunswick's current regulation.

Side under-ride protection is being developed for trial during this pilot project with assistance of UNB's Truck Accident Investigation Group

Anti-lock brakes on the tractor drive axles have been shown to reduce jackknife accidents. The proposed tractor did not have a long wheelbase therefore it is more susceptible to jackknife induced accidents caused by over-braking. Anti-lock brakes contribute significantly to overall vehicle safety and were mandated.

Automatic brake slack adjusters are required on all wheels.

Tridem Axle Group: By replacing the center tandem axle group with a close spread tridem group, a 41% reduction in ESAL's for the vehicle will be realized. This represents a significant reduction in pavement wear attributed to the vehicle. Using a tridem axle group improves the roll stability of the vehicle by increasing the roll stiffness.

Tractor Wheelbase: The tractor specified in the design has a wheelbase of 4.5 meters (177 inches). Short wheelbase tractors are not recommended for B-Train operation (3). No tractor shorter than 4.5 meters can be used for this application.

Routing considerations: The condition of the special permit restricted the vehicle to a specific route. The roadway was studied for geometric and safety concerns and the final route was chosen after consultation with city traffic officials in Saint John and Moncton. Passing sight distances associated with the additional vehicle length were considered. No special hours of operation were deemed necessary at this time.

Load Security requirements were put in place to prevent both longitudinal and lateral movement of the 5 paper rolls being transported in each trailer. These rolls can weight up to 5,600 lbs with diameters of up to 84" and 103" height. The use of cargo-belt strapping was used for lateral and longitudinal restraint such that the paper rolls could withstand a deceleration of 0.6g for at least 5 seconds. The rear roll was also restrained from falling out of the trailer should the doors open. Friction mats were placed on the floors of the trailers. A specific loading pattern was specified to eliminate any lateral imbalance of the vehicle as shown in **Figure 11**. The two rolls positioned in the center of the trailer will require dunnage to prevent them from shifting.

Driver training requirements are being mutually agreed upon.

Gross Vehicle Combination Mass is limited to 47,000 kg but can be increased if vehicle safety analysis satisfies TAC performance criteria.

CONCLUDING DISCUSSION

The implementation of size and weight policy that permits carriers to create special purpose non conforming vehicle configurations has proven to be an effective tool in fostering improved transport productivity and safety. The engineering performance measures used to determine vehicle stability and control characteristics, have evolved to a mature and reliable state making such policy initiatives practical.

The availability of a fair and objective method for vehicle evaluation based on engineering principles, helps to create cooperative relations between the transport industry and the regulatory authorities. It eliminates the frustrations associated with rigid design restrictive policy by providing a clear set of performance based criteria that provide incentive for vehicle innovation leading to improved transport productivity and safety.

Improvements in vehicle safety are achieved through improvements in vehicle design and operational practice. By classifying these vehicles as special permit vehicles, certain operational safety concerns can be made conditional of the permit. Even without such an operational safety requirement within the permit, the Canadian experience has been that transporters take special care to ensure that their non-conforming vehicle operations are not jeopardized by poor safety practice.

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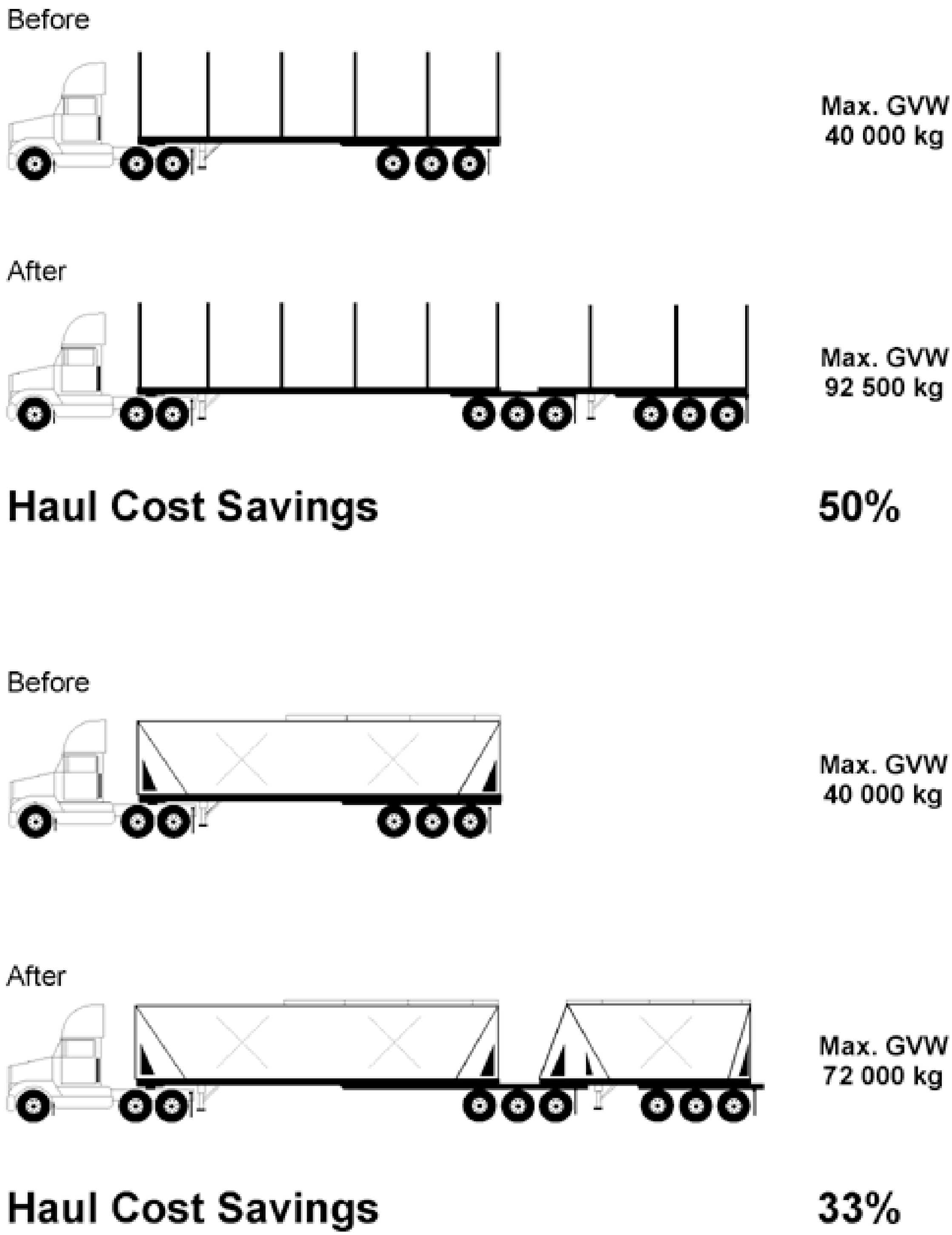

Figure 1 Examples of special vehicles and transport cost savings

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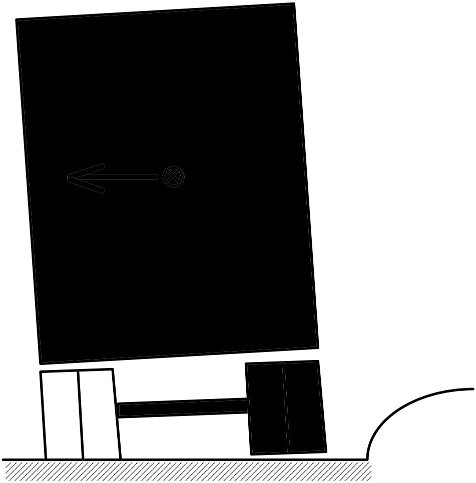

Figure 2. Onset of vehicle rollover

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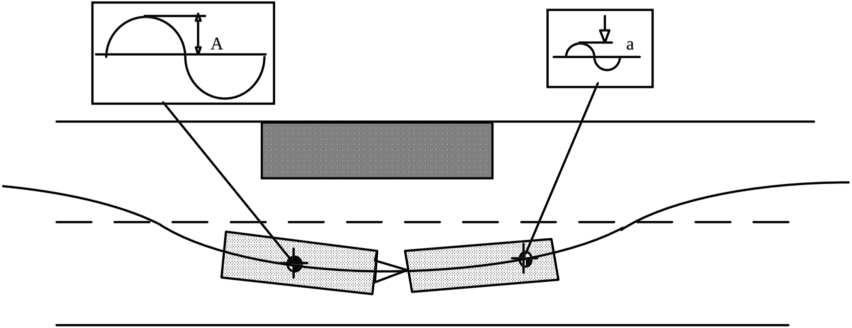

$$RA = A / a$$

Figure 3. Rearward amplification.

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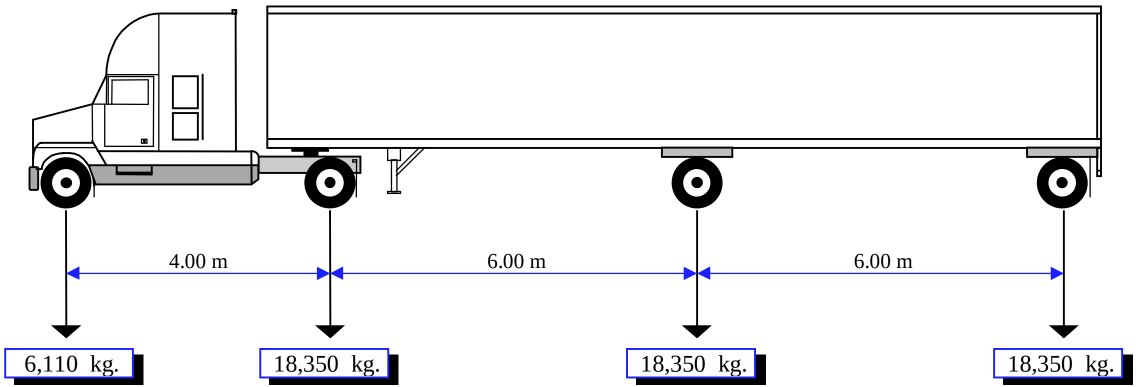

Figure 4 - CS 600 Design Truck

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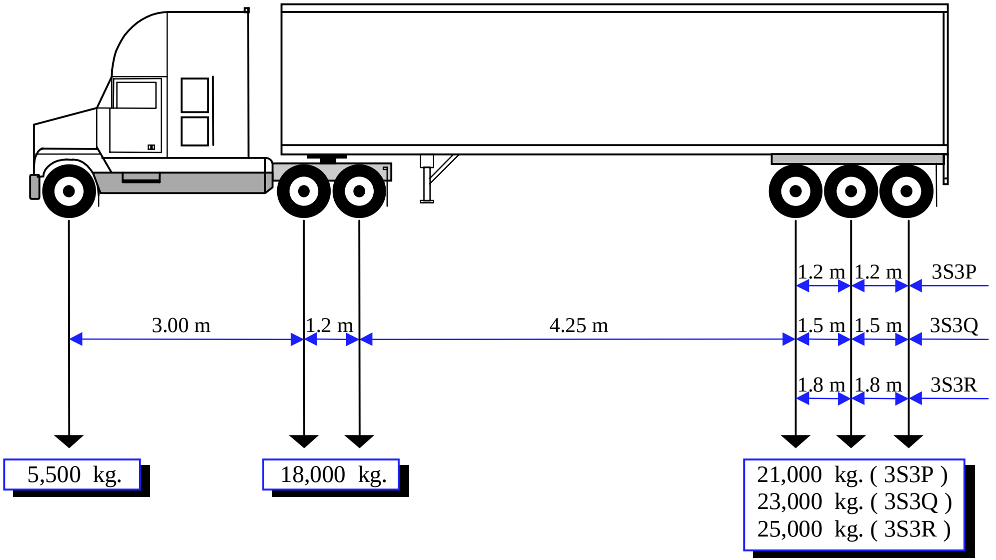

Figure 5 - Short Tridem Semi-Trailer Trucks (3S3P, 3S3Q, 3S3R)

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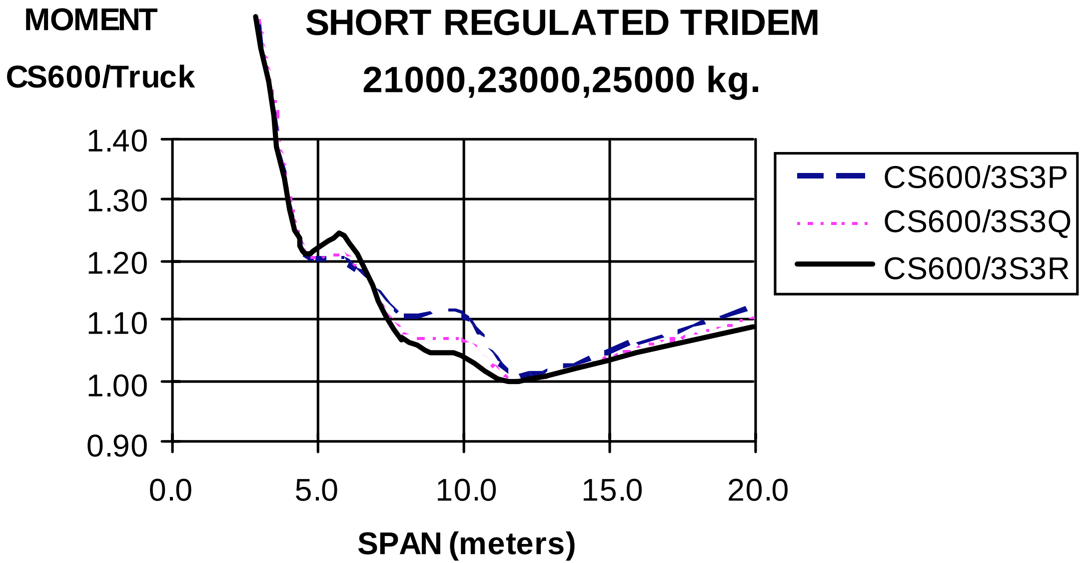

Figure 6 - Moment Comparison of Tridem Truck To CS600

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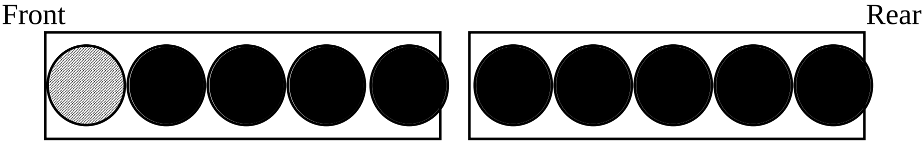

Figure 7. Rolls exceed interior trailer space when loaded in a straight line.

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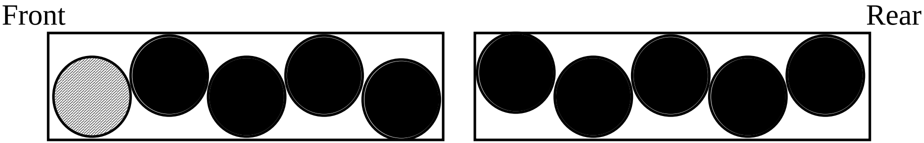

Figure 8. Offset loading pattern minimizes trailer length.

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Front *Rear*

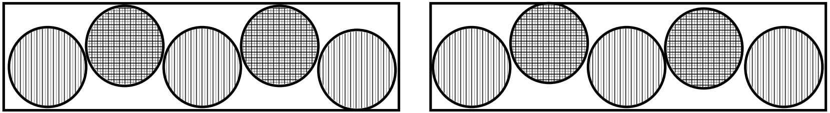

Figure 9. Worst scenario loading pattern resulting in lateral shift in the center of mass.

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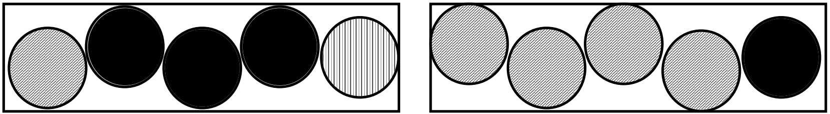

Figure 10. Mandated loading pattern to achieve maximum stability.

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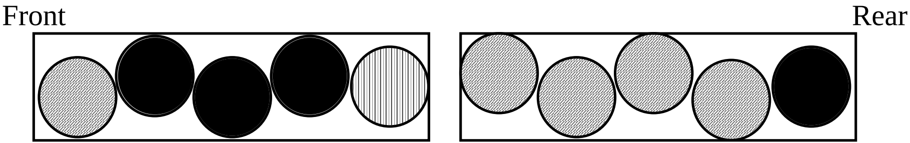

Figure 11. Recommended loading pattern to achieve maximum stability.

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