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WESTERN LOG TRUCK CONFIGURATIONS STUDY

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WESTERN LOG TRUCK CONFIGURATIONS STUDY

by

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March 1998

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16. Abstract

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SUMMARY

A forest industry survey conducted in Alberta and British Columbia identified an overall trend in highway hauling toward an increase in the number of axles in order to increase the average payload capability of each tractor/trailer unit. In Alberta, the tractor/tandem jeep/tandem pole trailer and the Super B-train are expected to become the most popular configurations, while in British Columbia the tractor/triaxle trailer is expected to be the most prevalent. The proportion of dedicated configurations for hauling short logs is also expected to increase in both Alberta and British Columbia.

A yaw/roll model was developed by the National Research Council Canada (NRC) and the University of Victoria (UVic) specifically for log truck configurations equipped with compensating reaches. The simulation results obtained by this model correlate well with the field test results for both lane change and J-turn manoeuvres. This yaw/roll model can therefore be used to estimate log truck dynamic performance for configuration ranking and design improvement.

The yaw/roll model was used in conjunction with nine Transportation Association of Canada (TAC) and NRC performance measures to assess the dynamic performance of the most common log truck configurations under Alberta and British Columbia weight and dimension regulations. High-speed offtracking was the performance measure that the log truck configurations had the most difficulty meeting. Only the tandem tractor/tandem pole trailer, tandem tractor/tridem pole trailer, tridem tractor/tandem pole trailer, and tridem tractor/tridem pole trailer under Alberta legal weights, and the tandem tractor/tandem pole trailer under BC legal weights (with winter logging truck weight allowances) were able to meet the performance standard for high-speed offtracking. This deficiency can be safely tolerated with the following exceptions: doglogger, tandem tractor/tandem jeep/tandem pole trailer, and tandem tractor/jeep/tandem pole trailer under Alberta winter weights; and the double doglogger, tandem tractor/quadaxle trailer, and tandem tractor/jeep/triaxle trailer under BC legal weight regulations (with winter logging truck weight allowances). All configurations with tridem pole trailers were unable to meet the performance standard for friction demand, particularly under Alberta loading conditions. However, the friction demand of these configurations was improved when a tridem tractor was used instead of a tandem tractor. Generally, the use of a tridem tractor instead of a tandem tractor improved or maintained the overall dynamic performance of pole trailer configurations, while increasing payload for Alberta and BC legal weights. Under Alberta winter weights, payload was either reduced or maintained with a tridem tractor due to a combination of gross weight restrictions and increased tare weight, but overall performance was improved significantly.

All configurations when loaded to Alberta legal weights had a better overall dynamic performance than the reference TAC Super B-train. The tridem tractor/tridem pole trailer had the highest overall ranking under this loading condition despite its friction demand deficiency. The tandem tractor/tandem jeep/tandem pole trailer had the lowest overall performance in this category.

Under Alberta winter weight (green route) allowances, overall performance was degraded relative to that obtained at Alberta legal weight allowances. All configurations except for the tridem tractor/tridem pole trailer had an overall dynamic performance below the TAC Super B-train, and failed to meet the performance standard for static rollover threshold and load transfer ratio for most load densities.

Apart from the high-speed offtracking and friction demand performance deficiencies noted previously, the majority of configurations loaded to BC legal weights (with winter logging truck weight allowances) met the performance standard. The tandem tractor/tandem jeep/tandem pole trailer, tandem tractor/quadaxle trailer, double doglogger, and tandem tractor/jeep/triaxle trailer exhibited lower overall performance than the TAC Super B-train and had difficulty meeting the performance standard for static

rollover threshold and load transfer ratio. The tandem tractor/tandem pole trailer and the double doglogger exhibited the highest and lowest ranking overall under this weight regime.

A sensitivity analysis conducted for a tandem tractor/tandem jeep/tandem pole trailer showed that dynamic performance could be improved as a result of increased inter-group spacing, decreased forward load bias, decreased hitch offset, increased tire stiffness, increased bunk width, increased axle width, and decreased payload.

An example optimization exercise of a tandem tractor/tandem jeep/tandem pole trailer and an alternative tandem tractor/tandem jeep/tridem pole trailer configuration illustrated that significant improvements in dynamic performance could be achieved. The deficiency in high-speed offtracking performance was addressed by using 295/75R22.5 tires, which have a higher vertical and cornering stiffness than standard logging configuration tires (11R24.5). The performance was improved further for Alberta configurations, by increasing the jeep axle width from 2.59 m to 3.05 m, since regulations in Alberta allow for a maximum vehicle width of 3.2 m. The use of an alternative tandem tractor/tandem jeep/tridem pole trailer configuration allowed payload to be increased by 4 000 kg for Alberta legal weights and maintained for BC legal weights, while meeting all performance standards at all load densities. However, under Alberta winter weight allowances, payload was decreased by 1 700 kg for this configuration relative to the tandem tractor/tandem jeep/tandem pole trailer in order to meet all the performance standards at all load densities. Increased payloads (2 500 kg) can be achieved when wide bunks are used on the trailer as well as the jeep for Alberta winter weights, making it necessary to load mixed butts and tops.

SOMMAIRE

Un sondage effectué auprès de l'industrie forestière de l'Alberta et de la Colombie-Britannique a fait ressortir une grande tendance dans le transport du bois sur route, à savoir l'augmentation du nombre d'essieux des ensembles articulés, mue par la recherche d'une plus grande productivité. En Alberta, la combinaison tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem et le super-train double de type B sont appelés à devenir les configurations les plus populaires, tandis qu'en Colombie-Britannique, c'est l'ensemble tracteur/remorque à trois essieux qui semble le plus prometteur. La proportion de configurations spécialement conçues pour le transport de courtes grumes devrait également augmenter dans l'une et l'autre provinces.

Le Conseil national de recherches (CNR) et l'Université de Victoria ont développé un modèle de simulation des mouvements de roulis et de lacet spécialement conçu pour l'étude de configurations de grumiers incorporant une barre d'attelage télescopique. Une fois validé au moyen de résultats d'essais sur piste comportant des manoeuvres de changement de voie et de virage serré, ce modèle a servi à évaluer le comportement dynamique de configurations de grumiers, en vue de les classer selon leurs mérites respectifs et d'en améliorer la conception.

Le modèle a été conjugué à neuf critères de performance mis au point par l'Association des transports du Canada et le CNR pour l'étude du comportement dynamique des configurations de grumiers les plus couramment utilisées en Alberta et en Colombie-Britannique, en conformité des règlements sur la masse et les dimensions des véhicules en vigueur dans ces provinces. Le décalage latéral à haute vitesse s'est révélé le critère le plus exigeant. Seules les combinaisons tracteur tandem/semi-remorque à poutre télescopique tandem, tracteur tandem/semi-remorque à poutre télescopique tridem, tracteur tridem/semi-remorque à poutre télescopique tandem et tracteur tridem/semi-remorque à poutre télescopique tridem chargées selon les règles albertaines, ainsi que l'ensemble tracteur tandem/semi-remorque à poutre télescopique tandem conforme aux règles de la C.-B. (masse maximale autorisée pour les véhicules forestiers en hiver) étaient à la hauteur du critère établi pour le décalage latéral à haute vitesse. Cette faiblesse peut être tolérée sans danger, sauf dans le cas des configurations suivantes : *doglogger*, tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem, et tracteur tandem/diabolo/semi-remorque télescopique tandem chargés selon les règles albertaines; et *doglogger* double, tracteur tandem/semi-remorque à quatre essieux et tracteur tandem/diabolo/semi-remorque à trois essieux chargés conformément aux règles de C.-B. (masse maximale autorisée pour les véhicules forestiers en hiver). Aucune des configurations composées d'une semi-remorque à poutre télescopique tridem n'a répondu au critère fixé pour la force de frottement, encore moins lorsqu'elles étaient chargées selon les règles albertaines. Toutefois, la force de frottement de ces configurations se trouvait améliorée lorsqu'un tracteur tridem était utilisé plutôt qu'un tracteur tandem. En effet, les ensembles comprenant une semi-remorque à poutre télescopique tractée par un tracteur tridem affichaient généralement un comportement dynamique global supérieur ou égal à celui obtenu avec un tracteur tandem, tout en admettant une charge utile supérieure, compte tenu des masses maximales autorisées en Alberta et en C.-B. Les règles albertaines touchant les masses admissibles en hiver interdisaient l'augmentation de la charge utile à bord des ensembles composés d'un tracteur tridem, quand elles n'en forçaient pas la réduction, sous l'effet du jeu combiné des limites de masse brute et de l'augmentation de la masse à vide (ajout d'un essieu); mais on a noté une amélioration sensible du comportement global du véhicule.

Toutes les configurations chargées selon les règles albertaines affichaient un comportement dynamique global supérieur à celui du super-train double de type B homologué par l'ATC, faisant office de véhicule de référence. Dans ces conditions de charge, l'ensemble tracteur tridem/semi-remorque à poutre télescopique tridem s'est classé en tête des configurations, malgré des faiblesses au chapitre de la force de frottement. La combinaison tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem s'est classée au dernier rang à ce critère.

Les résultats globaux enregistrés en tenant compte des masses autorisées par l'Alberta en hiver («route verte») se sont avérés inférieurs à ceux obtenus en fonction des masses généralement autorisées. Toutes les configurations, à l'exception de l'ensemble tracteur tridem/semi-remorque à poutre télescopique tridem, ont affiché un comportement dynamique global inférieur à celui du super-train double de type B ATC, et n'ont pas atteint la norme de performance établie pour ce qui est de l'accélération latérale maximale (ou seuil de renversement) sous essai statique, et du rapport de transfert de charge pour la plupart des densités de charge.

Mises à part les faiblesses relevées plus haut touchant le décalage latéral à haute vitesse et la force de frottement, la majorité des configurations chargées selon les règles de la C.-B. (masse maximale autorisée pour les véhicules forestiers en hiver) ont respecté les normes de performance. Les ensembles tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem, tracteur tandem/semi-remorque à quatre essieux, *doglogger* double et tracteur tandem/diabolo/semi-remorque à trois essieux ont tous affiché une performance globale inférieure à celle du super-train double de type B ATC et avaient peine à respecter les normes de performance établies en ce qui a trait au seuil de versement sous essai statique et au rapport de transfert de charges. L'ensemble tracteur tandem/semi-remorque à poutre télescopique tandem et le *doglogger* double ont reçu le meilleur et le pire classement global, respectivement, selon ce scénario.

Une analyse de sensibilité portant sur un ensemble tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem a démontré que le comportement dynamique s'améliore à la mesure de l'augmentation de la distance entre les groupes d'essieux, de la rigidité des pneus, de la largeur du berceau et de la voie du véhicule, et de la diminution du déséquilibre de la charge vers l'avant, du déport de l'attelage et de la charge utile.

Un exercice d'optimisation type d'un ensemble tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem et d'une variante sous la forme d'une combinaison tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tridem a clairement montré qu'il est possible d'améliorer considérablement le comportement dynamique des véhicules. On a pallié les faiblesses au chapitre du décalage latéral à haute vitesse en équipant les véhicules de pneus 295/75R22.5, caractérisés par une rigidité verticale et une raideur en virage supérieures à celles des pneus de véhicules forestiers ordinaires (11R24.5). On a réalisé des gains de performance encore plus marqués pour les configurations albertaines, en faisant passer de 2,59 m à 3,05 m la voie du diabolo, les règlements de cette province fixant à 3,2 m la largeur maximale des véhicules. L'utilisation de la variante tandem/diabolo tandem/semi-remorque à poutre télescopique tridem a permis soit d'augmenter de 4 000 kg la charge utile par rapport à la masse autorisée en Alberta, soit de la maintenir, par rapport aux règles en vigueur en C.-B., sans compromission aucune au chapitre des performances, quelle que soit la densité de charge. Toutefois, compte tenu des masses maximales établies en Alberta en hiver, il a fallu charger cette variante de 1 700 kg de moins, par rapport au tracteur tandem/diabolo tandem/semi-remorque à poutre télescopique tandem, pour pouvoir respecter toutes les normes de performance, sous toutes les densités de charge. Il est possible d'accroître la charge utile (de 2 500 kg), compte tenu des masses autorisées en Alberta en hiver, en utilisant des berceaux de grande largeur sur la semi-remorque et sur le diabolo, ce qui oblige à des chargements bidirectionnels.

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INTRODUCTION

The forest-resource industry is highly dependent on heavy-truck transport to move logs from the harvesting sites to the mills. Harvesting areas have become increasingly remote, making road access limited because of the physical barriers presented by the steep grades or poor ground conditions. The costs associated with mountain and wet site road construction dictate that only single-lane roads are practical and, in the case of mountainous roads, that steep grades and sharp curves must be tolerated. The logging operations in these remote areas are often conducted during the winter months when frost stabilizes the mountain or wet site road structures. This means that a large proportion of the transportation of logs in difficult-access areas takes place when roads are snow covered or icy. These conditions, coupled with steep grades, sharp curves, and narrow roads can challenge both the driver and the vehicle, and have been the major design influences for current log-hauling configurations. Most western Canadian log-hauling configurations have a compensating reach (Figure 1) which enables the configuration to negotiate a network of predominantly narrow roads and sharp curves. Most of these configurations can be disassembled when traveling empty so that the trailer is stowed on the tractor, a feature that increases manoeuvreability and traction. The additional weight on the drive axles allows these configurations to climb steep grades while empty.

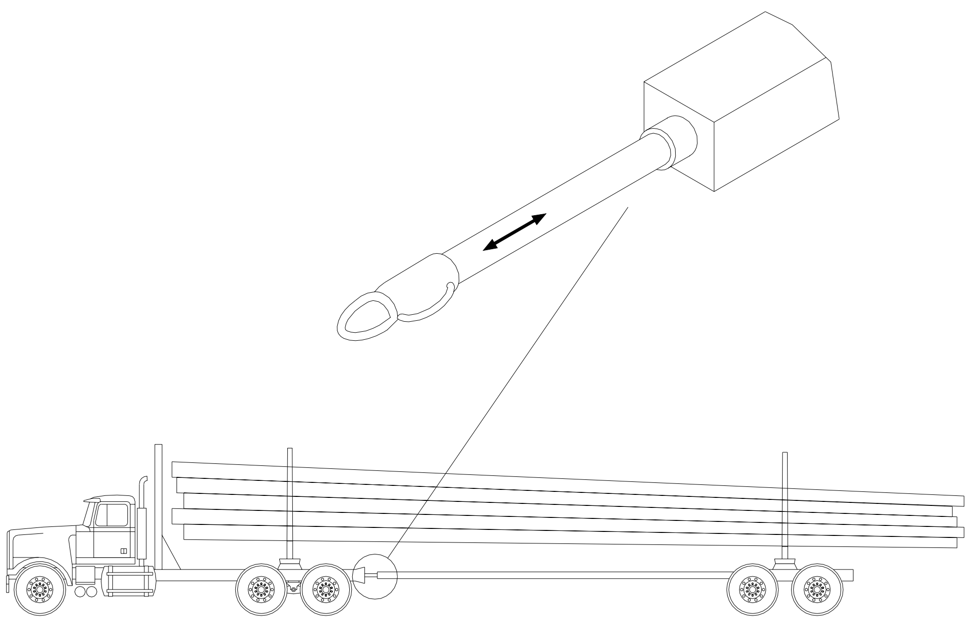


Figure 1. Compensating reach.

In addition to these existing operational constraints, the forest industry in British Columbia and Alberta will be faced with new log transportation challenges in the future. In Alberta the forest industry is expanding and the fibre demands will intensify to the extent that marginal smallwood stands will be harvested and transportation distances for this resource will be extended. The industry in British Columbia is also experiencing longer transportation distances and reduced log dimensions as second-growth forests are harvested or higher elevation stands are accessed. These anticipated changes will increase transportation costs and demand log-hauling innovations to maximize efficiency.

Over the years, the forest-transport industry has responded to the demand to improve efficiency by developing a broad range of different log-hauling configurations. More than ten compensating reach type truck/trailer configurations are currently in use by the forest industry in British Columbia and Alberta. In most cases each of these configurations exist in a number of different versions that have been developed by truck operators themselves or by local and regional trailer manufacturers. The main focus in development of these configurations has been manoeuvreability and payload maximization. An example of such a development is the combination of two tandem-axle pole trailers to bring about a version of the quadaxle trailer. The range of modifications undertaken includes add-on-single-tire self-steering axles, sliding king pins and sliding bunks for jeeps, wider bunks (where permitted), single and dual tire assemblies combined on quadaxle trailers, and trailers controlled by cable-reach systems. Adding to the proliferation of configurations are more recent developments such as tridem tractor units, tridem pole trailers, and twin steering axle tractors. There are approximately 3 500 highway log-hauling units operating in these two provinces, and therefore a process to evaluate the safety of these configurations is needed.

The truck configurations analyzed by the TAC (Transportation Association of Canada)[1] Weights and Dimensions Study represent less than 20% of the truck configurations now used to transport logs in British Columbia and Alberta (Parker, 1995). Of the many configurations that are commonly used for log hauling in Alberta and British Columbia, only the B-train, tractor/semi-trailer, and truck/full trailer have been studied for stability and control characteristics. The remaining units, which use a compensating reach mechanism, are fundamentally different from the vehicles considered under the TAC Vehicle Weights and Dimensions Study. Their true behavioral characteristics in terms of dynamic performance, stability, and related safety issues were unknown. Consequently, neither British Columbia nor Alberta have applied the TAC weights and dimensions recommendations to logging trucks.

In earlier work, conducted by the Vehicle Dynamics Laboratory[2] of the National Research Council Canada (NRC) for the Transportation Development Centre (TDC)/Forest Engineering Research Institute of Canada (FERIC) feasibility study of tridem drive axle tractors (El-Gindy et al., 1990), it was found that some log-hauling vehicle configurations should be discouraged, while others offer relatively substantial benefits. The study, however, was analytical in nature and presented only preliminary results. It used computer simulation based on derived first order estimates of the rollover threshold and directional stability of the vehicles examined. Before any final decisions could be made, it became necessary to undertake a more detailed analysis and perform field testing to validate computed performance characteristics.

It was clear that some mechanism for evaluating this group of vehicles was required to determine whether poorly performing vehicles could be improved or should be eliminated while the more stable units could be promoted. It was also uncertain whether performance standards developed during the TAC Weights and Dimensions Study were totally appropriate for evaluating most log-hauling vehicle configurations. It was established through the preliminary NRC work that these vehicles were fundamentally different in their dynamic behavior by nature of their coupling arrangements, multi-articulation points, load/vehicle interactions, and longer wheelbases.

To address this situation, FERIC, with partial funding from Transport Canada, initiated the study that is represented by this report. A steering committee was formed to broaden awareness of the study, to provide feedback on the plans and results, and to review and approve the individual work elements. The committee comprised representatives of industry (forest product companies, truck fleet operators, and

[1] Formerly RTAC - Roads and Transportation Association of Canada.

[2] Currently Centre for Surface Transportation Technology.

equipment manufacturers), provincial regulatory agencies (ministries of forests and transportation), research organizations (NRC and the University of Victoria (UVic)), the Insurance Corporation of British Columbia (ICBC), and the Transportation Development Centre (TDC) of Transport Canada (chair).

OBJECTIVES

The objective of this study was to provide the western forest products industry, its truck equipment suppliers, log haulers, and regulatory authorities with long term direction for the development and deployment of safer, more productive log truck configurations.

To accomplish this objective, the following sub-objectives were developed:

1. Undertake an industry survey to determine future trends and to gather load and truck information.

2. Conduct a series of dynamic tests of representative configurations to measure performance characteristics under controlled conditions on a test track.

3. Develop and validate a computer model to evaluate the dynamic performance of these specific log truck configurations.

4. Apply the model to evaluate and rank the dynamic performance of the configurations under both BC and Alberta weights and dimensions regulations.

5. Apply the models to explore modifications that would improve the dynamic performance of marginal configurations.

SCOPE

The study was limited to long log-hauling configurations appropriate to the forest industry in British Columbia and Alberta. The work involved an investigation of current and future transportation requirements from the logging site to the mill. An evaluation was undertaken of the ability of existing and proposed log-hauling configurations to meet these requirements while satisfying appropriate vehicle performance standards for safe operation, as well as highway infrastructure and operating restrictions. Performance standards for log-hauling configurations are equivalent, where appropriate, with performance standards established for general freight commercial vehicles operated on highways (i.e. TAC performance standards). One aspect that is not evaluated directly in this study is the impact of these configurations on pavements and bridges. However, the information from which to determine these impacts may be found in the Appendices.

METHODOLOGY

I. Survey

A detailed questionnaire was prepared and distributed to all woodland operations in Alberta and British Columbia with a 1991 annual allowable cut (AAC) on crown land greater than 150 000 m^3. The overall response rate was 71% of AAC.

The survey results were summarized and trends were noted in regional summary reports. These summary reports were discussed with representatives of the forest industry on a regional basis in order to interpret the survey findings. In addition, load densities were sampled at various operations, since this information was not readily available. Load density, in combination with load dimensions, provides a means of estimating the centre of gravity position and the inertial properties of a load of logs. The load density was computed by measuring the payload weight and the block volume (including air voids) of the load. The results of the survey and load density sampling were summarized in a final report (Parker, 1995).

II. Testing and Characterization of Two Western Log Truck Configurations

In the fall of 1992, various static and dynamic measurements were made on two western Canadian log truck configurations - a tandem tractor/tandem pole trailer and a tandem tractor/jeep/tandem pole trailer. This work was conducted to provide data which could be used to assess the accuracy of existing log truck simulation models (El-Gindy et al., 1990), and to develop and refine new models as necessary (Tong et al., 1995).

The static phase of the test program involved vehicle and component characterization. The following component characteristics were measured:

- Tractor steering system gear ratio
- Steer axle vertical and roll stiffnesses
- Drive axle vertical and roll stiffnesses
- Tractor frame torsional stiffness
- Jeep vertical and roll stiffnesses
- Jeep frame torsional stiffness
- Log load torsional stiffness
- Tire characterization

All of these measurements with the exception of the tire characterization were conducted at NRC's Centre for Surface Transportation Technology (CSTT) in Ottawa. The tire characterization was conducted by the University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor, Michigan, USA.

The full scale vehicle performance tests conducted on these configurations consisted of tilt table measurements, and high speed lane change and J-turn manoeuvres. The tilt table tests (Figure 2) were conducted at CSTT's Ottawa facilities with the remaining tests (Figure 3) conducted at Transport Canada's motor vehicle test centre at Blainville[3], Quebec. The details of the testing and component characterization methodology are summarized in the NRC report on this topic (Preston-Thomas, 1994).

[3] Now privatized as PMG Test and Research Centre.

Figure 2. Tilt table testing of tandem tractor/jeep/tandem pole trailer.

Figure 3. High speed lane change manoeuvre.

III. Development and Validation of Yaw/Roll Model

A yaw/roll model was developed jointly by NRC and UVic (Tong et al., 1995). The model was developed specifically for western log truck configurations with a compensating reach, and is based on the UMTRI yaw/roll model. The model is a non-linear time domain simulation that can predict the directional and roll response of logging configurations to a specified steering manoeuvre.

In the yaw/roll model the forward velocity of the tractor is assumed to remain constant during the manoeuvre. The simulation can be performed in either closed loop or open loop modes. In the open loop mode, the time history of the steering angle is input directly to the model. In the closed loop mode, the trajectory to be followed by the mass centre of the lead vehicle is specified, and an algorithm computes the required steering input to achieve this path.

The development of the NRC/UVic yaw/roll model included a validation process, as the simulation results were compared with field test measurements conducted by NRC (Preston-Thomas, 1994). The comparison was conducted for the two configurations with outriggers under two different manoeuvres, namely the J-turn and the lane change manoeuvre. For the purposes of the comparison, the measured steer angles from the field tests served as the steering input data (open loop) for the simulation.

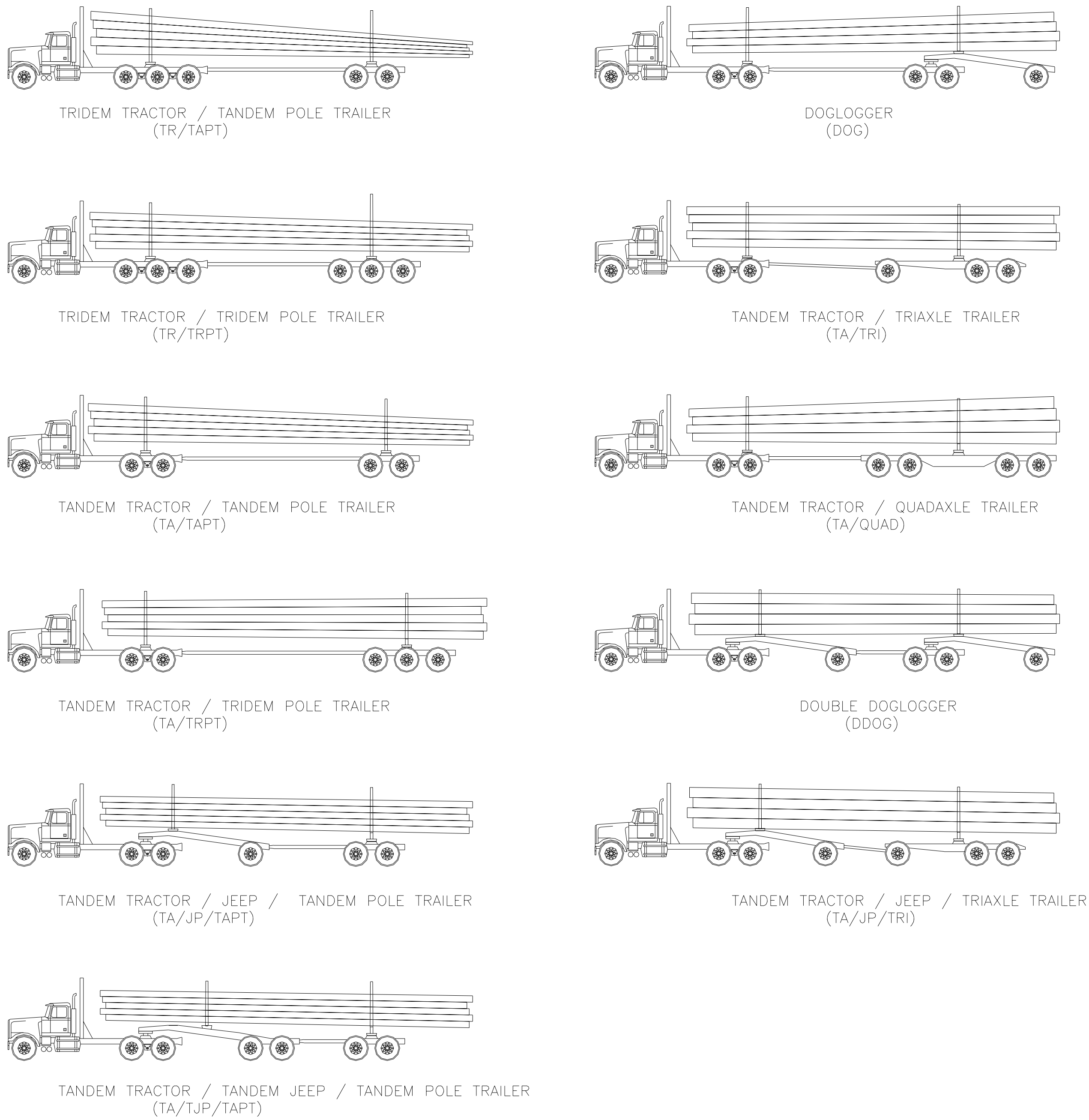
IV. Dynamic Evaluation of Existing Log Truck Configurations

The project steering committee (Appendix I) requested that simulations be conducted for state-of-the-art trailers and a range of load densities, so that a range of dynamic performance of current trailer designs could be evaluated. FERIC surveyed the majority of trailer manufacturers in Alberta and BC for current design specifications (Appendix II), and used the most favorable in the simulations of each log truck configuration. A range of load densities[4] (95% confidence interval with a margin of error of less than 20 kg/m^3) was determined separately for Alberta and BC (Appendix III) based on data collected during the survey of log-hauling trends, and additional load sampling in Alberta.

Using the yaw/roll model and applying the range of load densities, simulations were conducted according to the weight and dimension regulations of the respective provinces (see Appendix IV for details) for the configurations illustrated in Figure 4. Note that some configurations which were simulated for BC do not operate in Alberta. The specific simulated configurations are as indicated in Table 1.

In cases where the low density loading resulted in height restrictions being reached before maximum axle loads were reached, an additional simulation was run at an intermediate load density where maximum axle loads were achieved at the maximum allowable load height.

[4] Load density is calculated from payload weight and block volume (including air voids, which typically make up 40% of the volume).



* Note - Abbreviation of configuration in brackets

Figure 4. Western log truck configurations evaluated in study.

Table 1. Matrix of Simulated Configurations

Configuration	Weight and Dimension Regulations		
	Alberta Legal	Alberta Winter (green route)	British Columbia Legal (including winter logging truck weight allowances)
tandem tractor/tandem pole trailer	X	X	X
tandem tractor/tridem pole trailer	X	X	X
tridem tractor/tridem pole trailer	X	X	X
tandem tractor/jeep/tandem pole trailer	X	X	X
doglogger	X	X	X
tandem tractor/triaxle trailer			X
tridem tractor/tandem pole trailer	X	X	X
tandem tractor/tandem jeep/tandem pole trailer	X	X	X
tandem tractor/quadaxle trailer			X
double doglogger			X
tandem tractor/jeep/triaxle trailer			X

X indicates simulation conducted

In addition, simulations were also conducted for a reference TAC 8-axle Super B-train (Figure 5) under maximum legal Alberta and British Columbia weight and dimension regulations (additional winter weight allowances not included), so that direct comparisons could be made between these western long log truck configurations and this approved legally loaded TAC configuration. This configuration was chosen as the reference configuration by the project steering committee since it is the preferred heavy haul configuration in western Canada, as it allows payload maximization, meeting an objective of the western Canadian forest industry. The Super B-train is used predominantly by the forest industry to haul short logs. Other configurations are also used for hauling short logs, but were considered beyond the scope of this study, as they were previously covered in the TAC weights and dimensions study, and the Ontario Ministry of Transportation study involving straight trucks and truck trailer combinations (Billing, Lam 1992).

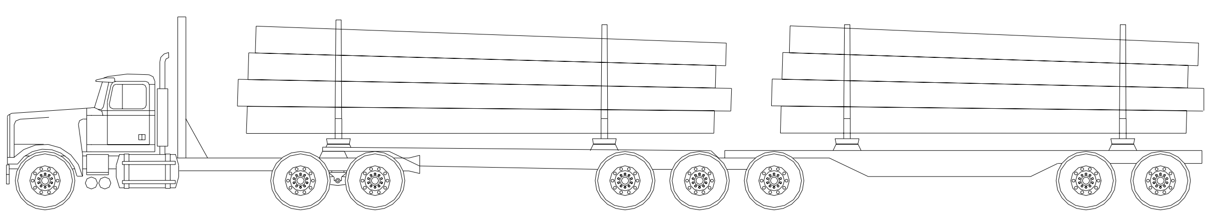


Figure 5. Reference TAC configuration : 8-axle Super B-train.

In order to evaluate the dynamic performance of these configurations, the following performance measures were calculated from the simulation data:

High Speed Steady State Measures and their respective performance standards

a) *Static Rollover Threshold (SRT)* The static rollover threshold is the level of steady lateral acceleration beyond which the configuration rolls over. The measure is expressed as the lateral acceleration (in g's) at which all wheels on one side, except the steer axle, lift off the ground. Configuration performance is considered satisfactory if the SRT is greater than or equal to 0.35 g. This performance standard was modified from the TAC level of 0.40 g by the project steering committee, as an SRT exceeding 0.35 g is considered acceptable by vehicle dynamics specialists (El-Gindy, 1995) and most logging configurations would have difficulty meeting the 0.40 g TAC standard. This performance measure is determined during a ramp steer manoeuvre (ramp steer rate of 2 deg/sec at steering wheel) at a forward velocity of 100 km/h[5]. This slow ramp steer input results in a mild quasi spiral path trajectory that is essentially free of transient disturbances but also allows a single run of the yaw/roll model to be used to predict the rollover stability (Ervin et al., 1986). This measure has been shown to correlate very closely with rollover accidents, which cause the majority of truck fatalities (Ervin et al., 1986), and is therefore a very significant performance measure to consider.

b) *High Speed Steady State Offtracking (HSOT)* High speed offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if HSOT is less than or equal to 0.46 m (TAC performance standard). This value represents a minimal clearance of 0.15 m between the trailer tires and the outside of a 3.66-m wide conventional traffic lane, when a 2.44-m-wide vehicle follows a path down the centerline of the lane. For a 2.59-m wide vehicle such as those evaluated in this study, the clearance between the trailer tires and the outside lane is reduced to 0.075 m. This performance measure is evaluated when the vehicle is operated in a 393-m curve radius, at a speed of 100 km/h, thereby attaining a steady lateral acceleration level of 0.2 g. The outboard tracking of the trailer axles in high speed turns has resulted in accidents particularly on interchange ramps where the trailer axles strike the curb and initiate rollover (Ervin et al., 1986). Other potential problems with excessive trailer outswing include the possibility of the trailer hitting traffic in the adjacent lane. Another study concluded that this performance measure was not of major importance, provided that trucks stayed well clear of the curb (Fancher et al., 1989). However, it is the authors' view that this performance measure is important to consider in the overall performance of a configuration and should be minimized wherever practically possible.

c) *Understeer Coefficient at 0.25g (USC)* Handling performance is evaluated at steady-state conditions by calculating the understeer coefficient at a lateral acceleration of 0.25 g. The calculations needed to evaluate the understeer coefficient used in the construction of the handling diagram are based upon a constant vehicle speed of 100 km/h, using $\{(d_{sw}/N_g - L/R), A_y\}$, where d_{sw} is the steering wheel angle and N_g is the steering box gear ratio. The reason for using the nominal front axle steering angle (d_{sw}/N_g) instead of the actual front-axle steer angle, is to account for the understeer attributable to the steering system compliance. Accordingly, the understeer coefficient of interest, K_u, expressed in units of "degrees per g", is defined by the equation:

[5] Normally the SRT is determined experimentally using a tilt table device.

$$K_u = d\left(\frac{d_{sw}}{N_g} - \frac{L}{R}\right) \Big/ d(A_y) \qquad .....(1)$$

The pass/fail criterion is addressed by comparing K_u with the critical understeer coefficient, K_{ucr}, which can be expressed as $-Lg/U^2$, where U is the vehicle speed (U = 27.77 m/s (100 km/h)), L is the tractor or truck wheelbase (in metres), and g is acceleration due to gravity (9.81 m/s^2). If the value of K_u is greater than the target value K_{ucr}, the vehicle will meet the criterion (TAC performance standard). For the configurations investigated in this study, the understeer coefficient must be greater than or equal to -4.515 and -4.848 for tandem (6.2 m wheelbase) and tridem (6.6 m wheelbase) tractors respectively[6]. This performance measure is determined using the same manoeuvre as "performance measure a)". This performance measure has not been linked directly to the accident record (Ervin et al., 1986), but remains an important consideration to overall configuration performance.

High Speed Transient Measures and their respective performance standards

These performance measures are all evaluated during a rapid lane change manoeuvre conducted at 100 km/h, yielding a lateral acceleration amplitude of 0.15 g and a period of 2.5 seconds at the tractor's mass centre. The literature shows that vehicles which perform poorly under this type of manoeuvre are heavily involved in accidents (Ervin et al., 1986, Fancher et al., 1989). Therefore it is very important that configurations meet or exceed the performance standards for these measures.

d) *Load Transfer Ratio (LTR)* The load transfer ratio is defined as the ratio of the absolute value of the difference between the sum of right wheel loads and the sum of the left wheel loads, to the sum of all the wheel loads. The front steering axle is excluded from the calculations because of its relatively high roll compliance. Configuration performance is considered satisfactory if the LTR is less than or equal to 0.60 (TAC performance standard).

e) *Transient offtracking (TOT)* Transient offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if TOT is less than or equal to 0.8 m (TAC performance standard).

f) *Rearward Amplification (RWA)* Rearward amplification is defined as the ratio of the peak lateral acceleration at the mass centre of the rearmost trailer to that developed at the mass centre of the tractor. Configuration performance is considered satisfactory if the RWA is less than or equal to 2.2, which is the current TAC performance standard. This performance standard has been revised several times since the vehicle weights and dimensions study was conducted in 1986. Initially the RWA performance standard was 1.4, but was increased to 1.8 and 2.0 in 1989 and 1992 respectively based on studies conducted by UMTRI. The performance standard was finally increased to its current level of 2.2 as a result of work conducted by NRC, also in 1992.

Low Speed Steady State Measures and their respective performance standards

These performance measures are all evaluated in a 90-degree turn at a vehicle speed of 8.25 km/h. During the manoeuvre, the centre of the front steer axle tracks an arc with a 12.8-m radius (approximately a 14-m outside-wheel-path radius). This low speed manoeuvre was modified by NRC from the TAC manoeuvre,

[6] Tandem drive tractors typically has a wheelbase of 6.2 m. The minimum allowable tractor wheelbase for a tridem drive tractor is 6.6 m.

where the turning radius was increased from 9.8 m to 12.8 m to accommodate long wheelbase tractors, which are used in this study. Due to the slow speed nature these performance measures do not appear to be important factors in fatal accident involvements. It is however important to consider these performance measures to reduce the possibility of collisions occurring at intersections, particularly under winter conditions.

g) *Friction Demand (FD)* The friction demand performance measure describes the non tractive tire friction levels required at the drive axles of a tractor. Excessive friction demand is a contributing factor to jackknife and also results in excessive tire wear. Friction demand is the absolute value of the ratio of the resultant shear force acting at the drive tires divided by the cosine of the tractor/trailer articulation angle to the vertical load on the drive tires. Configuration performance is considered satisfactory if FD is less than or equal to 0.1 (TAC performance standard).

h) *Lateral Friction Utilization (LFU)* Lateral friction utilization is a measure proposed by NRC to characterize the highest level of the lateral friction utilization at the steering axle. LFU is defined as the ratio of the sum of lateral forces to the vertical load, and the peak tire/road coefficient of adhesion. The tires of a steering axle that achieves a lateral friction utilization level of 1 are said to be saturated. Configuration performance is considered satisfactory if LFU is less than or equal to 0.80 (NRC recommended performance standard). Initially this performance measure was evaluated on a high friction surface. FERIC modified this measure by evaluating LFU on low friction surfaces, which are more critical for steering performance, by using low friction tire characteristics ($\mu = 0.2$).

i) *Low Speed Offtracking (LSOT)* Low speed offtracking is measured as the maximum lateral displacement of the centre-line of the last axle of the configuration from the path taken by the centre of the steer axle. Configuration performance is considered satisfactory if LSOT is less than or equal to 6 m (TAC performance standard).

The performance measure results are presented and interpreted for the three respective weight regulations by the following three methods:

(i) Relative Configuration Performance

The performance of the various configurations are compared and contrasted for each of the performance measures. The figures presented illustrate the range in performance caused by the variation in load density.

(ii) Individual Configuration Performance

The overall performance of each configuration is assessed in terms of the range of performance measure variation from the performance standards, thereby highlighting the strengths and weaknesses of each configuration.

(iii) Ranking of Configurations

The following procedure was developed with the guidance of the steering committee in order to determine an overall ranking of the configurations:

- As it applies to this group of heavy vehicles, each performance measure was assigned a weight (W) depending on its relative importance to overall safety, as follows:

High Speed Steady State Measures (account for 35% of overall assessment)

a) Static rollover threshold - 20%
b) High speed steady state offtracking - 10%
c) Understeer coefficient (handling) - 5%

High Speed Transient Measures (account for 45% of overall assessment)

d) Load transfer ratio - 20%
e) Transient offtracking - 10%
f) Rearward amplification - 15%

Low Speed Steady State Measures (account for 20% of overall assessment)

g) Friction demand - 6.7%
h) Lateral friction utilization - 6.7%
i) Low speed offtracking - 6.7%

- An overall performance measure, dynamic index (DI), was calculated for each configuration, incorporating all nine performance measures over the range of loading conditions. The low and high load densities result in a range of performance for each performance measure, which when summed together yield a single performance value DI calculated as follows (refer to Figure 6 for graphical representation of dynamic index):

$$DI = \sum_{i=1}^{9}\left[\frac{W_i}{5}\bullet\left[\left(1+\text{Max deviation}/100\right)+\left(1+\text{Min deviation}/100\right)+\left(\text{Proportion in acceptable zone}\right)\right]\right] \quad ......(2)$$

where i represents each performance measure
Max. and Min. deviations represent the percentage improvement relative to the performance standards (i.e. improvements are positive, reduction in performance is negative)
W represents assigned weight of measure
The proportion in the acceptable zone is a number between zero and one
The higher the value of DI, the better the overall performance.

For example, if a configuration's load transfer ratio ranges between 0.50 and 0.65, the maximum deviation from the performance standard of 0.6 is 16.7% lower (i.e., improvement in performance and therefore positive), the minimum deviation is 8.3% higher than the performance standard (i.e., reduction in performance and therefore negative), the proportion in the acceptable zone is 67% (i.e., between 0.5 and 0.6). Noting that load transfer ratio represents 20% of the dynamic index, the portion of the dynamic index attributable to the load transfer ratio is:

$$\frac{20}{5}\bullet\left[\left(1+0.167\right)+\left(1-0.083\right)+\left(0.67\right)\right]\cong 11.02$$

This calculation is repeated for the remaining performance measures, and summed together, resulting in a dynamic index for the configuration.

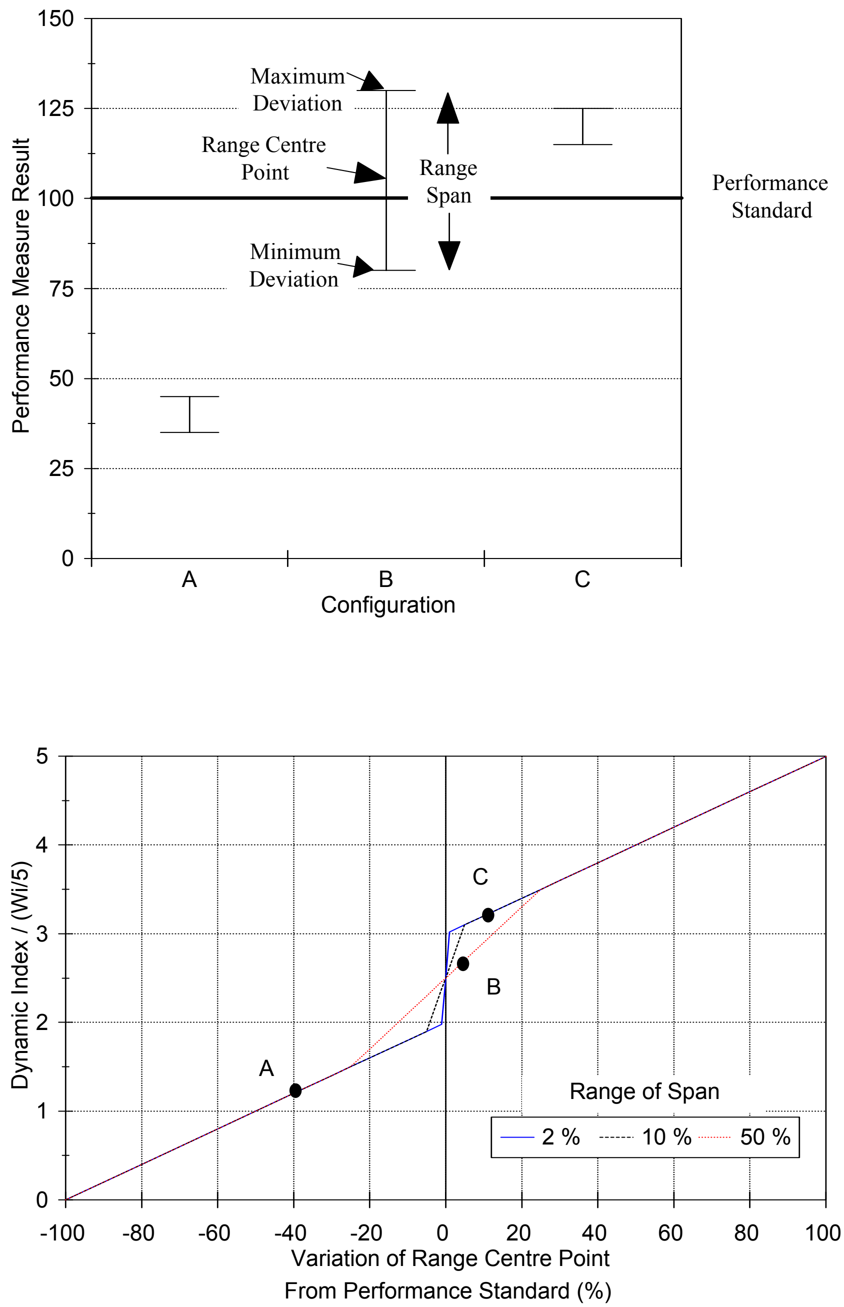


Figure 6. Graphical representation of dynamic index

V. Model Application to Explore Configuration Improvement Options

Individual configuration performance results from the interaction of many configuration parameters. Overall performance can be improved by adjusting the existing configuration parameters. In this section, various options are investigated to optimize the overall dynamic performance for a sample configuration the tandem tractor/tandem jeep/tandem pole trailer. This configuration was selected due to its popularity in Alberta and high productivity. **The optimization conducted in this section is an example only**, and should not be interpreted as the only solution. The objective of this section to illustrate potential improvements that could be applied for this and the remaining configurations. It will be necessary for the stakeholders to determine the optimization criteria and practical parameters specific to each province before any final optimizations may be carried out.

1. Sensitivity Analysis

Simulations were conducted for a sample configuration to determine the sensitivities of various configuration parameters on the nine performance measures. The baseline configuration was a tandem tractor/tandem jeep/tandem pole trailer, which had the same specifications that were used in the previous simulations for Alberta winter weights. The load density used in the analysis was the average of 448 kg/m^3 for Alberta loads. The analysis was conducted by varying one of the parameters by +20% and -20% keeping all others constant to determine the relative sensitivity of each performance measure to each of the following individual parameters:

- **a)** Inter-group spacing between jeep and pole trailer
- **b)** Proportion of payload forward on jeep
- **c)** Hitch offset of jeep
- **d)** Rear bunk width
- **e)** Tire stiffness
- **f)** Jeep axle track width
- **g)** Trailer axle track width
- **h)** Payload weight

2. Optimization and Evaluation

Based on the results of the sensitivity analysis, the configuration parameters were optimized for the tandem tractor/tandem jeep/tandem pole trailer and an alternative tandem jeep configuration with a tridem pole trailer[7] (Figure 7). In addition to optimizing the eight configuration parameters, wide track axles (2.59 m) were used on the tractor to further enhance stability. The goal in the optimization process was to meet the performance standard for each performance measure at all load densities and achieve as high a dynamic index as practically possible, while maximizing the payload up to the current allowance. In addition, low speed offtracking performance was minimized as much as possible, since these configurations must be able manoeuvre on narrow bush roads. For details of the reference and optimized configurations, refer to Appendix V.

[7] New or modified configurations such as this will require changes to regulations and review of infrastructure capabilities for each province.

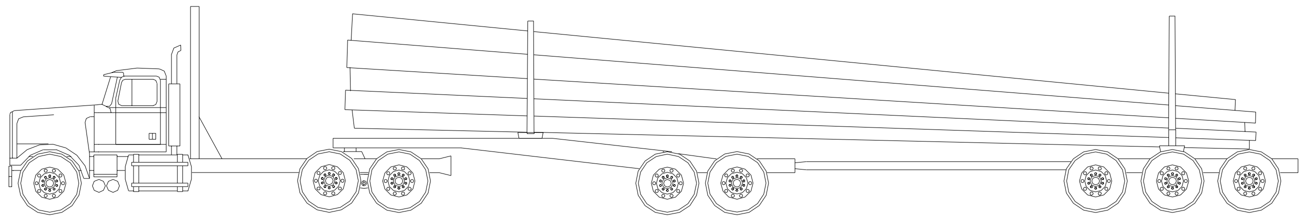


Figure 7. Alternative configuration : tandem tractor/tandem jeep/tridem pole trailer.

Simulations were conducted for these optimized configurations at the high and low load densities, and their dynamic indices calculated as previously described for the following loading conditions:

- **A.** Alberta legal weights
- **B.** Alberta winter weights (green route)
- **C.** British Columbia legal weights (with winter logging truck weight allowances)

In Alberta two loading methods were investigated and optimized for both the tandem tractor/tandem jeep/tandem pole trailer and the alternative tandem tractor/tandem jeep/tridem pole trailer configuration. The loading methods investigated were the status quo with all butts oriented forward, and an alternative method of mixing the butts and tops. In British Columbia, only the mixed orientation method of loading was investigated.

RESULTS AND DISCUSSION

I. Survey

In the fall of 1992, FERIC conducted a survey of the forest industry in Alberta and British Columbia to determine future trends in log-hauling practices (Parker 1995).

The overall trend is an increase in the number of axles in order to increase the average payload capability of each tractor/trailer unit. In Alberta, the tandem tractor/tandem jeep/tandem pole trailer and the Super B-train are expected to become the most popular configurations, while in British Columbia the tandem tractor/triaxle trailer, followed by the tandem tractor/tandem pole trailer and the tandem tractor/jeep/tandem pole trailer are expected to be the most prevalent. Since the survey was conducted tridem drive tractors have become legal for use with pole trailers in BC and Alberta; at this time they are still only a small part of the fleet, but their numbers are steadily increasing.

The proportion of dedicated configurations for hauling short logs is also expected to increase in both Alberta and British Columbia. The highest proportions of shortwood configurations are expected in northern and central Alberta (46% and 37% of the fleet respectively). In British Columbia, the survey indicated the highest proportions of dedicated shortwood configurations are expected in the northern and southern interior (23% and 18% respectively) but developments since then suggest that their numbers may increase more than initially thought. The overall expected increase in dedicated shortwood configurations indicates a need for further development and refinement of multi-bunk shortwood configurations. A need also exists in areas where both long and short logs are produced for convertible long/short log configurations.

Haul distances and therefore cycle times are expected to increase throughout Alberta and British Columbia. Double shifting will be more prevalent in Alberta, particularly during the winter months, and will also increase in British Columbia, as a means of improving truck utilization. Hauling will be relatively balanced throughout the year, except in northern Alberta where the majority of the volume will continue to be hauled during the winter. The number of active log trucks is expected to increase in northern Alberta by up to 37%, because of an increase in harvest levels. Elsewhere the number of active log trucks required is expected to decline, because of increases in truck capacity. In British Columbia, decreases in harvest levels and increases in double shifting will initially add to this decline. However, in the long term, increased fibre utilization may increase total truck requirements (particularly specialized configurations).

New log-hauling technologies that will improve configuration stability and tractive capability are being introduced. Anti-lock braking systems (ABS) and wide track axles will improve configuration dynamic performance, while central tire inflation (CTI) and tridem drive tractors will provide improved traction under most circumstances.

Load densities were found to range between 335 and 670 kg/m^3, with an average of 460 kg/m^3 for Alberta loads[8] and 500 kg/m^3 for British Columbia loads. In Alberta, load centre of gravity heights for winter loads range from 2.54 m to 2.80 m. In British Columbia, load centre of gravity heights range from 2.23 m to 2.73 m when loaded to typical maximum weights at average load densities. These load centre of gravity heights are similar to those found on most freight trucks.

II. Testing and Characterization of Two Western Log Truck Configurations

A series of high speed track tests, tilt table tests, and truck component measurements were conducted with two log-hauling configurations; the tandem tractor/tandem pole trailer, and the tandem tractor/jeep/tandem pole trailer for the purposes of providing data to evaluate the simulation models. The NRC report details the work on this subject (Preston-Thomas, 1994). It is important to note that these field tests were not conducted to provide an extensive database to completely validate the simulation models, but to provide an indication of the degree of accuracy that might be obtained from these models under a few selected circumstances. This avoided the need for extensive testing of all log-hauling configurations, and yet provides a basis from which to estimate the simulation model's accuracy and reliability.

The tilt table tests showed that the measured rollover threshold for the test conditions ranged from 0.36 g to 0.37 g for the tandem tractor/tandem pole trailer and from 0.30 g to 0.32 g for the tandem tractor/jeep/tandem pole trailer. These measurements provide a measure for checking model based predictions of roll stability.

Several lane change tests were conducted for both configurations on courses designed for peak lateral accelerations of 0.15 g and 0.25 g, which provided data for assessing the accuracy of the computer simulation models designed to evaluate yaw stability and lateral response characteristics of log trucks. Most of the peak lateral accelerations measured during these tests were substantially lower than the nominal design values, partly because of deviations between the intended and actual steer paths.

Several J-turn tests were conducted for both configurations. Each of these open loop manoeuvres consisted of a straight lead in followed by a step steer input that was held until the configuration reached steady state in its new cornering attitude. As for the lane change tests, these tests provided useful data for

[8] Following this, further sampling was conducted in Alberta to improve statistical accuracy (see Appendix III).

assessing the computer simulation model's accuracy in evaluating yaw and lateral response characteristics of log trucks.

III. Development and Validation of Yaw/Roll Model

The yaw/roll model was developed to analyse the dynamic responses of log-hauling configurations with one to four articulation points under different manoeuvres. The model predicts lateral accelerations, tire and suspension forces, roll, pitch, and yaw rates of each unit under a constant forward velocity. Simulations can be performed in either open or closed loop modes. In the open loop mode, the time history of either the front wheel steer angle or the steering wheel angle is provided as steering input. In the closed loop mode, the trajectory to be followed by the vehicle is specified and the steer wheel inputs are calculated.

The simulation results obtained by the yaw/roll model were in good agreement with the field test results for both the lane change and J-turn manoeuvres. The yaw/roll model was able to predict the unstable roll response when the configurations reached their rollover limits under a severe J-turn manoeuvre, thereby demonstrating the importance of the non-linear tire properties in modeling these configurations. The developed yaw/roll model can therefore be used to provide reliable estimates of log truck dynamics for configuration ranking and the improvement of vehicle design.

IV. Dynamic Evaluation of Existing Log Truck Configurations

As stated in the methodology, only long log configurations were evaluated in this study in addition to a reference TAC Super B-train, since long log configurations made up the majority of the log-hauling fleet when this study was initiated. However, the use of short log configurations has increased in recent years as predicted by the survey. It would therefore be beneficial to follow this study, with a short log configuration study using the same methodology developed in this study so that direct comparisons of configuration dynamic performance can be made of all log-hauling configurations.

Refer to Appendix VI for tables of performance measure results. The configuration codes for the graphs presented in this section are defined in Figure 4.

A. Alberta Legal Weights

(i) Relative Configuration Performance

a) Static Rollover Threshold (SRT)

All the configurations met the performance standard for the entire range of load densities, except for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) (Figure 8). The tridem tractor/pole trailer configurations (TR/TRPT, TR/TAPT) performed the best in terms of rollover stability. The lowest stability occurred for the tandem tractor/tandem jeep/tandem pole trailer with a SRT below the performance standard of 0.35 g for the entire range of load densities. The inferior performance of the tandem tractor/tandem jeep/tandem pole trailer results from the high payload and resulting high centre of gravity (cg) height of this configuration. The additional drive axle of the tridem tractor improved rollover stability over the tandem tractor, as it provides more rollover resistance than increase in payload and cg height. All configurations except for the tandem tractor/tandem jeep/tandem pole trailer had better rollover stability than the reference TAC Super B-train (BTRN).

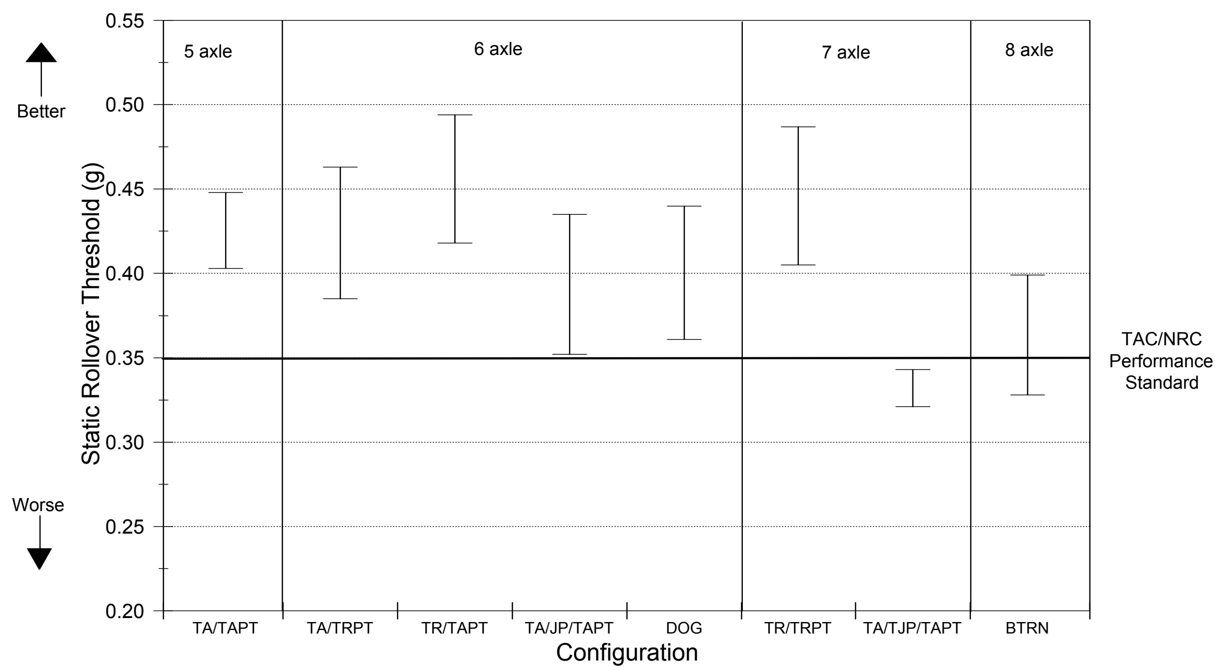


Figure 8. Static rollover threshold - Alberta legal weights.

b) High speed steady state offtracking (HSOT)

Only the four single articulating pole trailer configurations met the performance standard for high speed steady state offtracking (Figure 9). The doglogger experienced the worst levels of HSOT, while the best level of HSOT occurred for the tridem tractor/tandem pole trailer configuration. Generally, HSOT increases as the length of the configuration increases, and as the number of articulation points increase. All configurations exhibited a significant improvement in performance over the reference TAC Super B-train (BTRN) hauling logs. The three configurations failing to meet the TAC performance standard all had more than one articulation point with levels of HSOT below 0.55 m (<0.09 m above performance standard), which can be safely tolerated.

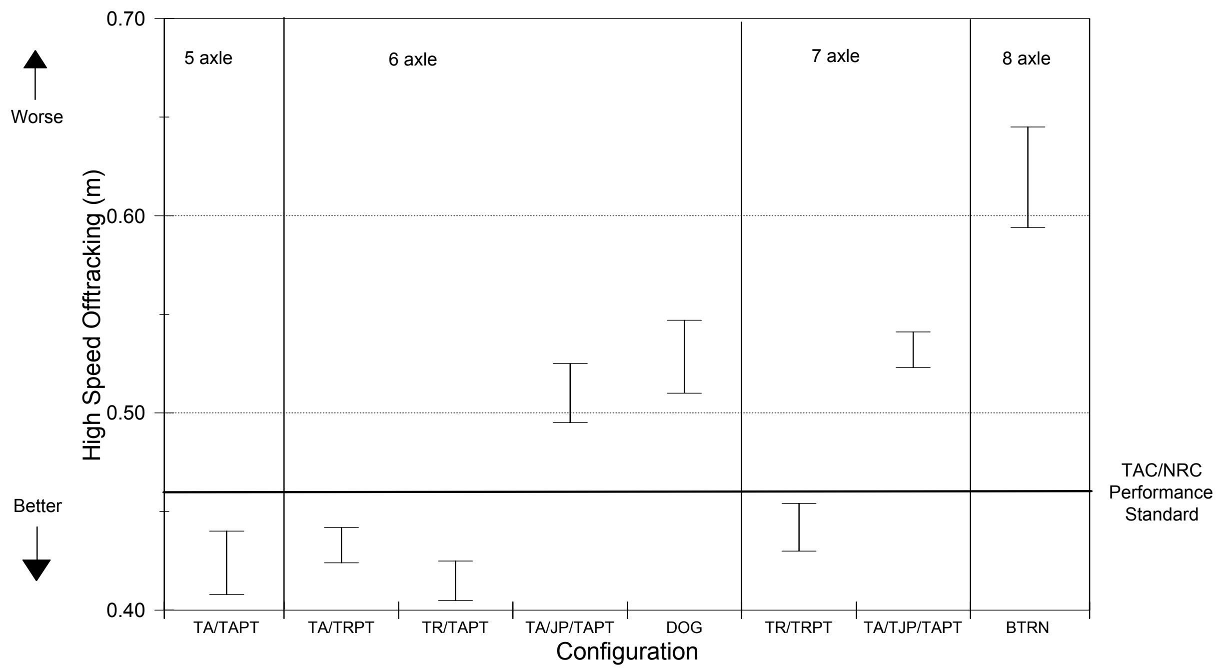


Figure 9. High speed steady state offtracking - Alberta legal weights.

c) Understeer coefficient at 0.25g (USC)

All the configurations met the performance standard for handling performance (Figure 10). The tridem tractor configurations (TR/TAPT, TR/TRPT) had relatively high levels of understeer, indicating that greater steering input is required to manoeuvre these configurations. The reference TAC Super B-train (BTRN) had a significantly lower understeer coefficient with oversteer tendencies.

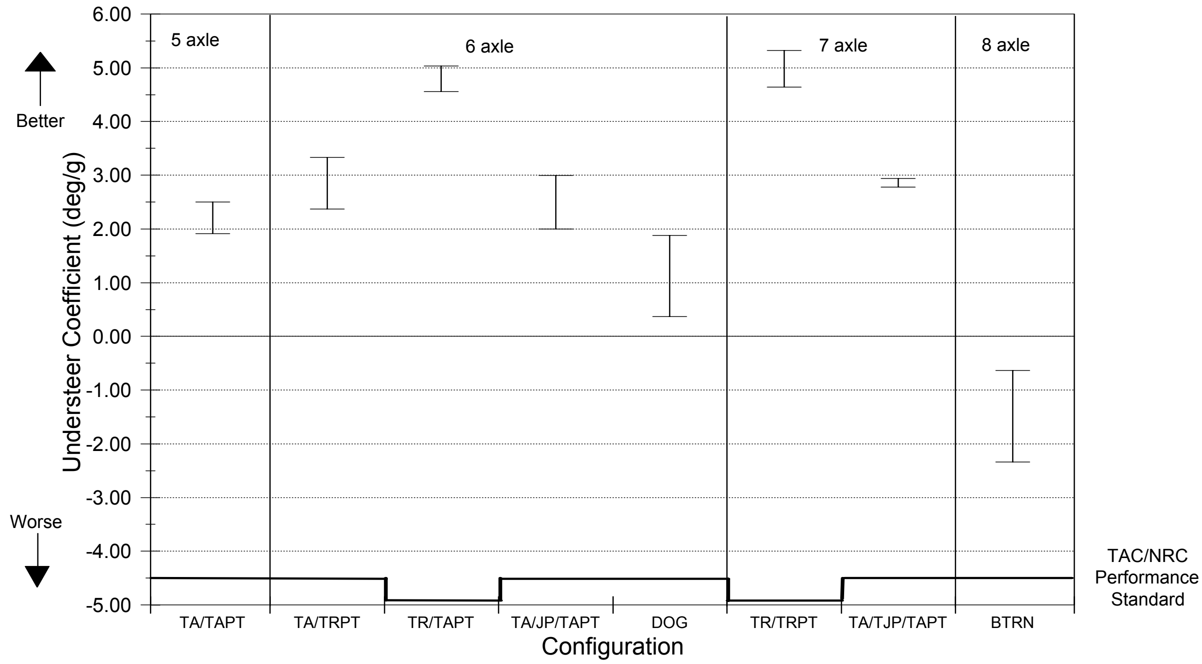


Figure 10. Understeer coefficient - Alberta legal weights.

d) Load transfer ratio (LTR)

The performance standard was met for all configurations (Figure 11). The tridem tractor/tandem pole trailer (TR/TAPT) and tridem tractor/tridem pole trailer (TR/TRPT) performed the best, while the performance of the doglogger (DOG) and tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) were the least desirable. The tridem tractor showed improved dynamic performance with an increase in payload capacity over the tandem tractor/pole trailer configurations, as the increased roll stability of the additional drive axle more than compensated for the increase in payload and cg height. The lower performance of the doglogger and tandem tractor/tandem jeep/tandem pole trailer relative to the single articulation point pole trailer configurations is likely caused by the increase in articulation points from one to two and the increased payloads and cg heights of these configurations. Interestingly, the performance and payload capability of the tandem tractor/jeep/tandem pole trailer improved over the tandem tractor/pole trailer configurations, as the single jeep's resistance to roll more than compensated for the increase in payload and cg height. Most configurations had an improved performance over the reference TAC Super B-train (BTRN), which exhibited a wide variation in performance and just failed to meet the performance standard under low load densities.

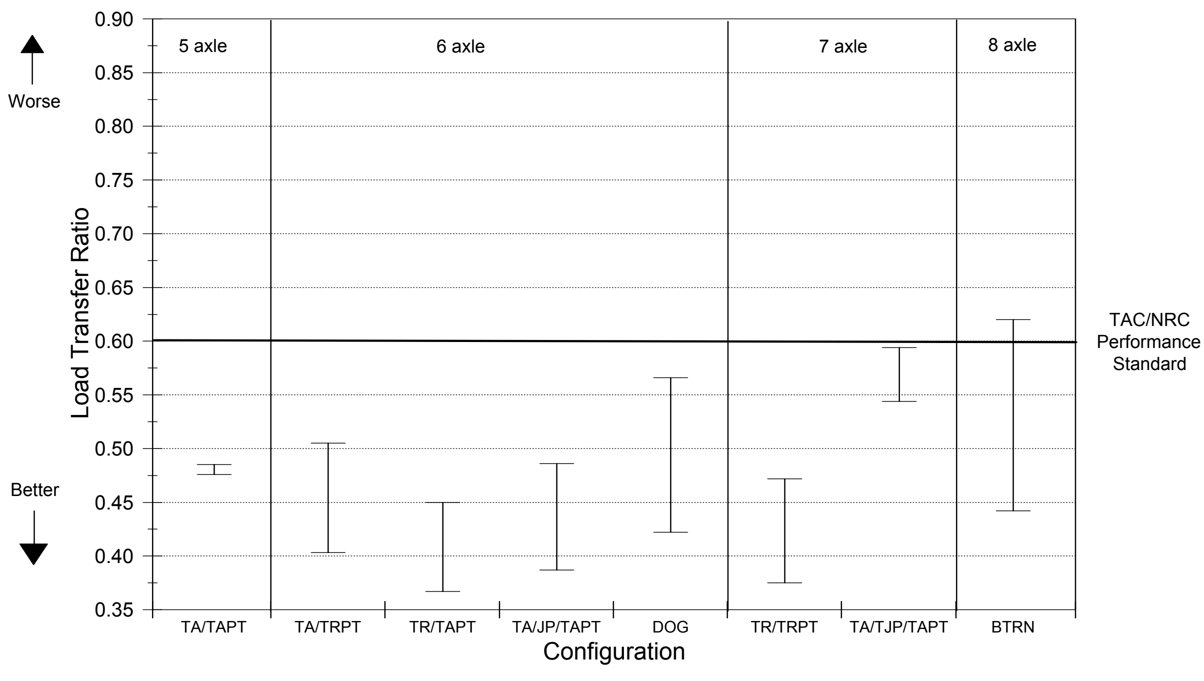


Figure 11. Load transfer ratio - Alberta legal weights.

e) Transient offtracking (TOT)

All configurations met the performance standard for transient offtracking (Figure 12). The tridem tractor/tandem pole trailer (TR/TAPT) performed best while the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) exhibited the worst performance with respect to this performance measure. All configurations exhibited improved levels of transient offtracking performance relative to the reference TAC Super B-train (BTRN).

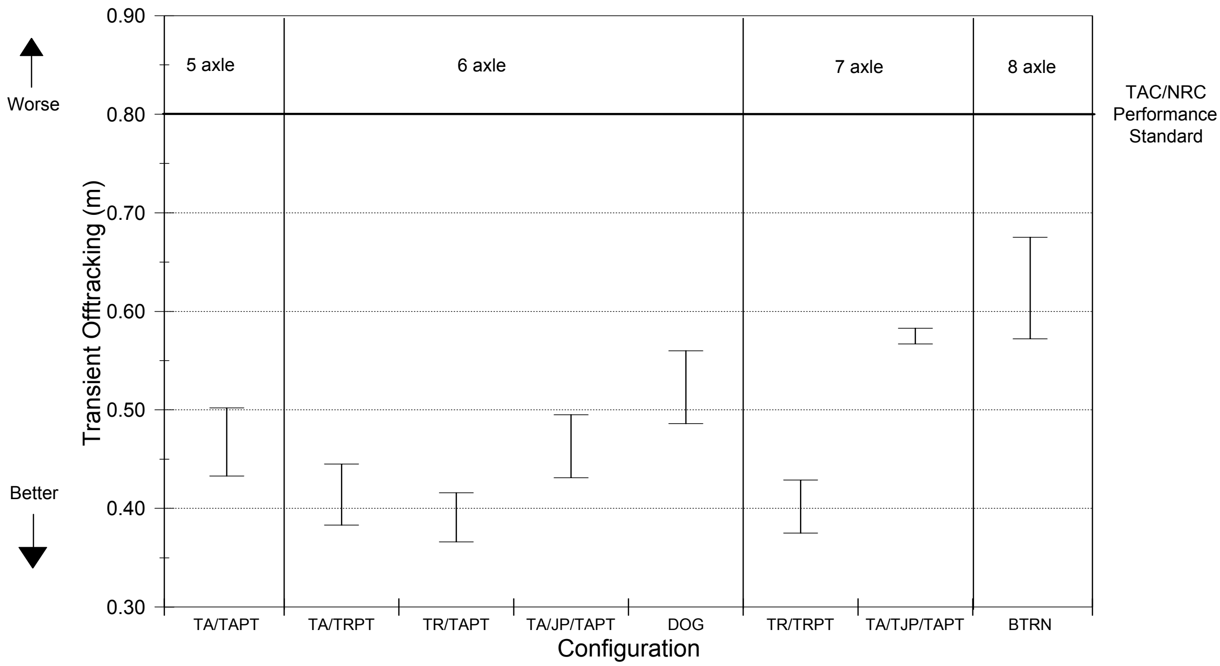


Figure 12. Transient offtracking - Alberta legal weights.

f) Rearward amplification (RWA)

Except for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), all the configurations met the performance standard for the entire range of load densities (Figure 13). The tandem tractor/tridem pole trailer (TA/TRPT) and tandem tractor/tandem jeep/tandem pole trailer performed the best and worst respectively in terms of rearward amplification. The inferior performance of the tandem tractor/tandem jeep/tandem pole trailer is primarily a result of the forward load bias of this configuration. All the single articulation point pole trailer configurations showed an improved performance over the reference TAC Super B-train (BTRN), while the doglogger and tandem tractor/jeep/tandem pole trailer exhibited marginally reduced performance. Only the tandem tractor/tandem jeep/tandem pole trailer performed significantly worse than the B-train.

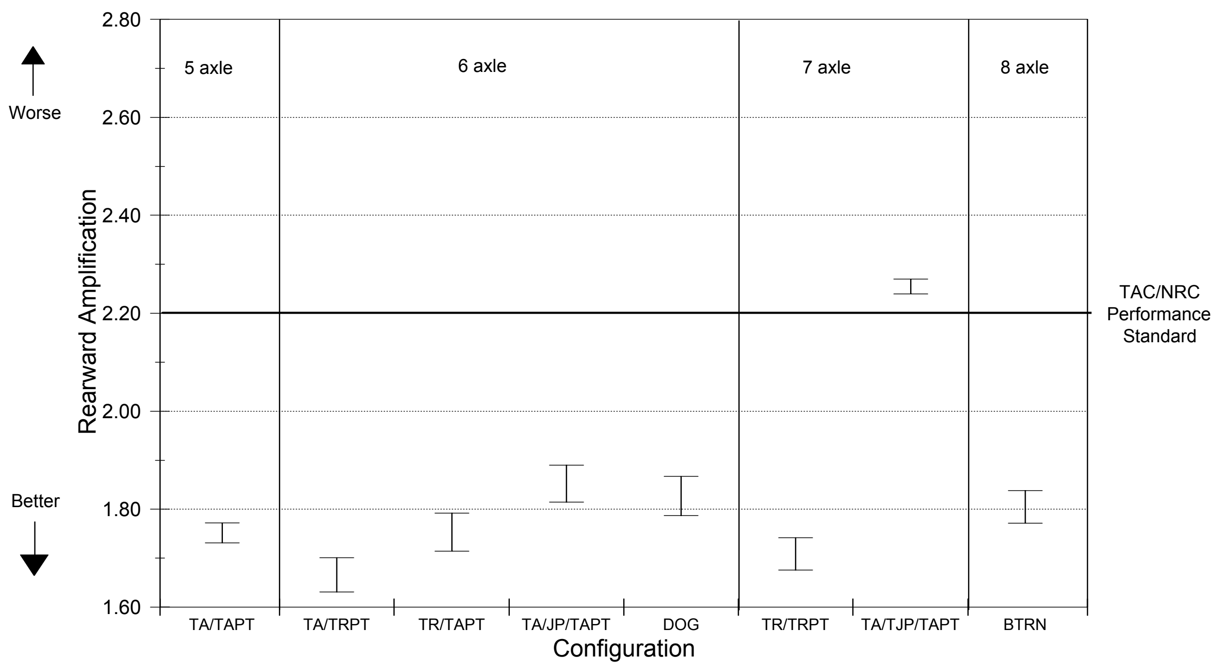


Figure 13. Rearward amplification - Alberta legal weights

g) Friction demand (FD)

Only the tridem pole trailer configurations (TA/TRPT, TR/TRPT) failed to meet the performance standard for friction demand at the drive axles (Figure 14). The best performer with respect to this performance measure was the tandem tractor/jeep/tandem pole trailer (TA/JP/TAPT). The tridem tractor/tridem pole trailer and the tandem tractor/tridem pole trailer experienced levels of FD as high as 0.14 and 0.18 respectively, indicating that these configurations (particularly the tandem tractor) have a possibility of jackknifing on slippery roads during sharp turns at low speed. However, the tridem tractor does reduce the level of FD relative to the tandem tractor because of the increased loading of the drive group. FD could be reduced by increasing the inter-group spacing between the drive and trailer groups and by decreasing the trailer group spread. However, under Alberta legal weights, reducing the trailer group spread would result in a decrease in allowable axle load from 23 000 kg to 21 000 kg. All configurations with the exception of the tridem pole trailer configurations showed improved performance over the reference TAC Super B-train (BTRN), which just failed to meet the performance standard for friction demand.

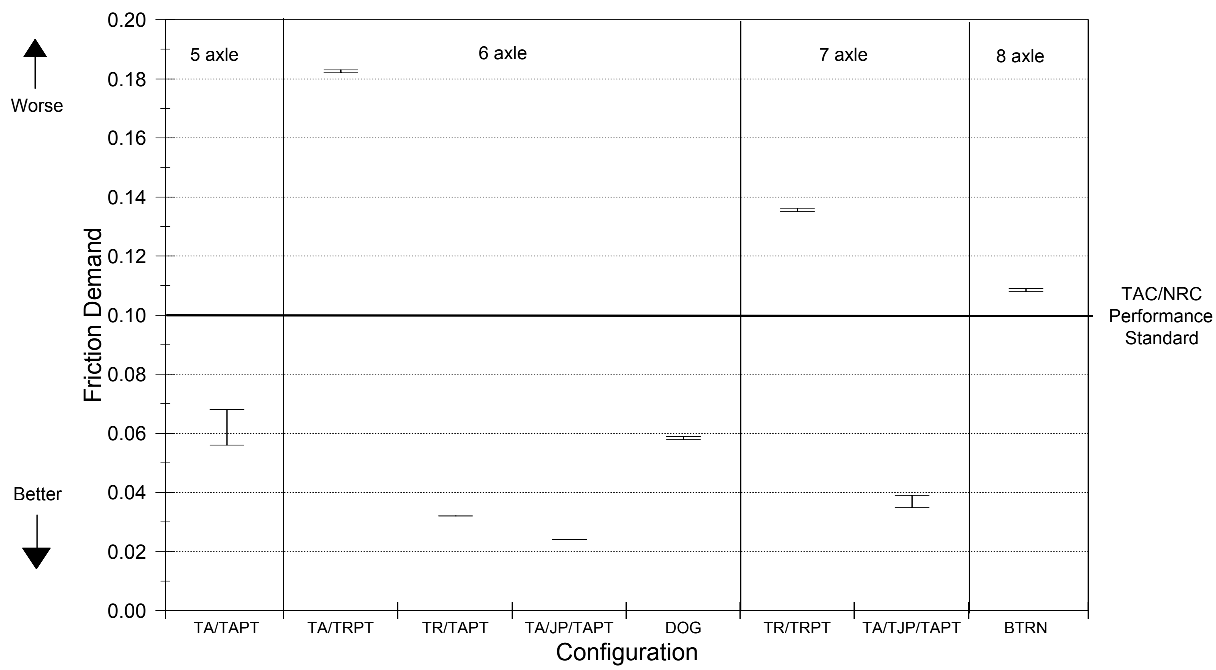


Figure 14. Friction demand - Alberta legal weights.

h) Lateral friction utilization (LFU)

All configurations met the performance standard for lateral friction utilization at the steering axle (Figure 15). The performance of the tridem tractor/tandem pole trailer (TR/TAPT) was the least favourable, with a LFU of 0.70, while the tandem tractor/tridem pole trailer (TA/TRPT) exhibited the best performance, with considerably reduced levels of LFU at 0.41. This means that these configurations have the ability to make tight turns at low speeds on low friction surfaces without experiencing ploughout. It is interesting to note that the tridem pole trailer improves steering performance, as the increased pintle hook force arising from the tridem trailer group helps push the tractor through the turn since the pintle hook position is rearward from the drive group (Parker et al., 1998). Apart from the tridem tractor configurations, these configurations have similar or better levels of LFU relative to the reference TAC Super B-train (BTRN).

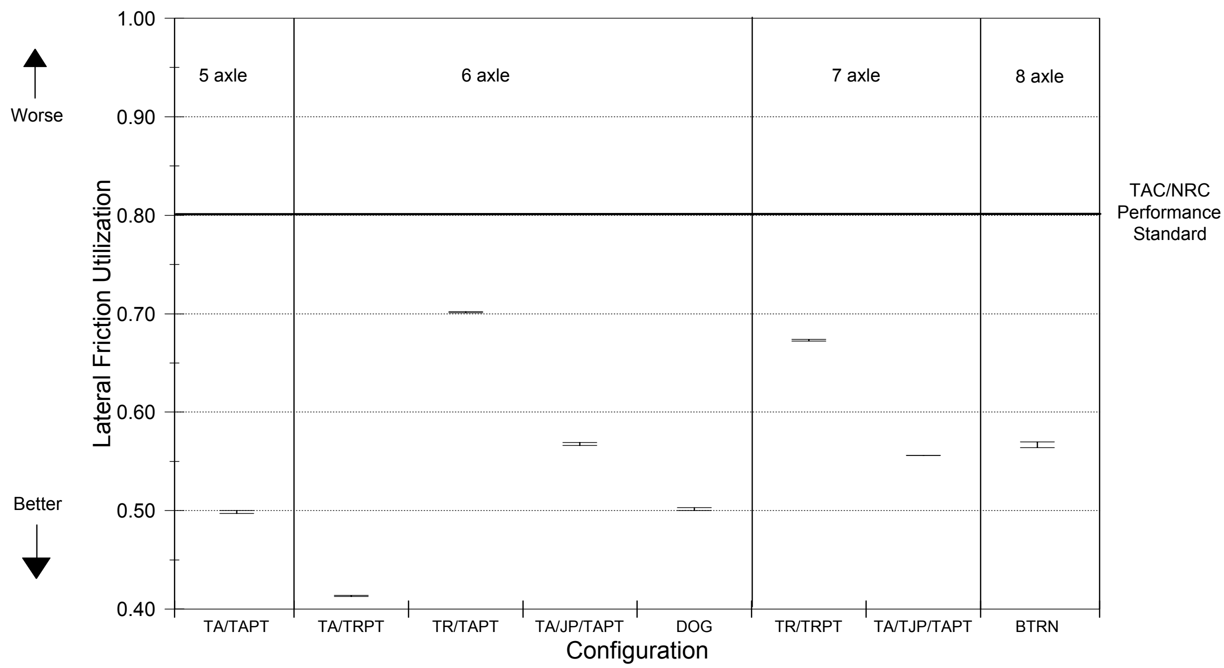


Figure 15. Lateral friction utilization - Alberta legal weights.

i) Low speed offtracking (LSOT)

All configurations easily met the performance standard (Figure 16). The compensating reach characteristic of these configurations has been designed to minimize LSOT relative to the reference TAC Super B-train (BTRN), allowing them to negotiate narrow roads with sharp corners. The highest level of LSOT of 3.86 m occurred for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), which is more than 2 m below the 6 m performance standard for LSOT.

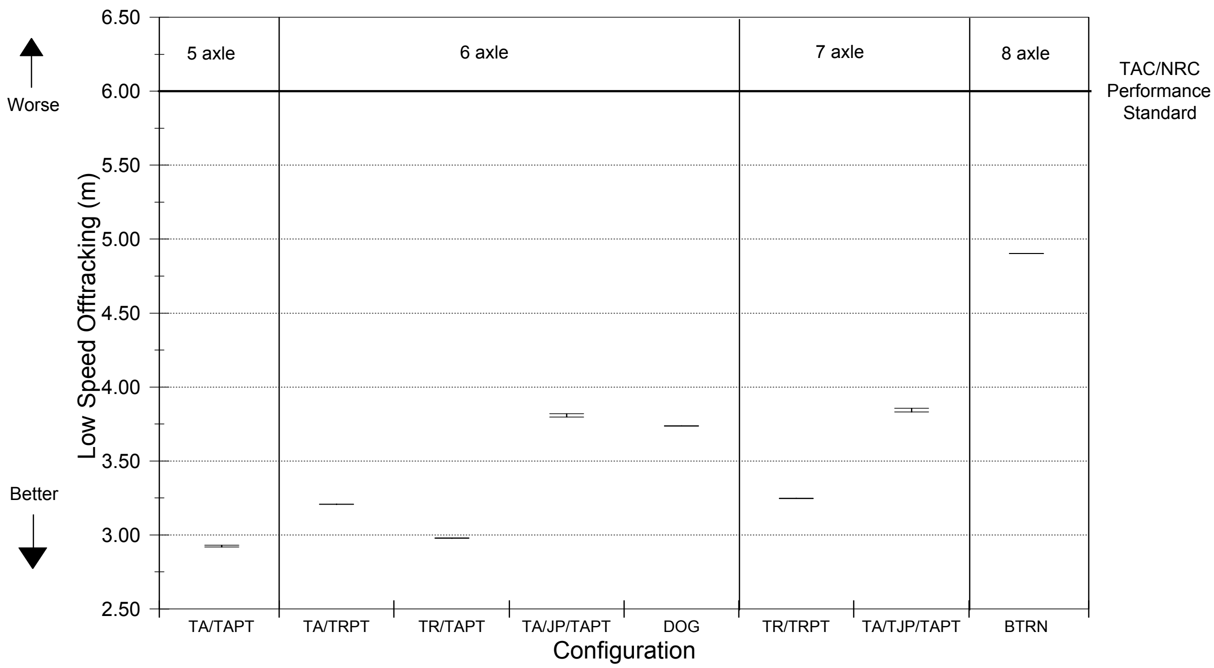


Figure 16. Low speed offtracking - Alberta legal weights.

(ii) <u>Individual Configuration Performance</u>

5 axle configurations

a) <u>Tandem tractor/tandem pole trailer</u>

The tandem tractor/tandem pole trailer exhibited improved performance over the performance standards for all performance measures (Figure 17).

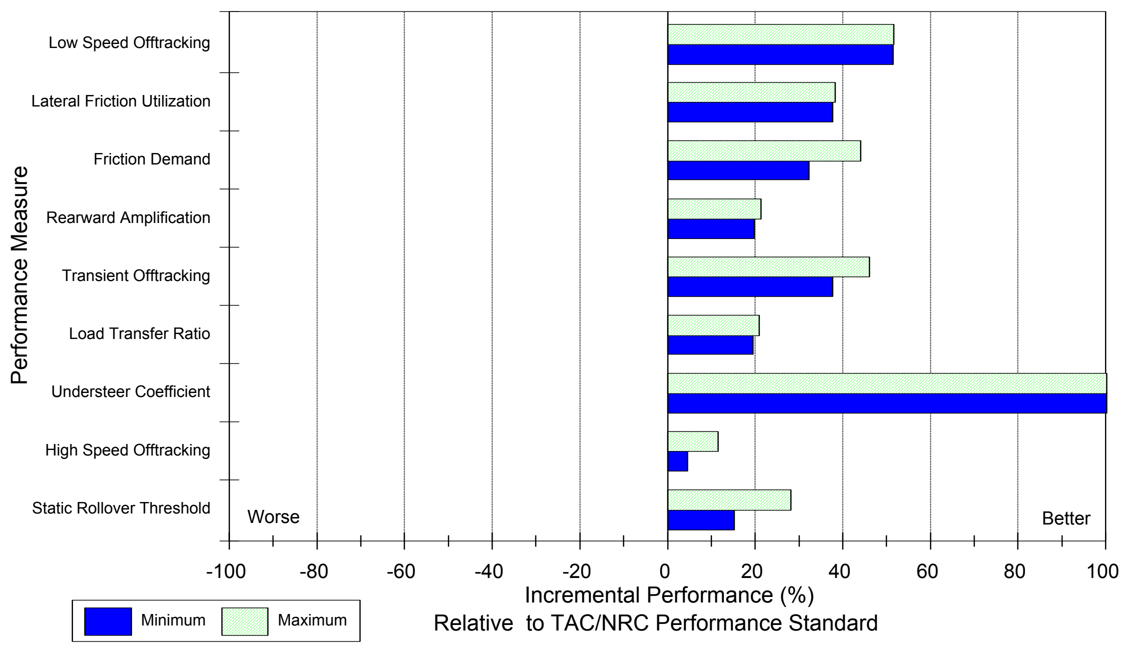


Figure 17. Tandem tractor/tandem pole trailer - Alberta legal weights.

6 axle configurations

b) Tandem tractor/tridem pole trailer

The tandem tractor/tridem pole trailer exhibited improved performance over the performance standards for all performance measures with the exception of friction demand (Figure 18). The level of friction demand was approximately 80% worse than the performance standard of 0.1. Possible options for addressing this deficiency include decreasing the hitch offset, increasing the inter-group spacing from the drive group to the trailer group, decreasing the trailer group spread, and decreasing the trailer group load.

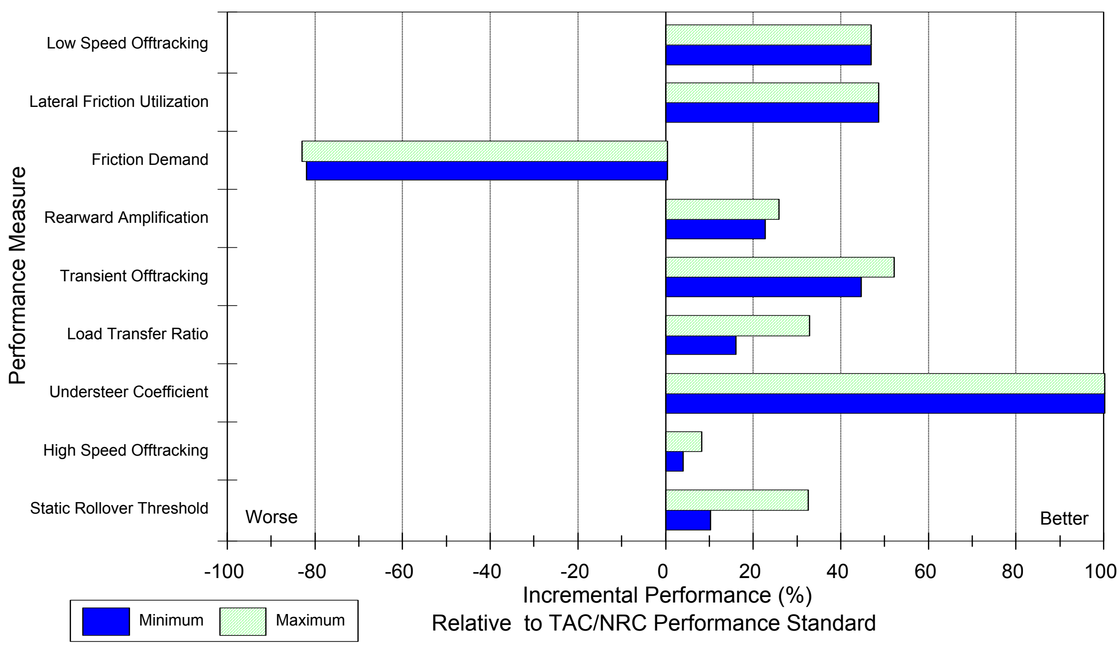


Figure 18. Tandem tractor/tridem pole trailer - Alberta legal weights.

c) <u>Tridem tractor/tandem pole trailer</u>

The tridem tractor/tandem pole trailer exhibited improved performance over the performance standards for all performance measures (Figure 19).

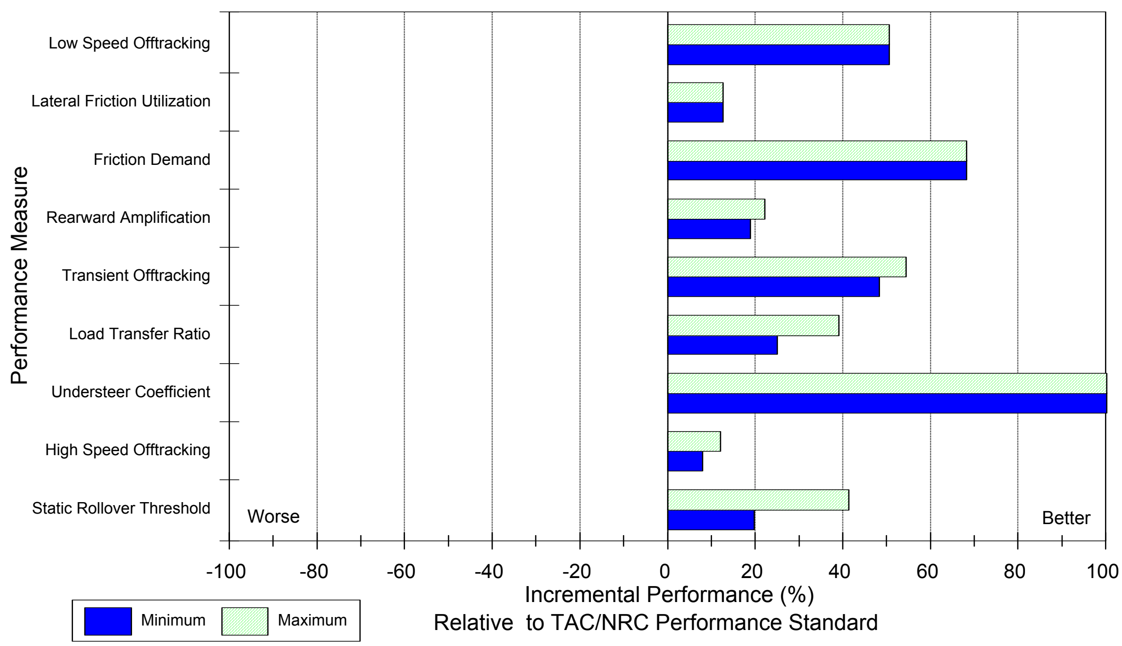


Figure 19. Tridem tractor/tandem pole trailer - Alberta legal weights.

d) Tandem tractor/jeep/tandem pole trailer

The tandem tractor/jeep/tandem pole trailer exhibited improved performance over the performance standards for all performance measures with the exception of high speed offtracking (Figure 20). The level of high speed offtracking was 8-14% worse than the performance standard. Possible solutions to this deficiency include reducing the overall length of the configuration, or using stiffer tires such as 11R22.5 tires instead of 11R24.5 tires[9] to resist the outboard trailer swing that occurs at high speeds.

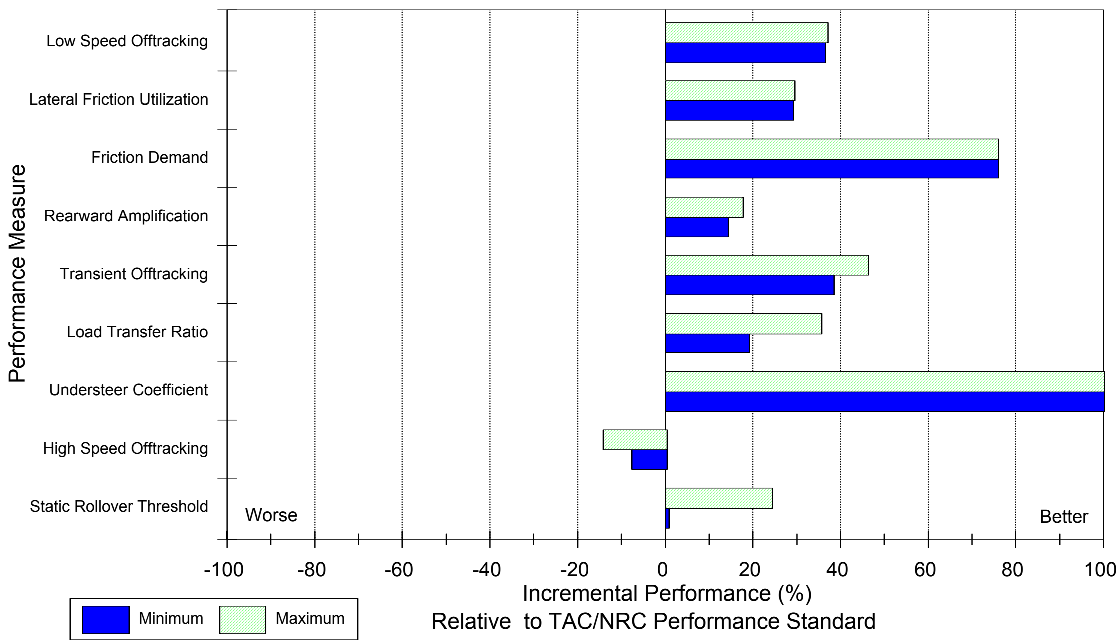


Figure 20. Tandem tractor/jeep/tandem pole trailer - Alberta legal weights.

[9] 11R22.5 tires have increased cornering and vertical stiffness relative to 11R24.5 tires.

e) Doglogger

The doglogger exhibited improved performance over the performance standards for all performance measures with the exception of high speed offtracking (Figure 21). The level of high speed offtracking was 11-19% worse than the performance standard. Possible solutions to this deficiency include reducing the overall length of the configuration, or using stiffer tires to resist the outboard trailer swing that occurs at high speeds.

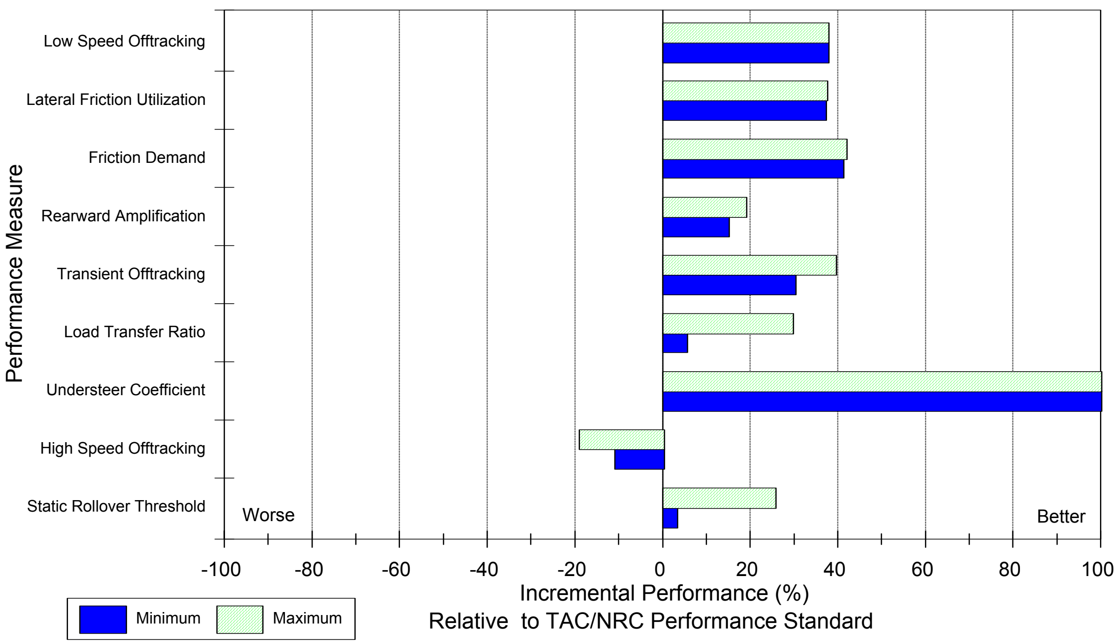


Figure 21. Doglogger - Alberta legal weights.

7 axle configurations

f) Tridem tractor/tridem pole trailer

The tridem tractor/tridem pole trailer exhibited improved performance over the performance standards for all performance measures with the exception of friction demand (Figure 22). The level of friction demand was approximately 38% worse than the performance standard. This deficiency could likely be addressed by simply decreasing the hitch offset and increasing the inter-group spacing from the drive group to the trailer group.

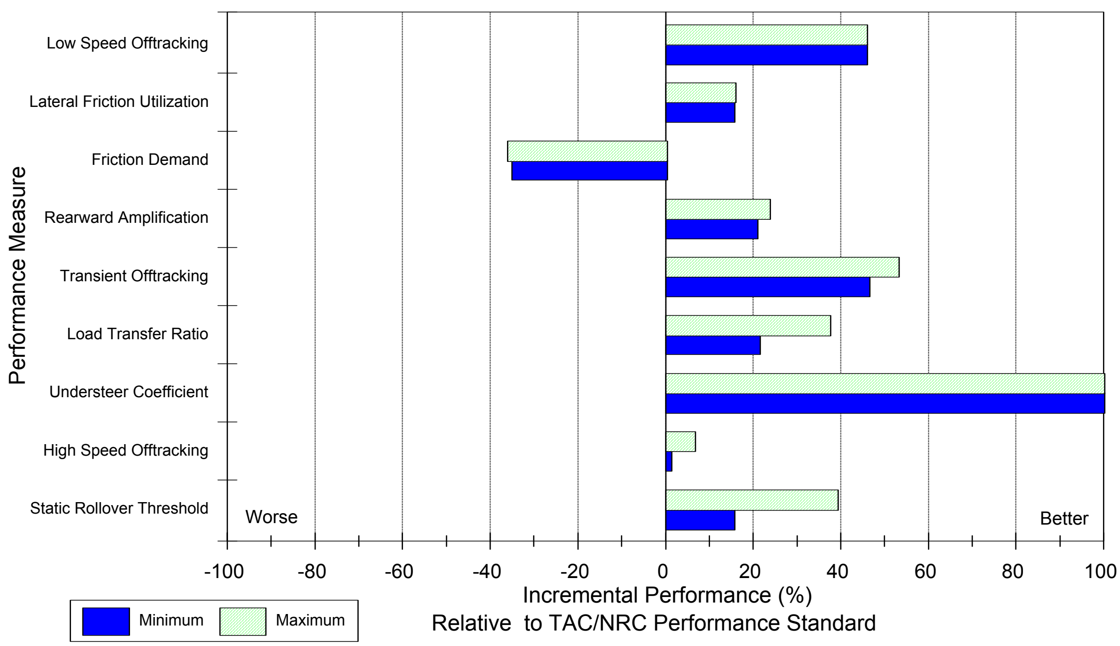


Figure 22. Tridem tractor/tridem pole trailer - Alberta legal weights.

g) Tandem tractor/tandem jeep/tandem pole trailer

The tandem tractor/tandem jeep/tandem pole trailer failed to meet the performance standards for three performance measures: high speed offtracking, static rollover threshold, and rearward amplification (Figure 23). The level of deviation from the performance standards was 14-18%, 2-8% , and 2-3% for high speed offtracking, static rollover threshold, and rearward amplification respectively. Addressing all of these deficiencies simultaneously requires optimization of several parameters such as inter-group spacing, hitch offset, tire characteristics, and load distribution.

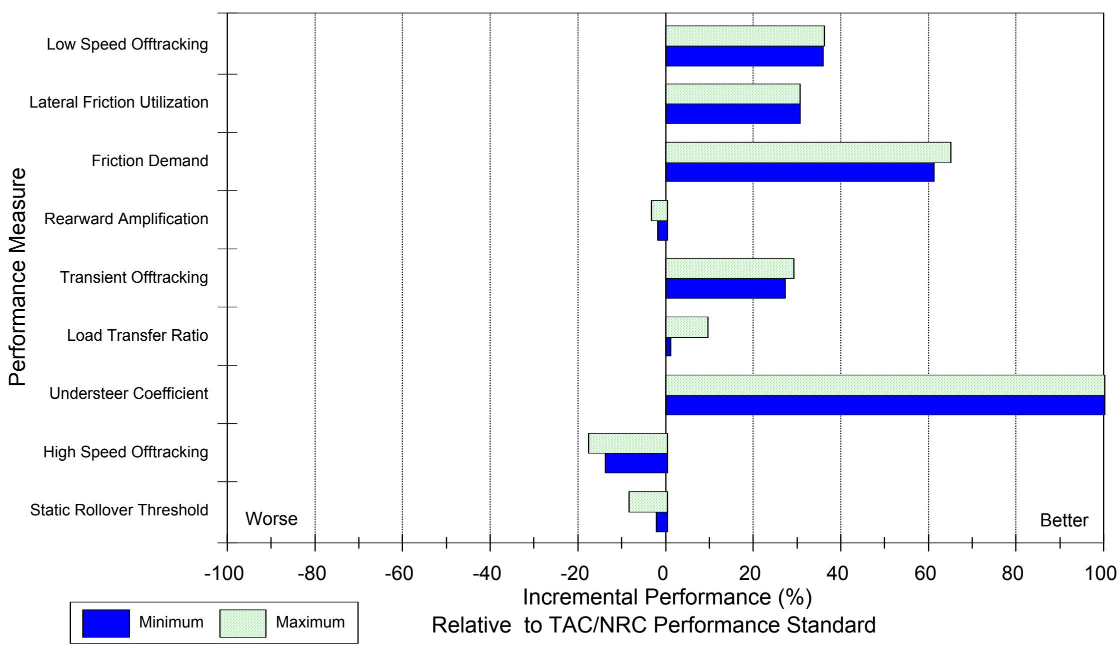


Figure 23. Tandem tractor/tandem jeep/tandem pole trailer - Alberta legal weights.

8 axle configurations

h) Super B-train

The Super B-train is presented here for comparative purposes. The log-hauling Super B-train equipped with 11R24.5 tires, failed to meet the performance standards for two performance measures for all load densities (high speed offtracking, friction demand), and another two performance measures at low load densities (static rollover threshold, load transfer ratio) (Figure 24). High speed offtracking was up to 40% worse than the performance standard. These results illustrate the sensitivity of dynamic performance to load and tire characteristics, as a similar B-train configuration investigated in the TAC study (Ervin et al., 1986) met all performance measures, when hauling a higher density load and equipped with 11R22.5 tires. Overall, all the logging configurations performed better than the reference TAC Super B-train, when hauling Alberta legal weights.

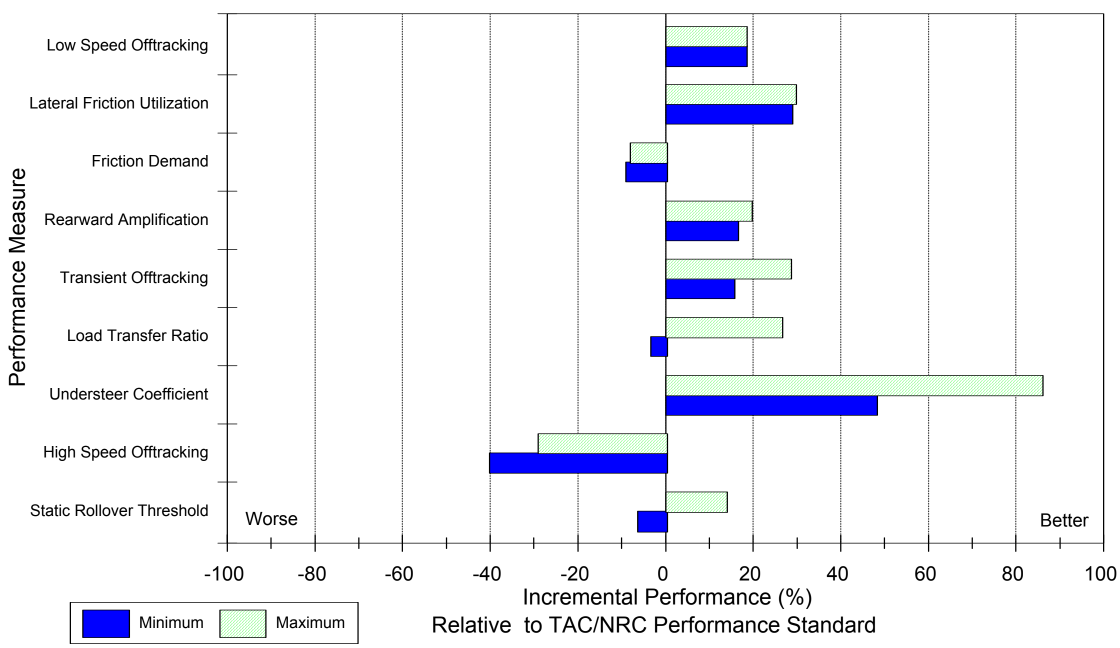


Figure 24. Super B-train - Alberta legal weights.

(iii) Ranking of Configurations

The single articulation configurations exhibited the best overall dynamic performance, with the tridem tractor/tandem pole trailer (TR/TAPT) performing the best overall with a dynamic index of 74.1 (Figure 25). The configuration with the lowest overall performance was the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), with a dynamic index (56.8) below the reference TAC Super B-train (BTRN) (59.2). Dynamic performance is strongly influenced by payload and number of articulation points (Figure 26), with the configurations carrying less payload and with fewer articulation points tending to perform better. The tridem tractor/tandem pole trailer and the tridem tractor/tridem pole trailer (TR/TRPT) both showed an improvement in overall performance over the tandem tractor/tandem pole trailer (TA/TAPT) and tandem tractor/tridem pole trailer (TA/TRPT) respectively, while increasing payload capacity. In both cases, the increased payload and cg height were more than compensated by the increased roll stiffness provided by the additional drive axle.

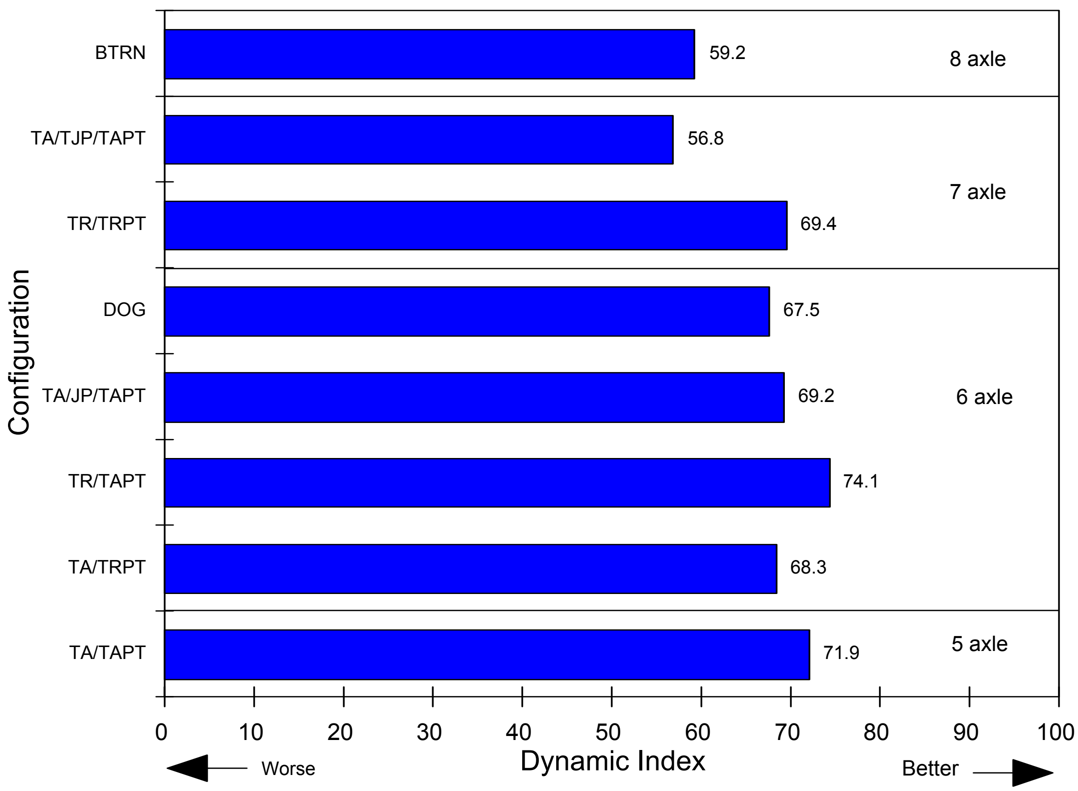


Figure 25. Dynamic indices - Alberta legal weights.

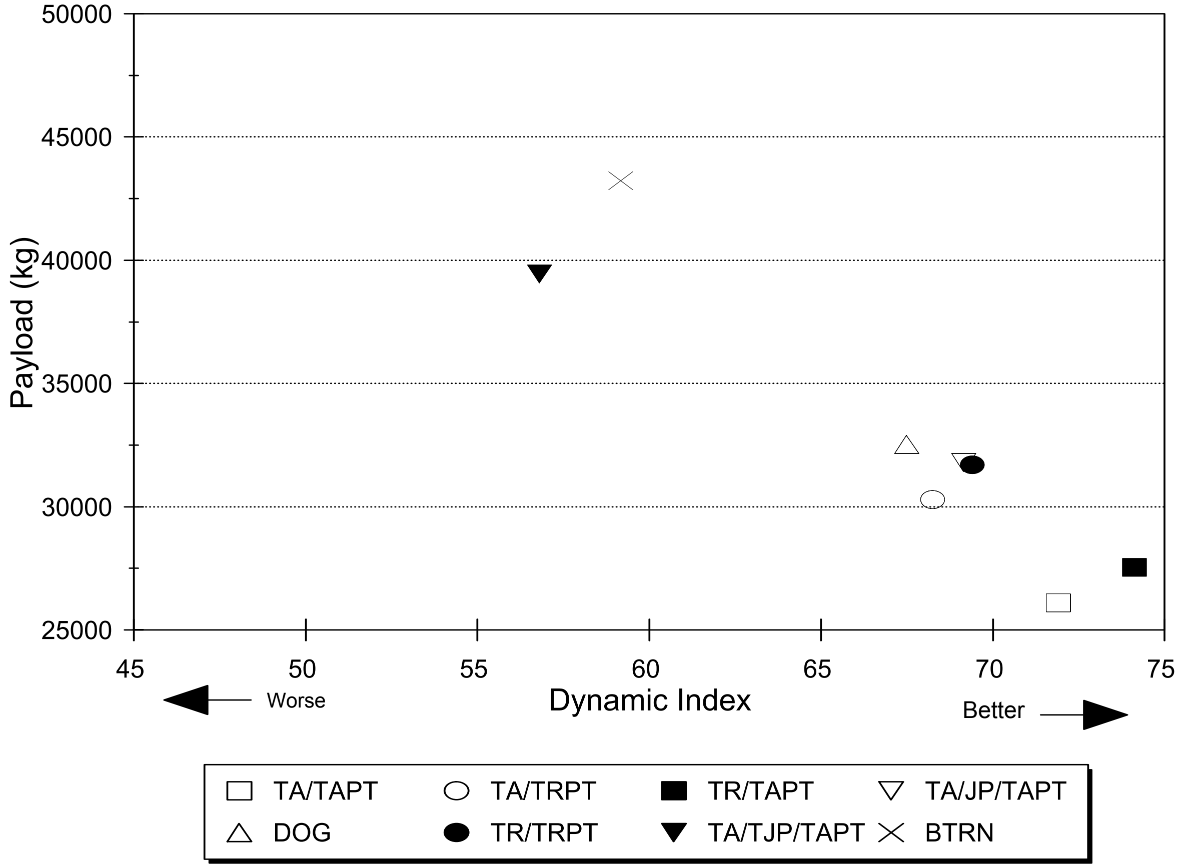


Figure 26. Overall performance - Alberta legal weights.

B. Alberta Winter Weights

(i) Relative Configuration Performance

a) Static rollover threshold (SRT)

The increased payloads and cg heights of Alberta winter weights greatly reduced the SRT for each configuration relative to Alberta legal weights. All configurations failed to meet the performance standard for most load densities (Figure 27). The performance standard was met only at the higher load densities for the tridem tractor configurations (TR/TAPT, TR/TRPT) and the tandem tractor/tridem pole trailer (TA/TRPT). The best overall performance in terms of rollover stability occurred for the tridem tractor/tridem pole trailer (TR/TRPT). The doglogger with low density logs experienced the worst level of SRT. As noted previously, the increased payload capacity of the double articulation point configurations resulted in reduced rollover stability relative to the single articulation point configurations. The tridem tractor/pole trailer configurations had improved performance over the tandem tractor/pole trailer configurations primarily because of the increased roll resistance provided by the additional drive axle. All configurations with the exception of the tridem tractor/tridem pole trailer had a significantly reduced rollover stability relative to the reference TAC Super B-train (BTRN) hauling Alberta legal weights.

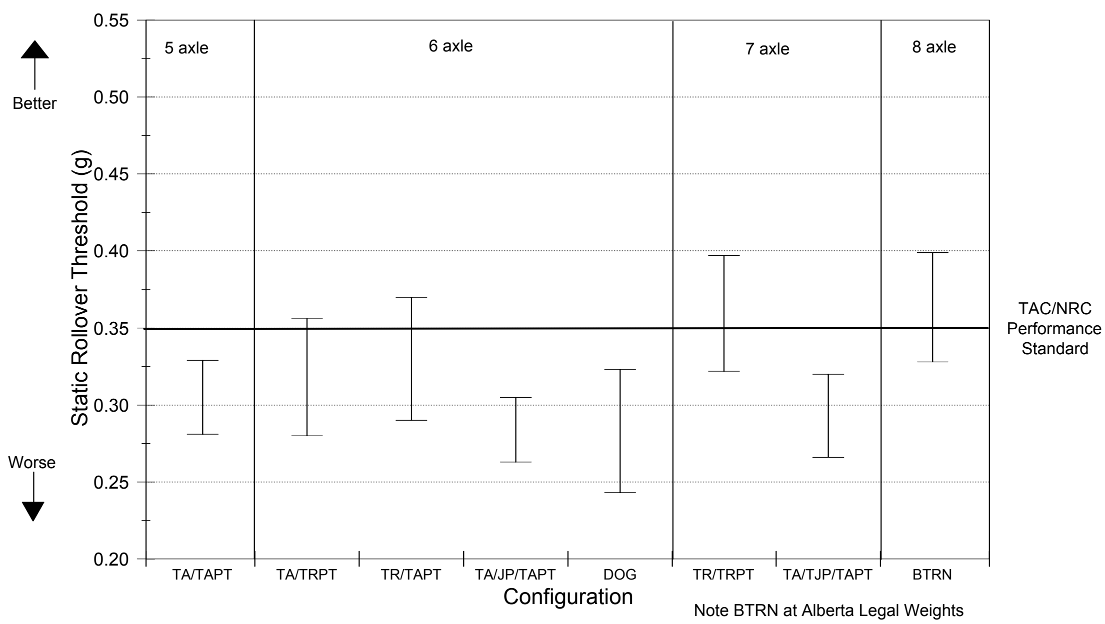


Figure 27. Static rollover threshold - Alberta winter weights.

b) High speed steady state offtracking (HSOT)

All configurations failed to meet the performance standard of 0.46 m for high speed steady state offtracking (Figure 28), as did the reference TAC Super B-train (BTRN). The tridem tractor/tandem pole trailer (TR/TRPT) experienced the best levels of HSOT, while the doglogger (DOG) showed the worst level of 0.68 m (at high load density). At the low load density, the doglogger did not achieve the steady state requirements, so that a value of HSOT could not be calculated. The increased payloads of these configurations under winter weight regulations relative to legal weight regulations resulted in a significant increase in HSOT, as the increased payload results in a greater centrifugal force acting at the trailer, leading to greater outswing. The high level of HSOT is also influenced by the geometric layout of these compensating reach configurations. All configurations exhibit low inboard offtracking tendencies at low speeds, but start to offtrack outboard as speed and lateral acceleration increase (Ervin et al., 1986). Generally the lower inboard offtracking at low lateral accelerations results in increased outboard offtracking at high lateral accelerations. The single articulation point pole trailer configurations exhibited lower levels of HSOT than the B-train, while the double articulation point configurations had equivalent or increased levels of HSOT relative to the B-train.

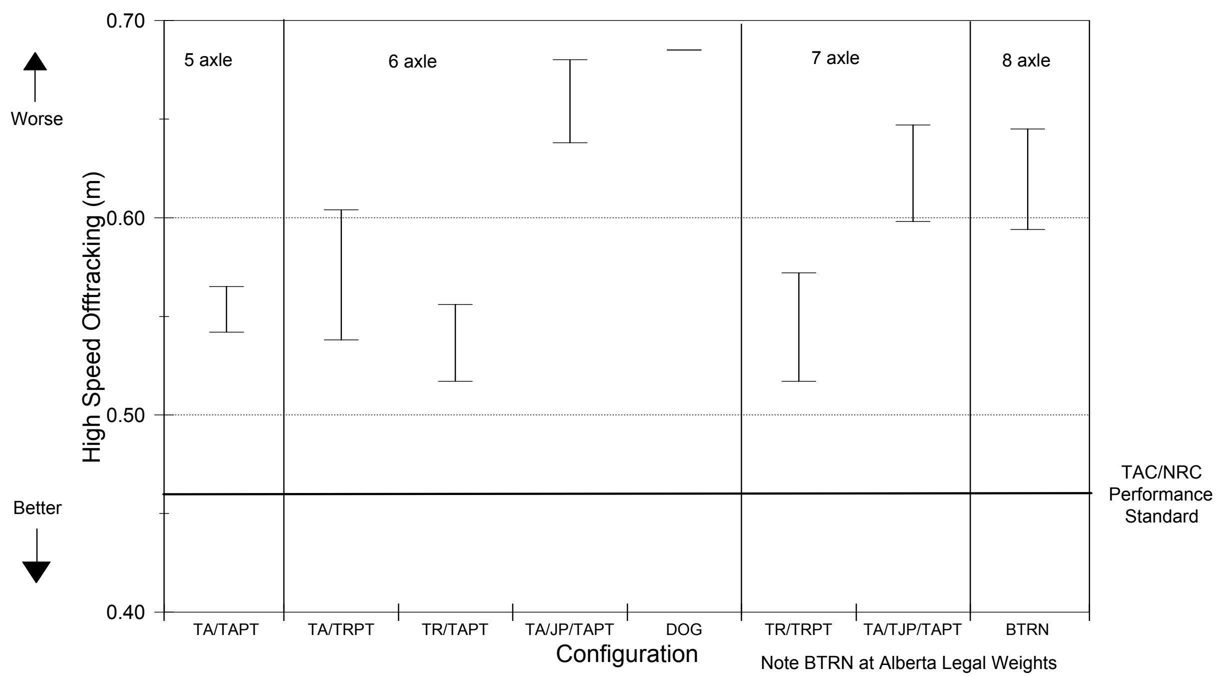


Figure 28. High speed steady state offtracking - Alberta winter weights.

c) Understeer coefficient at 0.25g (USC)

All configurations met the performance standard for handling performance (Figure 29). The increased weight on the drive group and trailer resulted in a decrease in understeer coefficient relative to Alberta legal weights, with most configurations exhibiting oversteer tendencies. Only the tridem tractor configurations (TR/TAPT, TR/TRPT) and the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) had understeer tendencies at these weights. The doglogger (DOG) exhibited the greatest oversteer tendencies at these weights, similar to the reference TAC Super B-train (BTRN) hauling maximum legal weights.

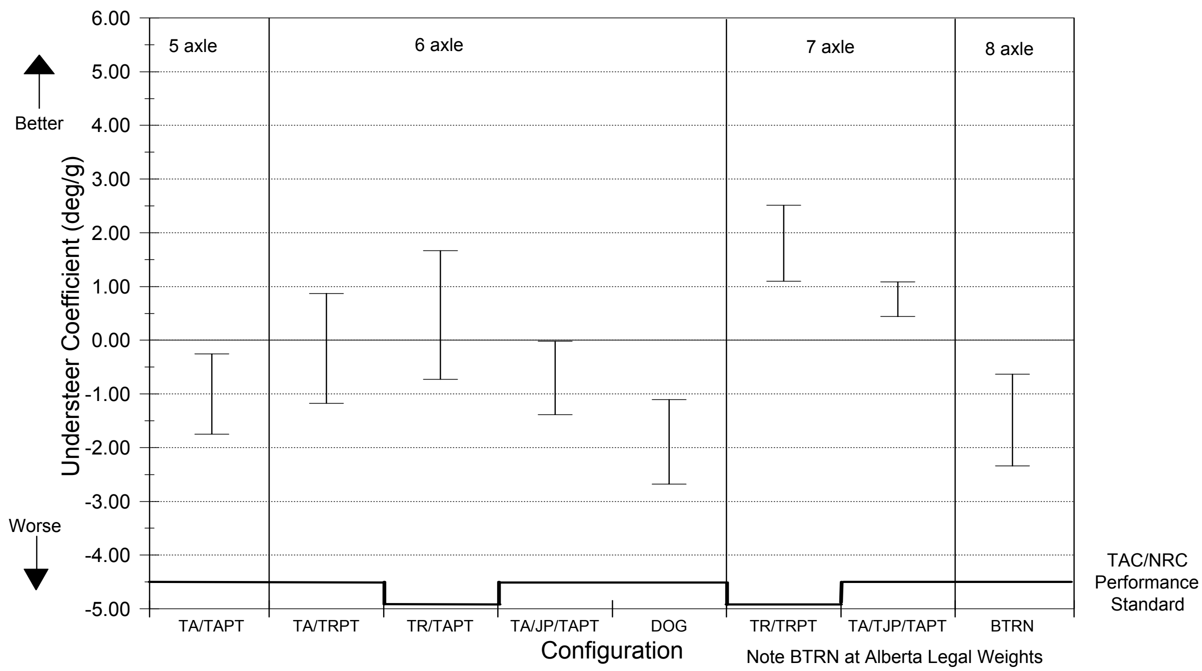


Figure 29. Understeer coefficient - Alberta winter weights.

d) Load transfer ratio (LTR)

Load transfer ratio was negatively affected by the increased payloads and cg heights, with all configurations except the tridem tractor/tridem pole trailer (TR/TRPT) failing to meet the performance standard for the full range of load densities (Figure 30). The tridem tractor/tridem pole trailer and doglogger (DOG) exhibited the best and worst performance in this category, respectively. The incremental reduction in performance from legal to winter weights was lowest for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), as the increase in payload was lowest for this configuration at 8 000 kg, approximately half the magnitude of the other configurations. Tridem groups provide the best performance in terms of dynamic stability since the load per axle is reduced relative to tandem and single axle groups. The dynamic stability of these configurations hauling these weights could be further improved if the axle roll stiffness were increased (e.g. addition of anti-sway bars). Only the tridem tractor/tridem pole trailer exhibited similar dynamic performance to the reference TAC Super B-train (BTRN); all other configurations exhibited reduced performance.

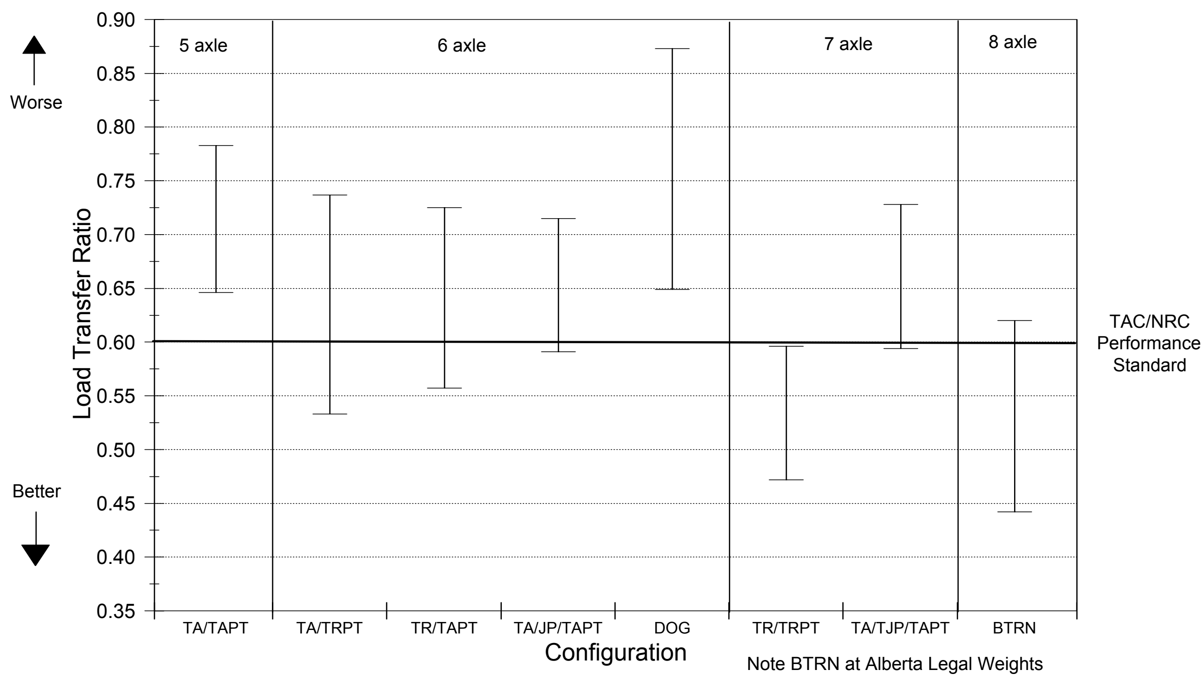


Figure 30. Load transfer ratio - Alberta winter weights.

e) <u>Transient offtracking (TOT)</u>

All configurations, except for the doglogger (DOG) and tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) loaded with low density logs, met the performance requirements for transient offtracking (Figure 31). The tridem tractor/tridem pole trailer (TR/TRPT) exhibited the best performance in this category. Only the tridem tractor/tridem pole trailer exhibited improved performance in terms of transient offtracking relative to the reference TAC Super B-train (BTRN), while the tandem tractor/tandem jeep/tandem pole trailer and the doglogger exhibited reduced performance.

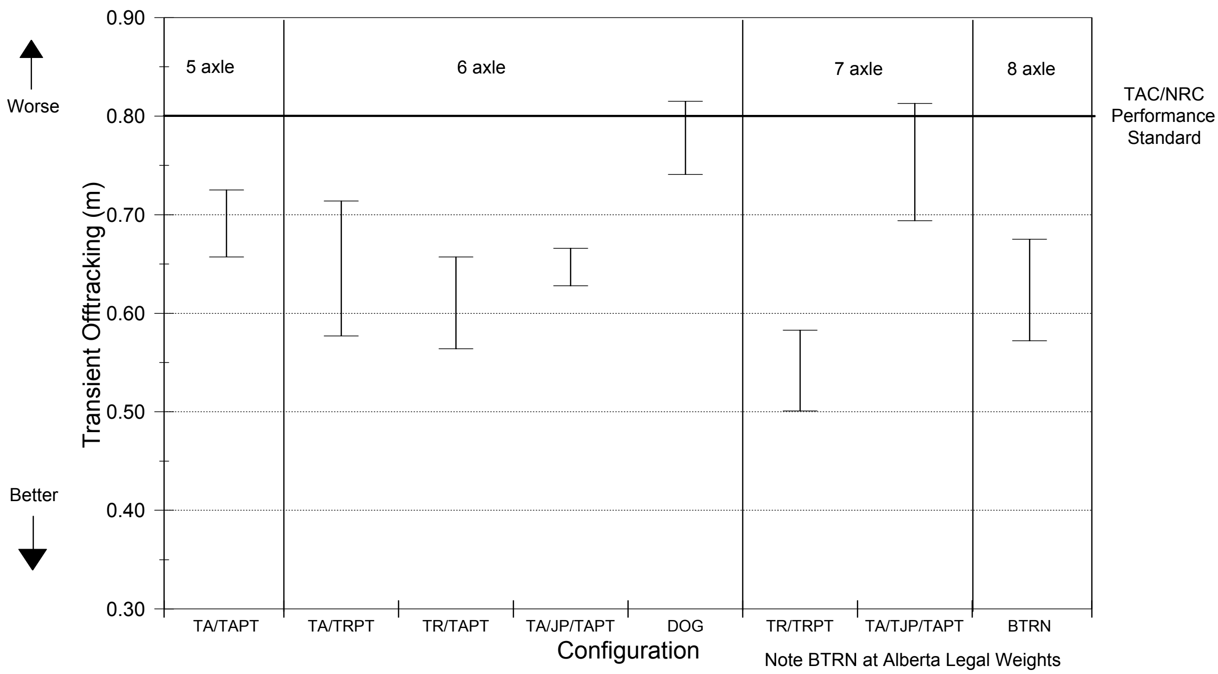


Figure 31. Transient offtracking - Alberta winter weights.

f) <u>Rearward amplification (RWA)</u>

All the configurations except the tandem tractor/tandem pole trailer (TA/TAPT) and tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) met the performance standard under the majority of loading conditions (Figure 32). The tandem tractor/tandem pole trailer met the performance standard only when loaded with high density logs. The tridem tractor/tridem pole trailer (TR/TRPT) and tandem tractor/tandem jeep/tandem pole trailer performed the best and worst respectively in terms of rearward amplification. The inferior performance of the tandem tractor/tandem pole trailer and tandem tractor/tandem jeep/tandem pole trailer is primarily caused by the forward load bias of these configurations, which is further increased under green route weight regulations. All configurations exhibited worse levels of RWA than the reference TAC Super B-train (BTRN).

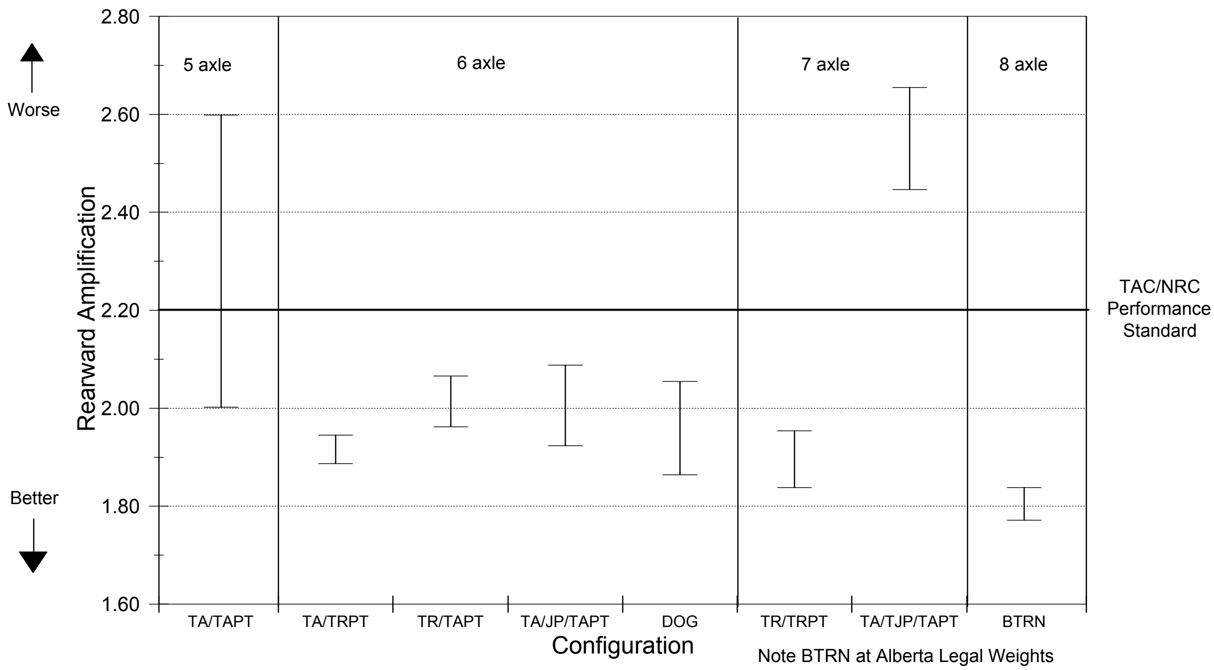


Figure 32. Rearward amplification - Alberta winter weights.

g) Friction demand (FD)

All configurations met the performance standard for friction demand at the drive axles, except the tridem pole trailer configurations (TA/TRPT, TR/TRPT) (Figure 33). The tridem tractor/tridem pole trailer and the tandem tractor/tridem pole trailer experienced levels of FD as high as 0.12 and 0.14 respectively. However, the tridem tractor reduced the level of FD relative to the tandem tractor due to the increased loading of the drive group. The increased loading of the drive group relative to the trailer group for the tandem tractor configuration under winter loading conditions causes a reduction in FD. Apart from the tridem pole trailer configurations, all other configurations exhibited superior performance relative to the B-train (BTRN), which just failed to meet the performance standard.

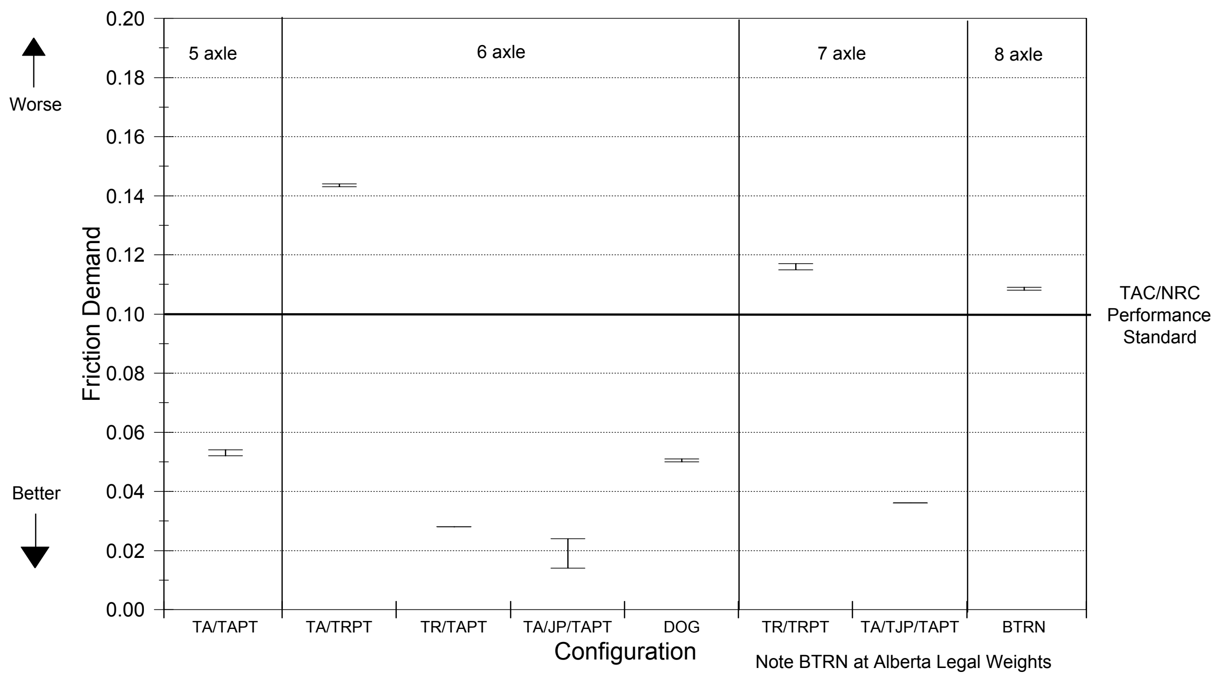


Figure 33. Friction demand - Alberta winter weights.

h) Lateral friction utilization (LFU)

All configurations met the performance standard for lateral friction utilization at the steering axle except the tridem tractor/tandem pole trailer (TR/TAPT) (Figure 34). The tridem tractor/tandem pole trailer experienced the worst level of LFU at 0.81, just exceeding the performance standard of 0.80. The tandem tractor/tridem pole trailer (TA/TRPT) had the best levels of LFU at 0.50. The increase in drive axle loads from legal weights caused an increase in LFU for all configurations. The performance of the tridem tractor configurations could be improved by either increasing the steering axle load, increasing the tractor wheelbase, or decreasing the drive group load (Parker et al., 1998). All configurations with the exception of the tandem tractor/tridem pole trailer had increased levels of LFU and therefore reduced steering performance relative to the B-train (BTRN).

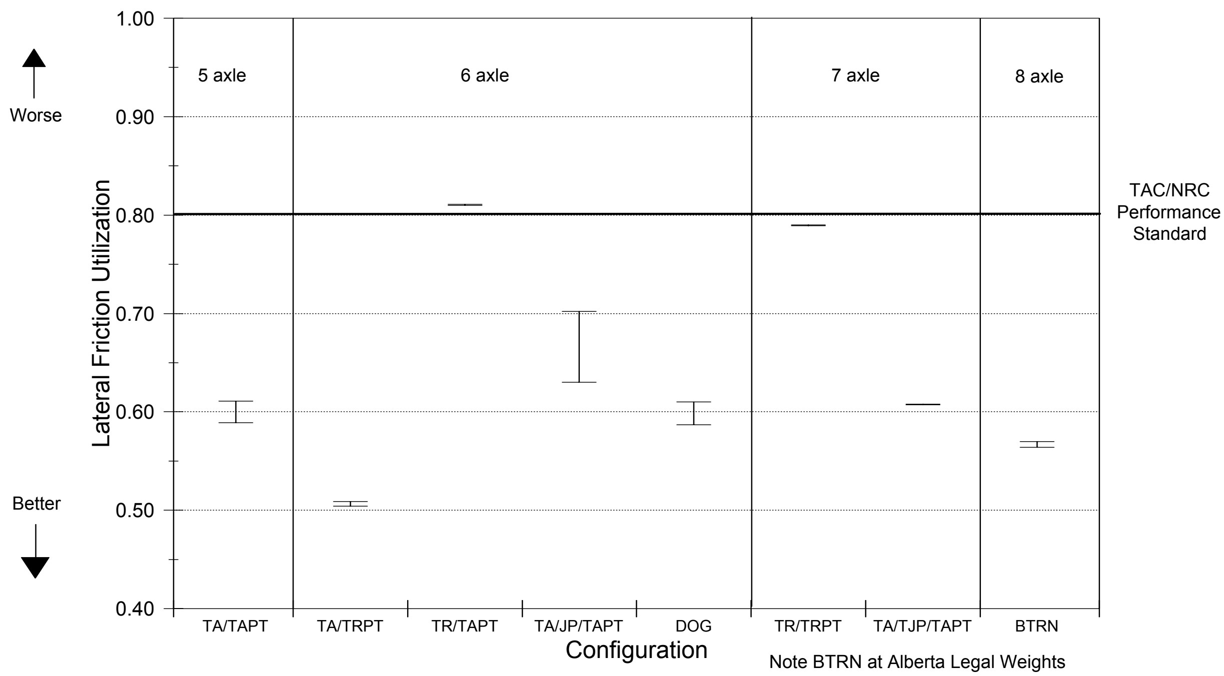


Figure 34. Lateral friction utilization - Alberta winter weights.

i) Low speed offtracking (LSOT)

All configurations easily met the performance standard (Figure 35). Overall length strongly influences LSOT, with the highest levels of LSOT occurring for the longer configurations such as the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT). All configurations do, however, have substantially reduced levels of LSOT relative to the reference TAC Super B-train (BTRN), which is a longer configuration.

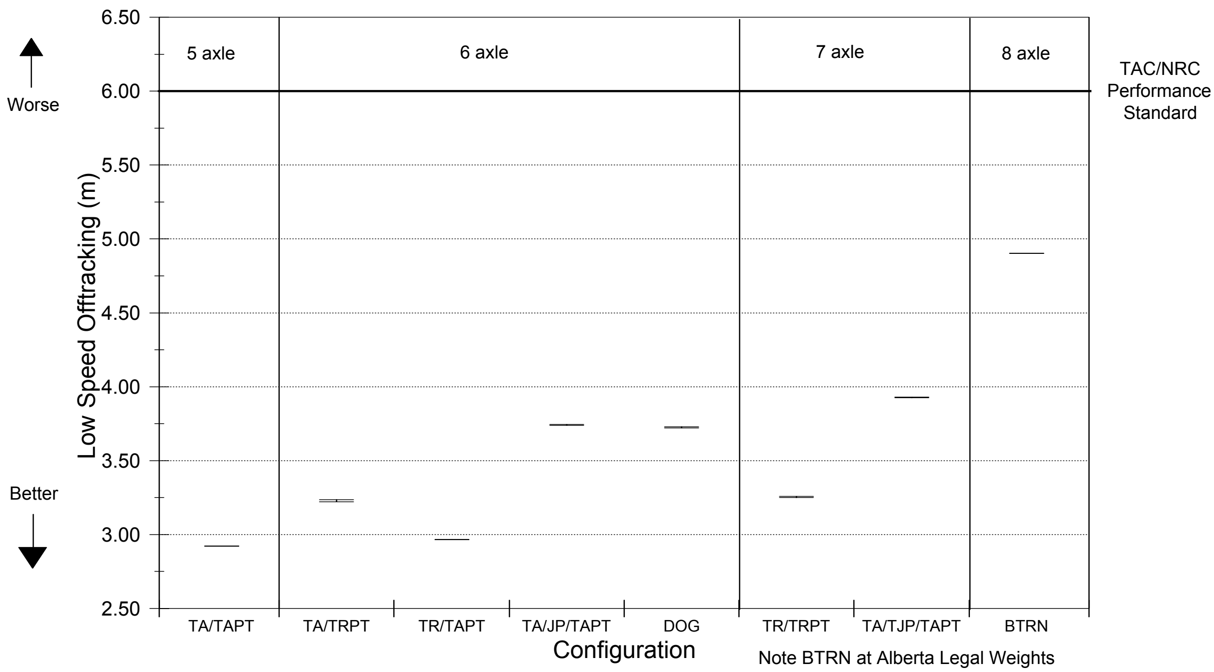


Figure 35. Low speed offtracking - Alberta winter weights.

(ii) Individual Configuration Performance

5 axle configurations

a) Tandem tractor/tandem pole trailer

The tandem tractor/tandem pole trailer exhibited a decrease in performance relative to the performance standards for four performance measures under the majority of loading conditions: static rollover threshold; high speed offtracking; load transfer ratio; and rearward amplification (Figure 36). A thorough investigation and optimization of the configuration parameters will be required in order to meet the performance standards. Possible solutions include wider axles, stiffer tires, increased suspension stiffness, decreased hitch offset, load redistribution (i.e., reduce load on drive group and increase load on trailer), and increased inter-group spacing. Performance standard performance could possibly be achieved by a combination of these options for current payload levels. An additional option beyond the optimization of these parameters is a reduction in payload.

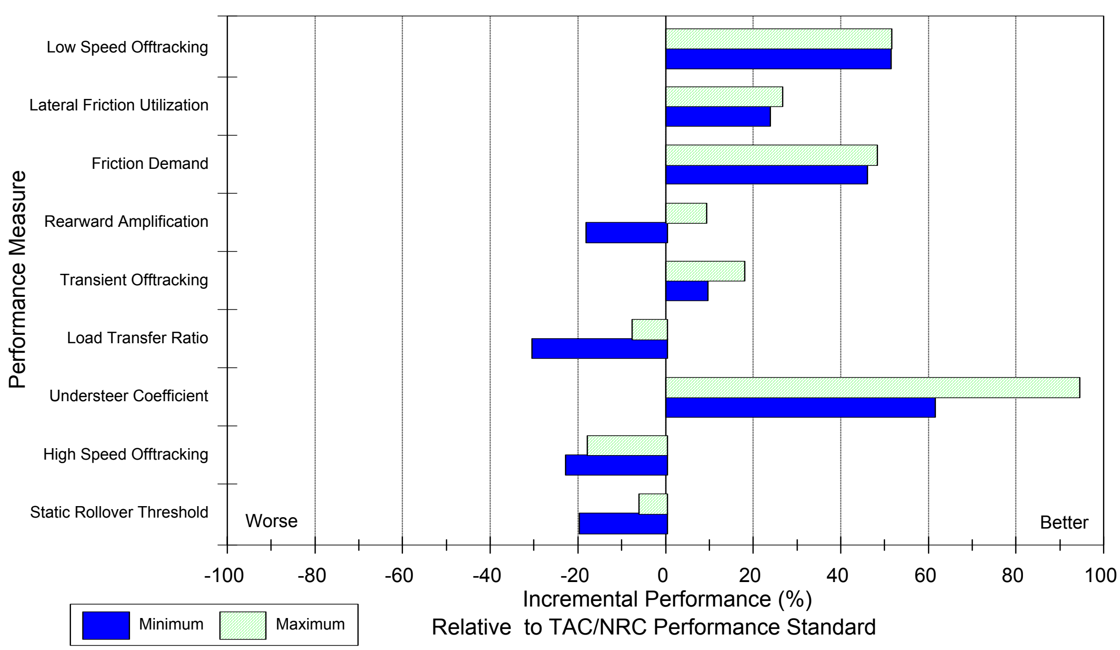


Figure 36. Tandem tractor/tandem pole trailer - Alberta winter weights.

6 axle configurations

b) Tandem tractor/tridem pole trailer

The tandem tractor/tridem pole trailer exhibited a decrease in performance relative to the performance standards for four performance measures under the majority of loading conditions: static rollover threshold; high speed offtracking; load transfer ratio; and friction demand (Figure 37). As for the tandem tractor/tandem pole trailer, a thorough investigation and optimization of the configuration parameters will be required in order to meet the performance standards.

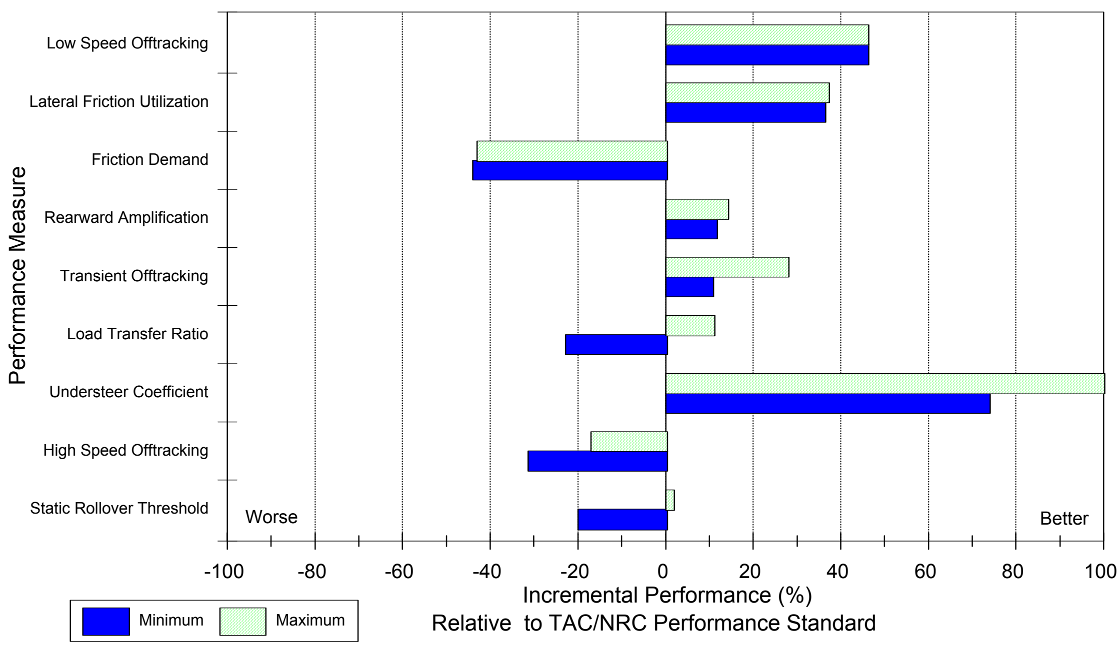


Figure 37. Tandem tractor/tridem pole trailer - Alberta winter weights.

c) Tridem tractor/tandem pole trailer

The tridem tractor/tandem pole trailer exhibited a decrease in performance relative to the performance standards for four performance measures under the majority of loading conditions: static rollover threshold; high speed offtracking; load transfer ratio; and lateral friction utilization (Figure 38). The performance level for lateral friction utilization was only marginally decreased from the performance standard, and a small increase in steering axle load or decrease in drive group load would likely rectify this deficiency. The remaining three deficiencies will need to be addressed by a thorough investigation and optimization of the configuration parameters in order to meet the performance standards.

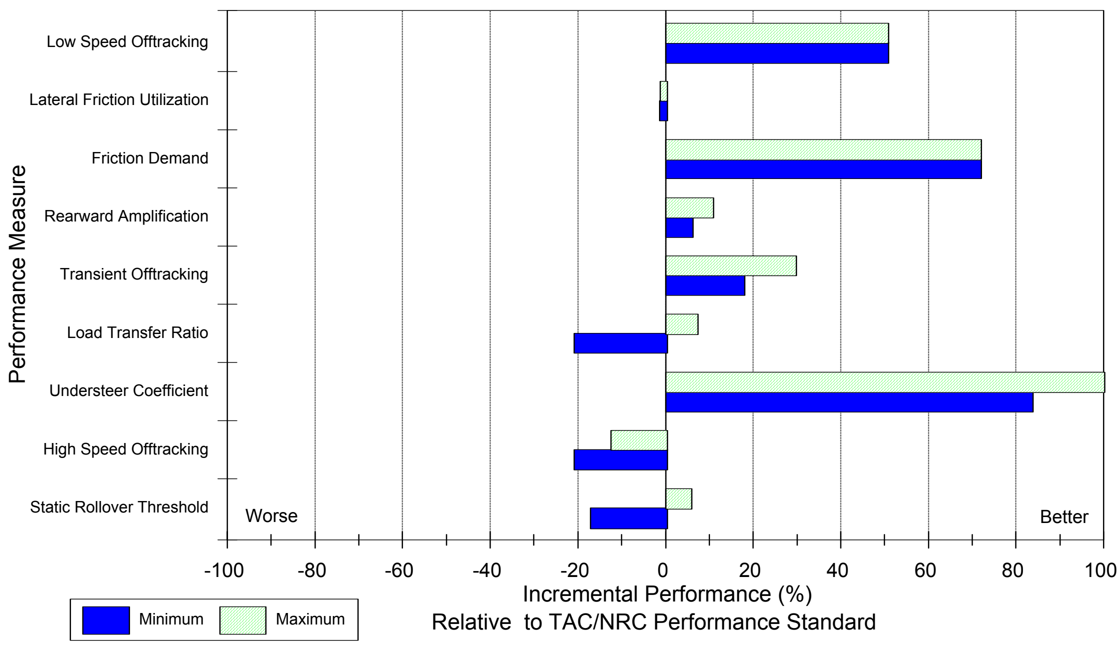


Figure 38. Tridem tractor/tandem pole trailer - Alberta winter weights.

d) <u>Tandem tractor/jeep/tandem pole trailer</u>

The tandem tractor/jeep/tandem pole trailer exhibited a decrease in performance relative to the performance standards for three performance measures under the majority of loading conditions: static rollover threshold; high speed offtracking; and load transfer ratio (Figure 39). The performance level of high speed offtracking was particularly reduced, by up to 48% from the performance standard. These deficiencies will need to be addressed by a thorough investigation and optimization of the configuration parameters in order to meet the performance standards.

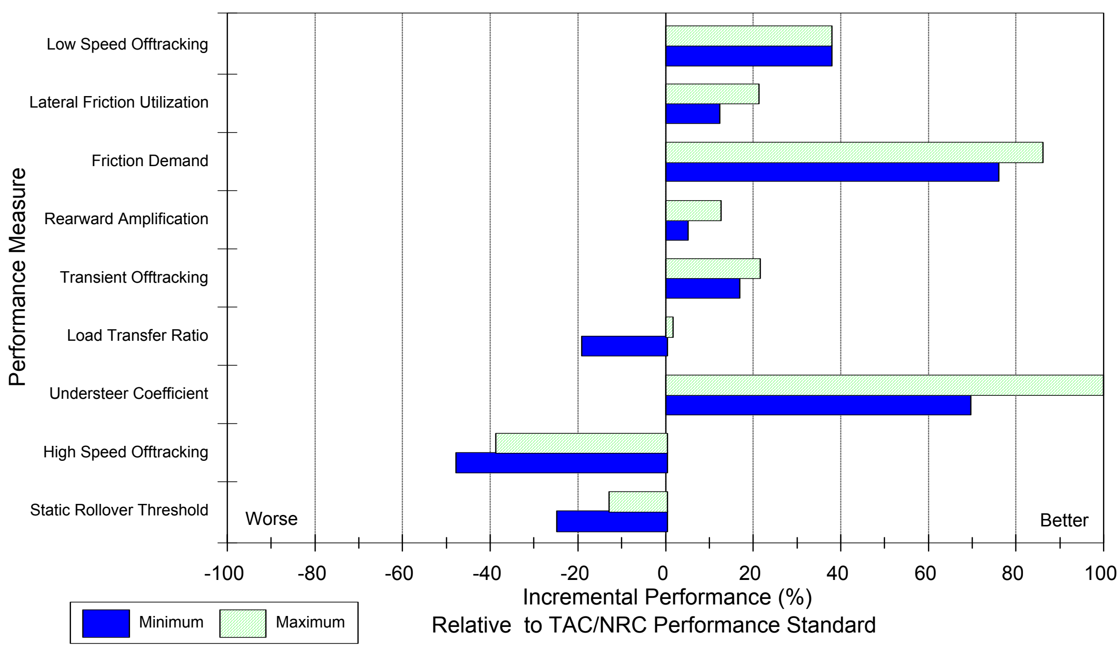


Figure 39. Tandem tractor/jeep/tandem pole trailer - Alberta winter weights.

e) Doglogger

The doglogger exhibited a decrease in performance relative to the performance standards for three performance measures under all loading conditions: static rollover threshold; high speed offtracking; and load transfer ratio (Figure 40). In addition, the performance standard for transient offtracking was not quite achieved when loaded with low density logs. The performance levels of static rollover threshold, high speed offtracking, and load transfer ratio were particularly degraded with this configuration with performance decreases of up to 31%, 49%, and 46% respectively below the performance standards. These deficiencies will require a thorough investigation and optimization of the configuration parameters, including payload level, in order to meet the performance standards.

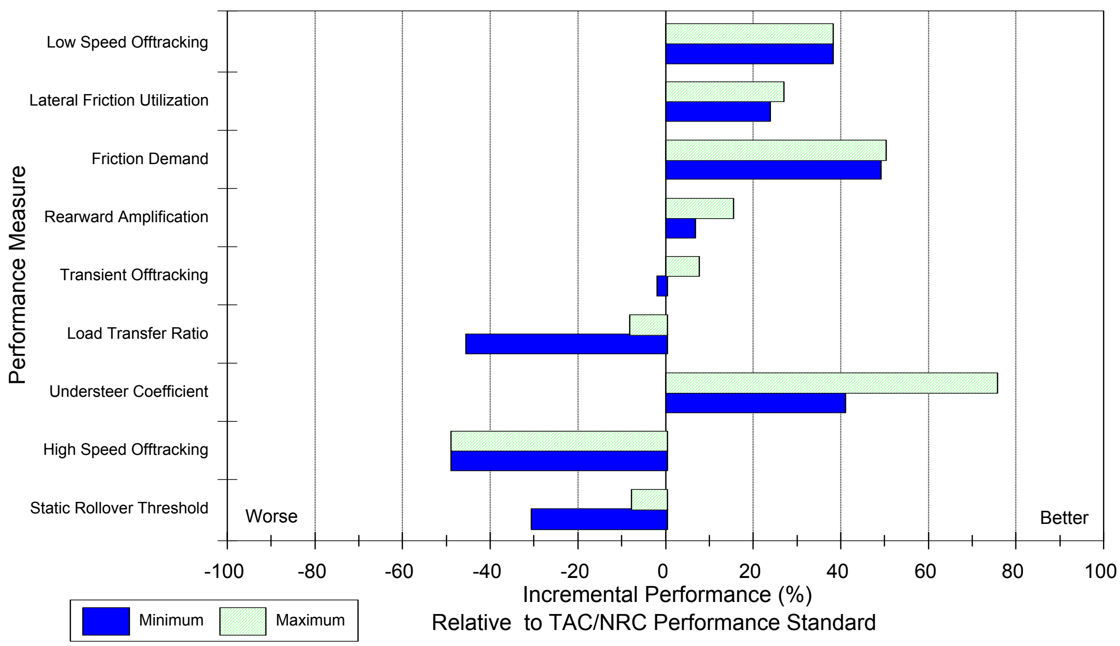


Figure 40. Doglogger - Alberta winter weights.

7 axle configurations

f) <u>Tridem tractor/tridem pole trailer</u>

The tridem tractor/tridem pole trailer exhibited a decrease in performance relative to the performance standards for two performance measures: high speed offtracking, and friction demand (Figure 41). In addition, the performance standard for static rollover threshold was not achieved at low load densities. This configuration will require the least amount of adjustment of all the configurations loaded to Alberta green route weights to meet the performance standards.

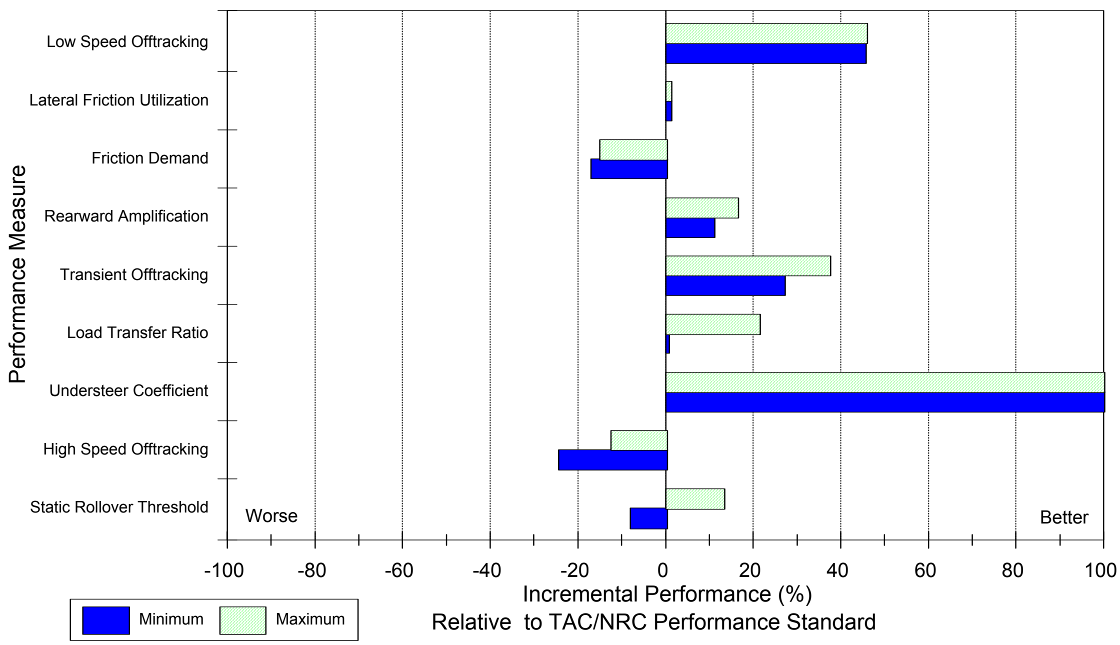


Figure 41. Tridem tractor/tridem pole trailer - Alberta winter weights.

g) Tandem tractor/tandem jeep/tandem pole trailer

The tandem tractor/tandem jeep/tandem pole trailer exhibited a decrease in performance relative to the performance standards for four performance measures: static rollover threshold; high speed offtracking; load transfer ratio; and rearward amplification (Figure 42). In addition, the performance level for transient offtracking was marginally below the performance standard at low load densities. The performance level of high speed offtracking was particularly reduced, by up to 41% from the performance standard. These deficiencies will need to be addressed by a thorough investigation and optimization of the configuration parameters in order to meet the performance standards.

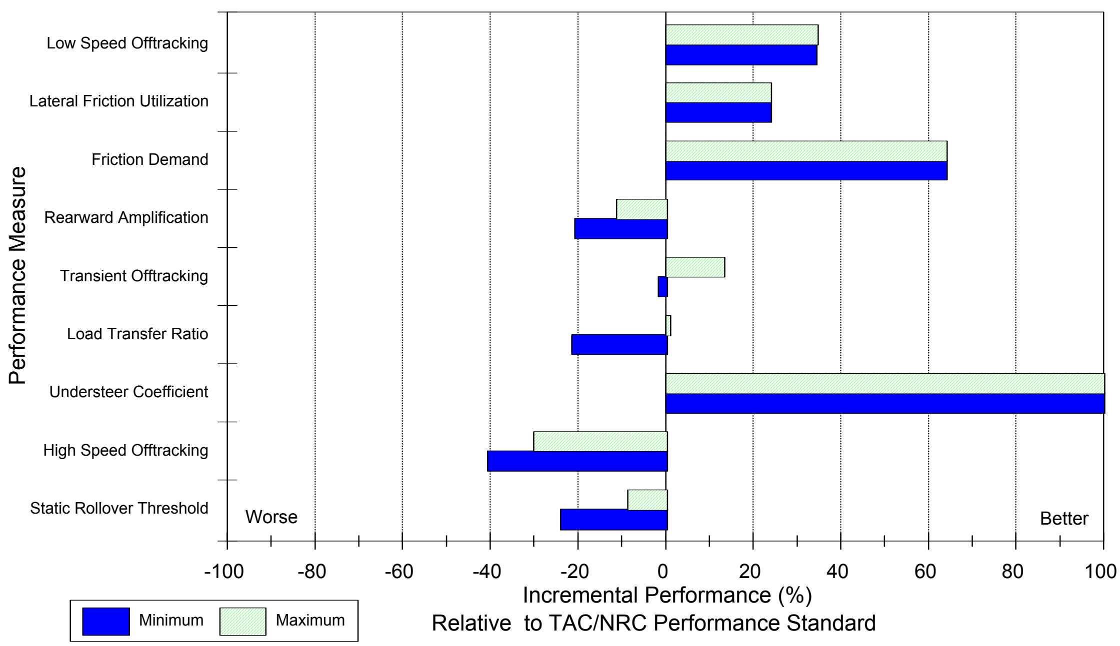


Figure 42. Tandem tractor/tandem jeep/tandem pole trailer - Alberta winter weights.

8 axle configurations

h) Super B-train

Refer to Alberta legal weights for the individual performance of the Super B-train. All logging configurations loaded to Alberta green route weights with the exception of the tridem tractor/tridem pole trailer exhibit a decrease in dynamic performance relative to the Super B-train loaded to Alberta legal weights.

(iii) Ranking of Configurations

The increased payloads characteristic of Alberta winter weights reduced the dynamic indices relative to legal weights (Figure 43). The tridem tractor/tridem pole trailer (TR/TRPT) performed the best overall with a dynamic index of 60.5 and was the only configuration with a higher dynamic index than the reference TAC Super B-train (BTRN) loaded to legal weights. The configuration with the lowest overall performance was the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), with a dynamic index of 48.0. The relationship between payload and dynamic performance was less distinct under this weight regime (Figure 44). The tridem tractor/tridem pole trailer had essentially the same payload capacity as the tandem tractor/tandem pole trailer (TA/TAPT) and tandem tractor/tridem pole trailer (TA/TRPT), but performed better overall because of the increased roll stiffness provided by the extra axles. The tridem tractor configurations performed significantly better overall than their tandem tractor counterparts. The tridem tractor/tridem pole trailer had essentially the same payload capacity as the tandem tractor/tridem pole trailer, but the tridem tractor/tandem pole trailer's (TR/TAPT) payload capacity was approximately 2 000 kg below the tandem tractor/tandem pole trailer. The tandem tractor/jeep/tandem pole trailer and the doglogger (DOG) both had the same payload level and number of axles but the doglogger experienced a lower level of overall dynamic performance. The tandem tractor/jeep/tandem pole trailer had significantly greater payload than the tandem tractor/pole trailer configurations, but achieved relatively the same dynamic index.

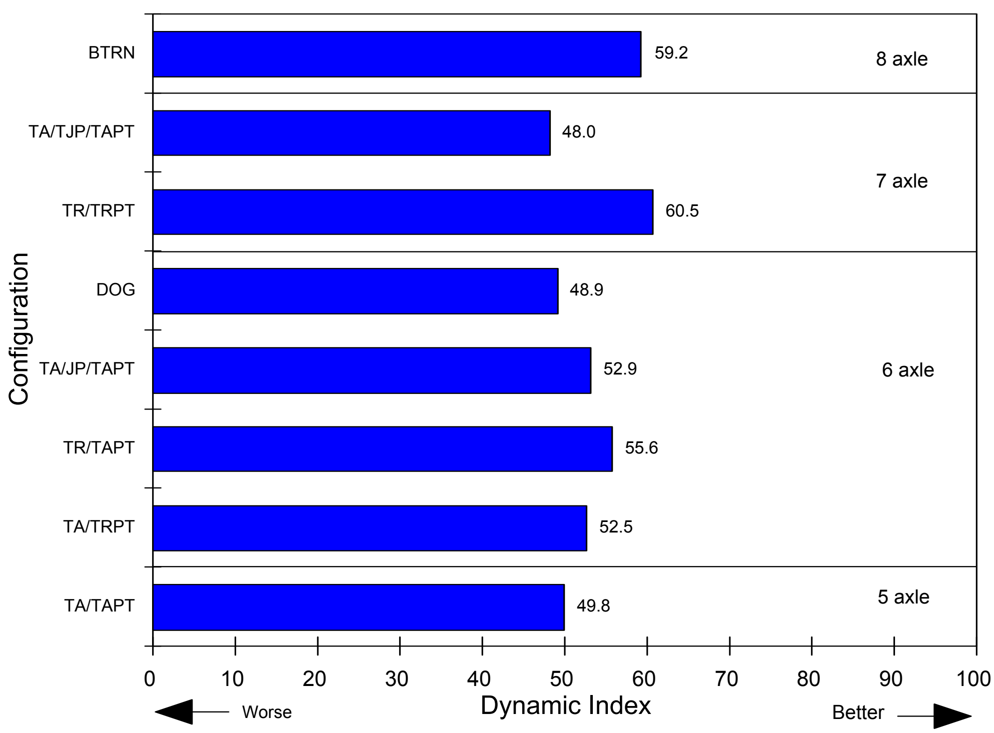


Figure 43. Dynamic indices - Alberta winter weights.

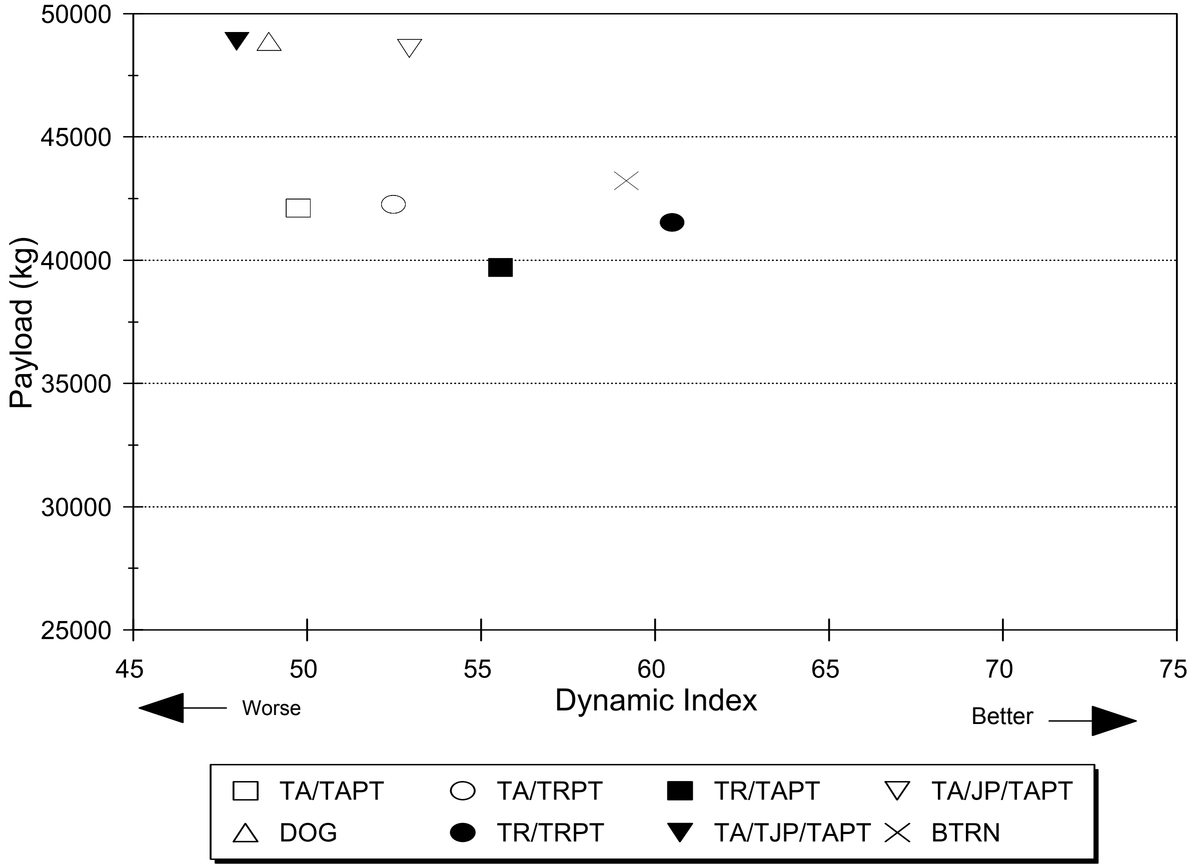


Figure 44. Overall performance - Alberta winter weights.

C. British Columbia Legal Weights (with Winter logging truck weight allowances)

(i) Relative Configuration Performance

a) Static rollover threshold (SRT)

All the 5-axle and 6-axle configurations and the 7-axle tridem tractor/tridem pole trailer (TR/TRPT) met the performance standard under most loading conditions (Figure 45). The double doglogger (DDOG), the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), and the tandem tractor/jeep/triaxle trailer (TA/JP/TRI) failed to meet the performance standard for the majority of load densities. In addition, the tandem tractor/quadaxle trailer (TA/QUAD) failed to meet the performance standard at low load densities. The double doglogger experienced the worst levels of stability performance. The best performance in this category was recorded by the 5-axle tandem tractor/tandem pole trailer (TA/TAPT). Performance was degraded marginally with the increase in payload for the other pole trailer configurations relative to the 5-axle configuration, but remained at acceptable levels. This trend in the performance of the pole trailer configurations in BC differed from that in Alberta because of the higher tridem group load allowance in BC. The increase in roll stiffness provided by the additional axle essentially just compensates for the increased payload and cg height. All configurations with the exception of the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), the double doglogger, the tandem tractor/jeep/triaxle trailer, and the tandem tractor/quadaxle trailer exhibited similar levels of rollover stability to the reference TAC Super B-train (BTRN).

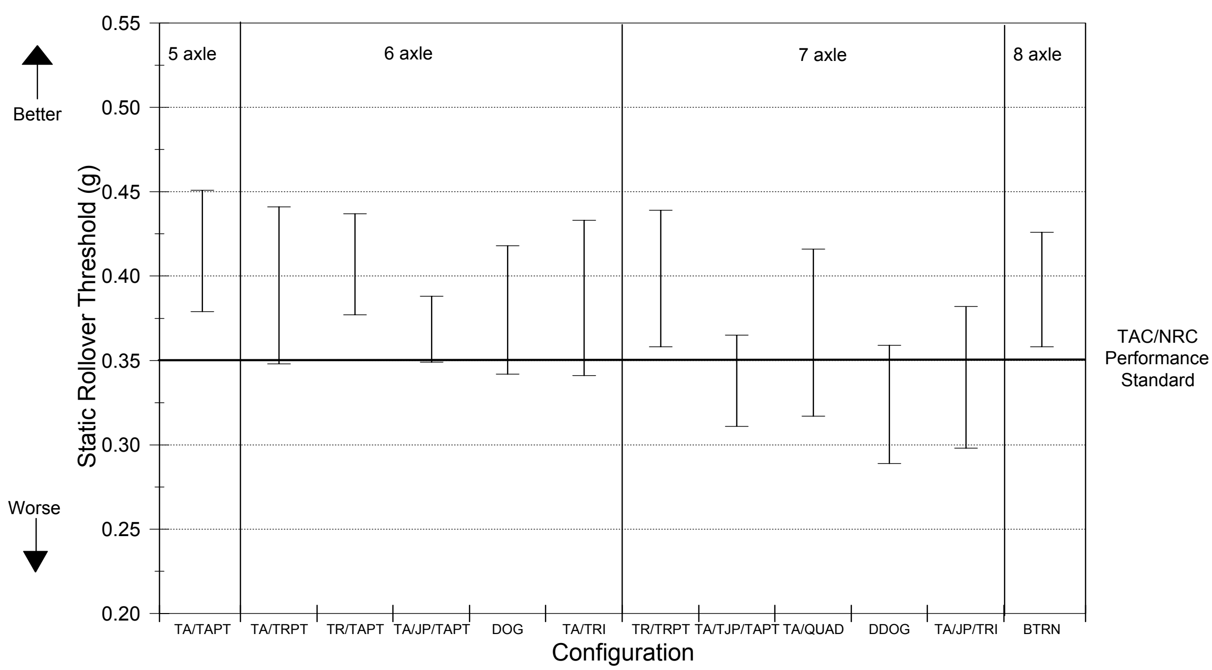


Figure 45. Static rollover threshold - BC legal weights (with winter logging truck weight allowances).

b) High speed steady state offtracking (HSOT)

All configurations except the tandem tractor/tandem pole trailer (TA/TAPT) at the highest load density failed to meet the performance standard for high speed offtracking (Figure 46). The single articulation point pole trailer configurations achieved the best HSOT values, while the worst levels of HSOT occurred for configurations with high payloads and articulation points located more rearward. The tandem tractor/quadaxle trailer (TA/QUAD) experienced the highest and therefore worst level of HSOT. The high speed offtracking performance of these configurations is largely influenced by payload, payload location, overall length, and the location of articulation points. Despite not meeting the performance standard, all configurations with the exception of the tandem tractor/quadaxle trailer, the double doglogger (DDOG), and the tandem tractor/jeep/triaxle trailer (TA/JP/TRI) exhibited lower levels of HSOT than the reference TAC Super B-train configuration (BTRN), and can be safely tolerated.

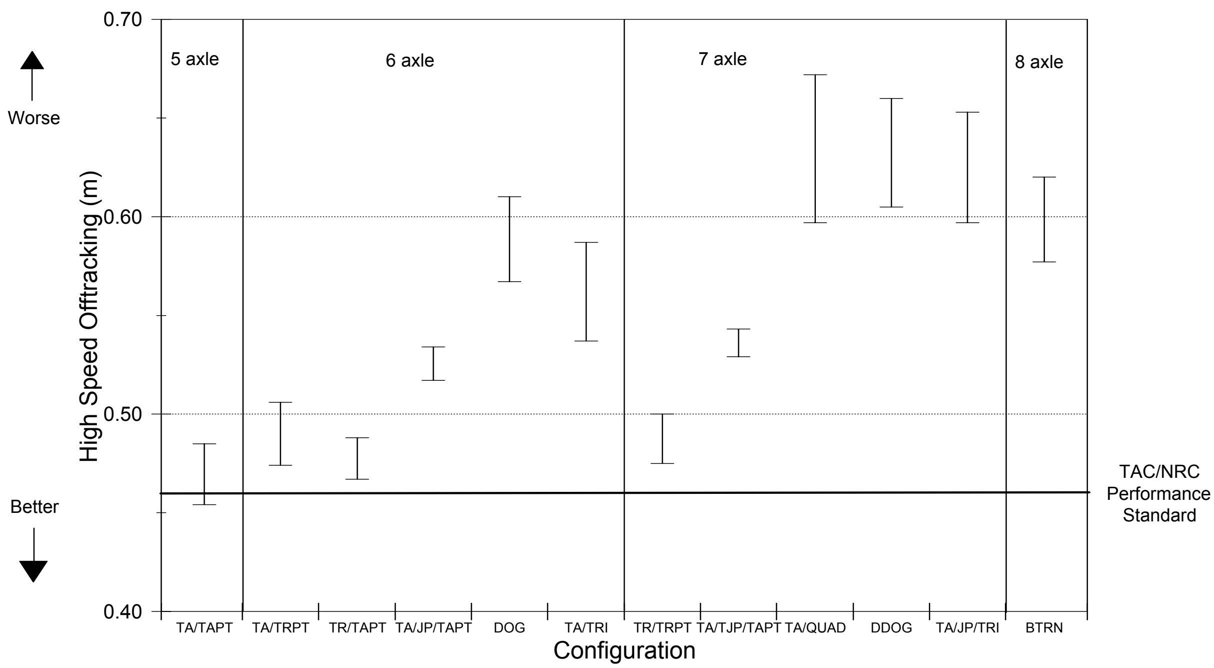


Figure 46. High speed steady state offtracking - BC legal weights (with winter logging truck weight allowances).

c) <u>Understeer coefficient at 0.25g (USC)</u>

All configurations met the handling performance standard (Figure 47). The tridem tractor configurations (TR/TAPT, TR/TRPT) had the highest levels of understeer. Configurations with rearward articulation points exhibited slight oversteer over a significant proportion of the loading conditions, similar to that shown by the reference TAC Super B-train (BTRN).

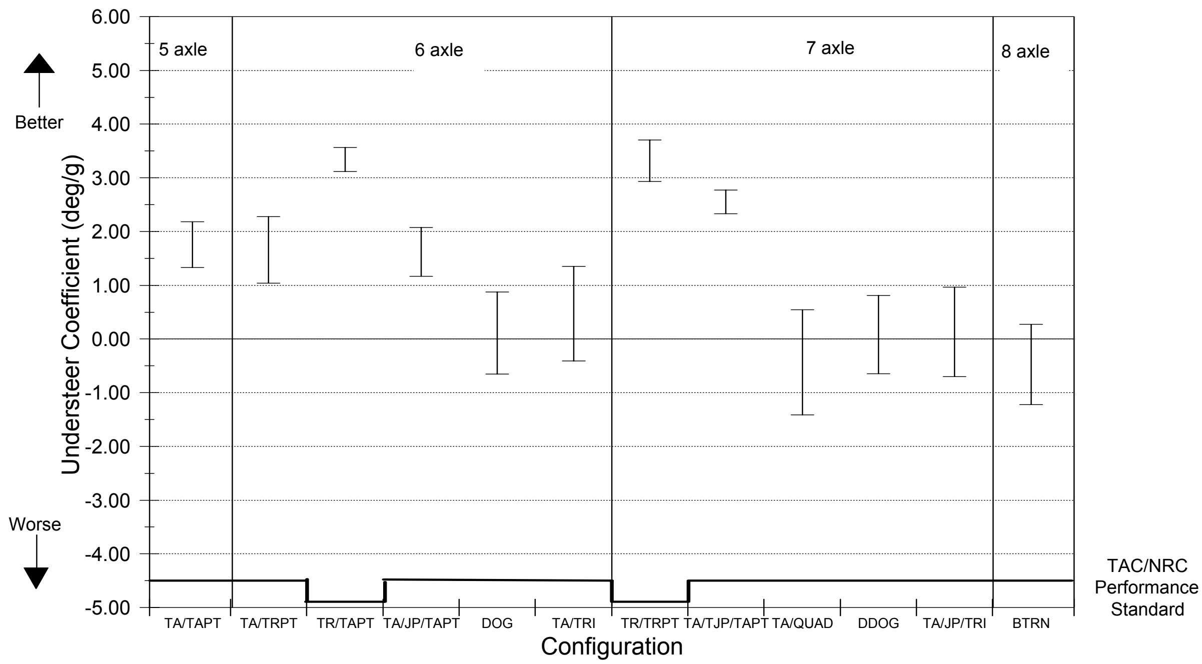


Figure 47. Understeer coefficient - BC legal weights (with winter logging truck weight allowances).

d) Load transfer ratio (LTR)

The dynamic stability performance standard was met for the majority of configurations and load densities (Figure 48). The performance standard was not met at the lower load densities for the tandem tractor/triaxle trailer (TA/TRI), the tandem tractor/quadaxle trailer (TA/QUAD), the double doglogger (DDOG), and the tandem tractor/jeep/triaxle trailer (TA/JP/TRI). These are all cases where the axles were unable to provide sufficient roll resistance to the increased payload and cg height. The tandem tractor/quadaxle trailer exhibited the worst levels of LTR, while the best dynamic stability performance occurred for the tridem tractor/tandem pole trailer (TR/TAPT) and the tandem tractor/tandem pole trailer (TA/TAPT). The additional drive axle of the tridem tractor allowed for equivalent dynamic stability at increased payload relative to the tandem tractor/pole trailer configurations. The single articulation point pole trailer configurations exhibited dynamic stabilities which were equivalent to the reference TAC Super B-train (BTRN), whereas all other configurations showed a reduction in dynamic stability relative to the B-train.

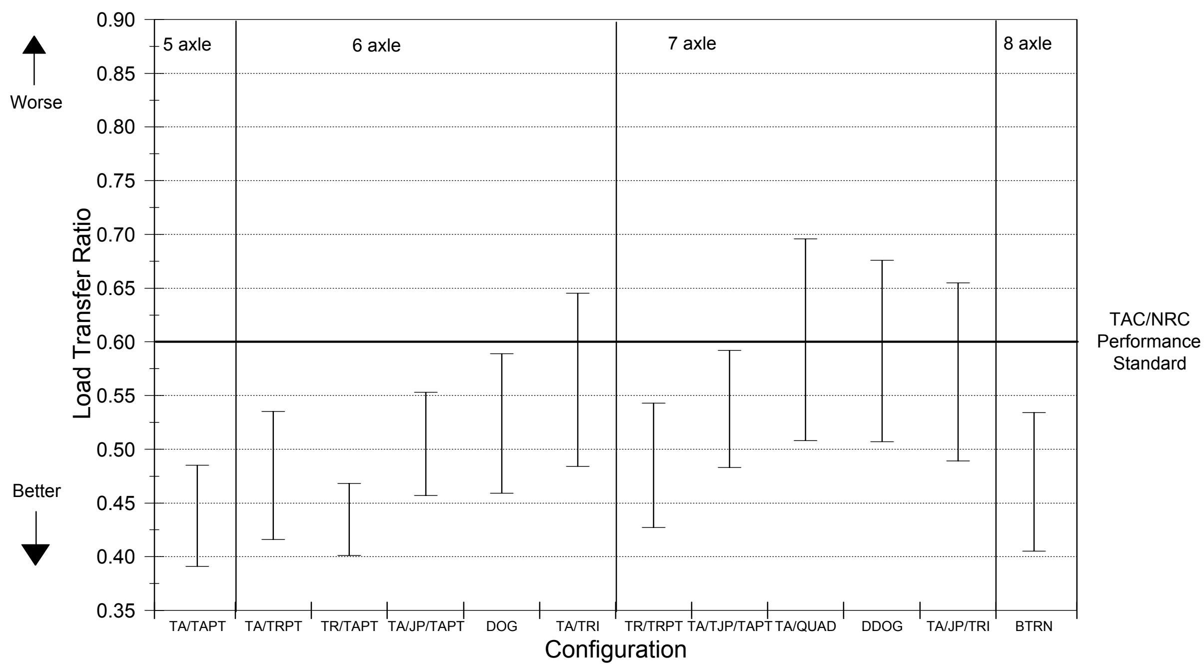


Figure 48. Load transfer ratio - BC legal weights (with winter logging truck weight allowances).

e) <u>Transient offtracking (TOT)</u>

All the configurations met the performance requirements for transient offtracking (Figure 49). The best levels of TOT occurred for the single articulation point pole trailer configurations with the tandem tractor/tandem pole trailer (TA/TAPT) experiencing the best level overall. The tractor/quadaxle trailer (TA/QUAD) exhibited the worst level of TOT. Only the single articulation point configurations achieved improved levels of TOT relative to the reference TAC Super B-train (BTRN); all other configurations showed equivalent or reduced performance in terms of transient offtracking relative to the B-train.

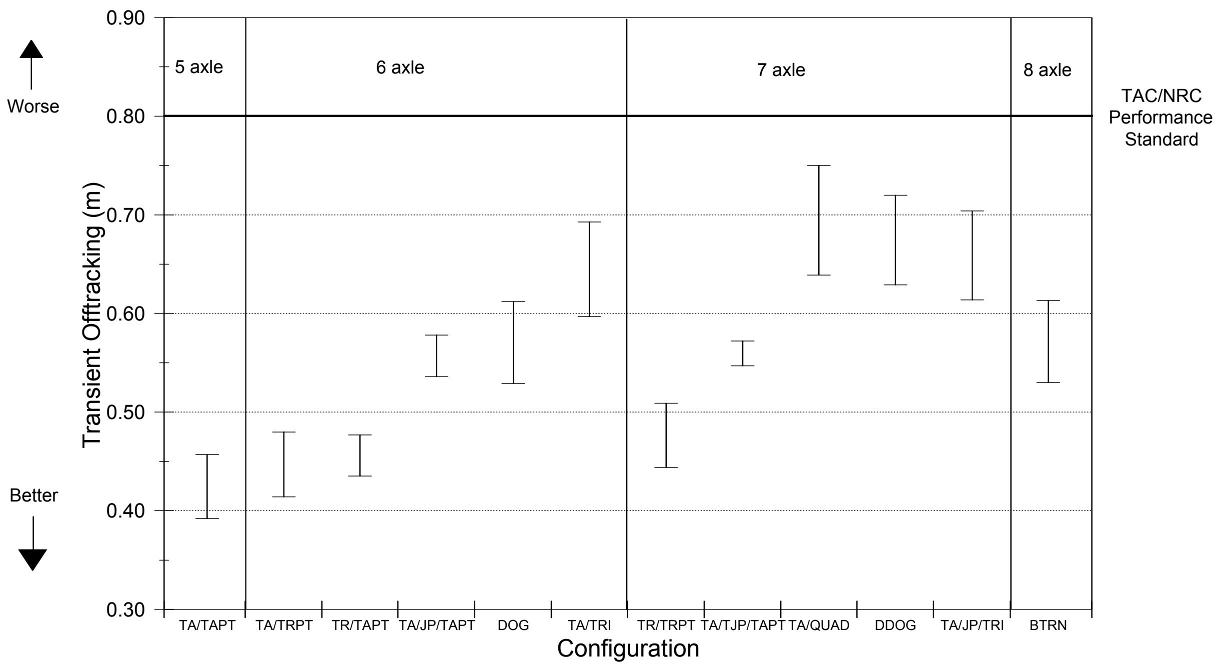


Figure 49. Transient offtracking - BC legal weights (with winter logging truck weight allowances).

f) Rearward amplification (RWA)

All configurations met the performance standard for rearward amplification for all loading conditions (Figure 50). The single articulation point pole trailer configurations had the best levels of rearward amplification with the tandem tractor/tandem pole trailer (TA/TAPT) performing the best overall. The worst level of RWA occurred for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) just below the performance standard of 2.2. The reduced performance of the tandem tractor/tandem jeep/tandem pole trailer results primarily from the forward load bias of this configuration. The single articulation point configurations exhibited improved levels of RWA, while the multiple articulation point configurations showed similar or increased levels relative to the reference TAC Super B-train (BTRN).

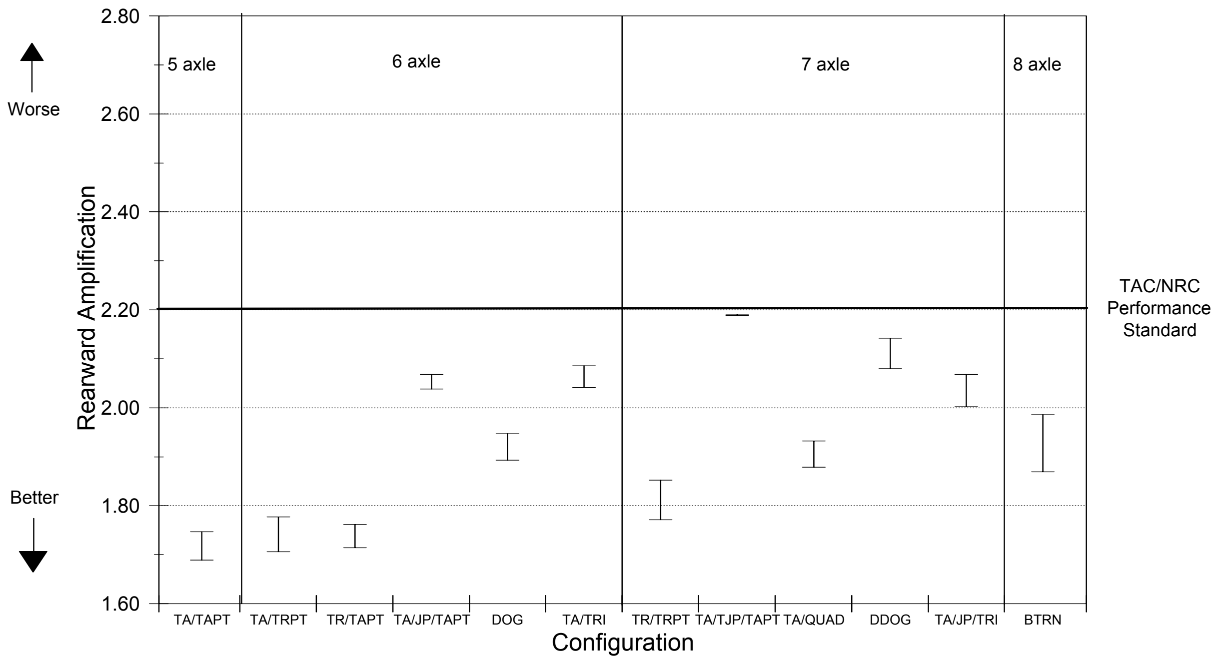


Figure 50. Rearward amplification - BC legal weights (with winter logging truck weight allowances).

g) Friction demand (FD)

The friction demand performance standard was met for all configurations except the tridem pole trailer configurations (TA/TRPT, TR/TRPT) (Figure 51). The tandem tractor/tridem pole trailer exhibited the worst level of FD of 0.18, well above the performance standard of 0.10. The FD level for the tridem tractor/tridem pole trailer configuration ranged between 0.09 and 0.11, just exceeding the performance standard under some loading conditions. The improved performance of the tridem pole trailer configurations in BC relative to Alberta results primarily from the shorter tridem group spread in BC. There is no load advantage for an increase in spread for the tridem group as exists in Alberta. Only the tridem pole trailer configurations exhibited reduced performance relative to the reference TAC Super B-train (BTRN); all other configurations showed improved performance in terms of friction demand relative to the B-train.

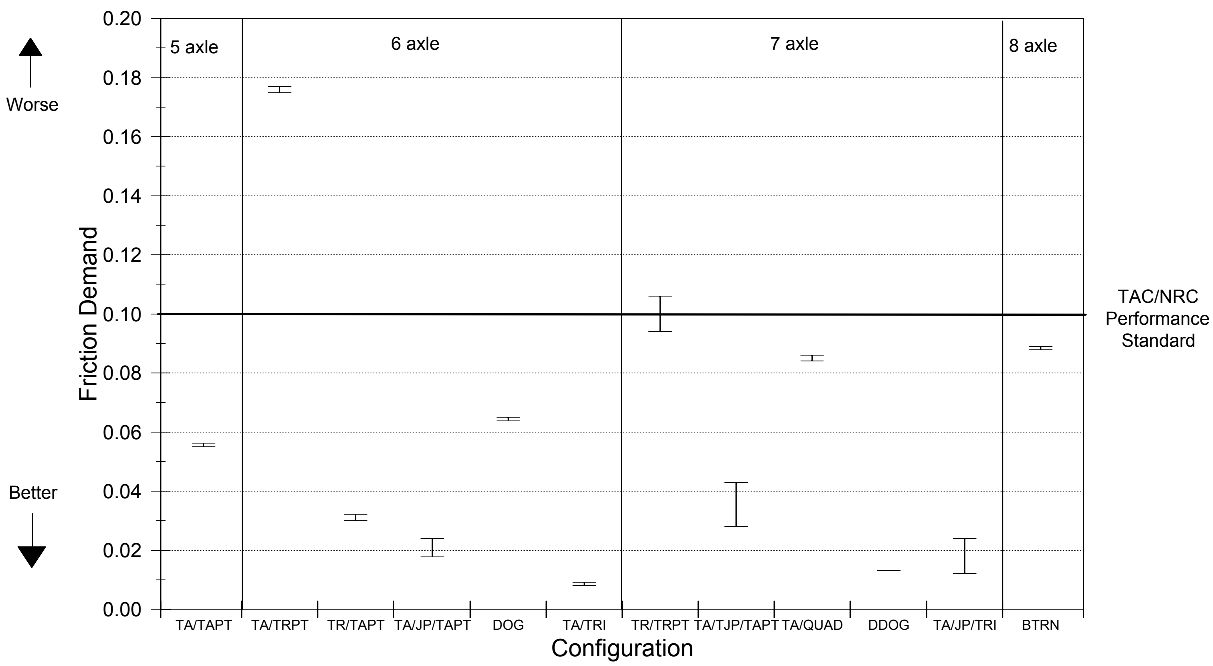


Figure 51. Friction demand - BC legal weights (with winter logging truck weight allowances).

h) Lateral friction utilization (LFU)

All configurations met the performance standard for lateral friction utilization at the steering axle (Figure 52). The best and worst levels of LFU were experienced by the tandem tractor/tridem pole trailer (TA/TRPT) and tridem tractor/tandem pole trailer (TR/TAPT), respectively. All configurations except the tridem tractor configurations exhibited similar or improved LFU performance relative to the reference TAC Super B-train (BTRN).

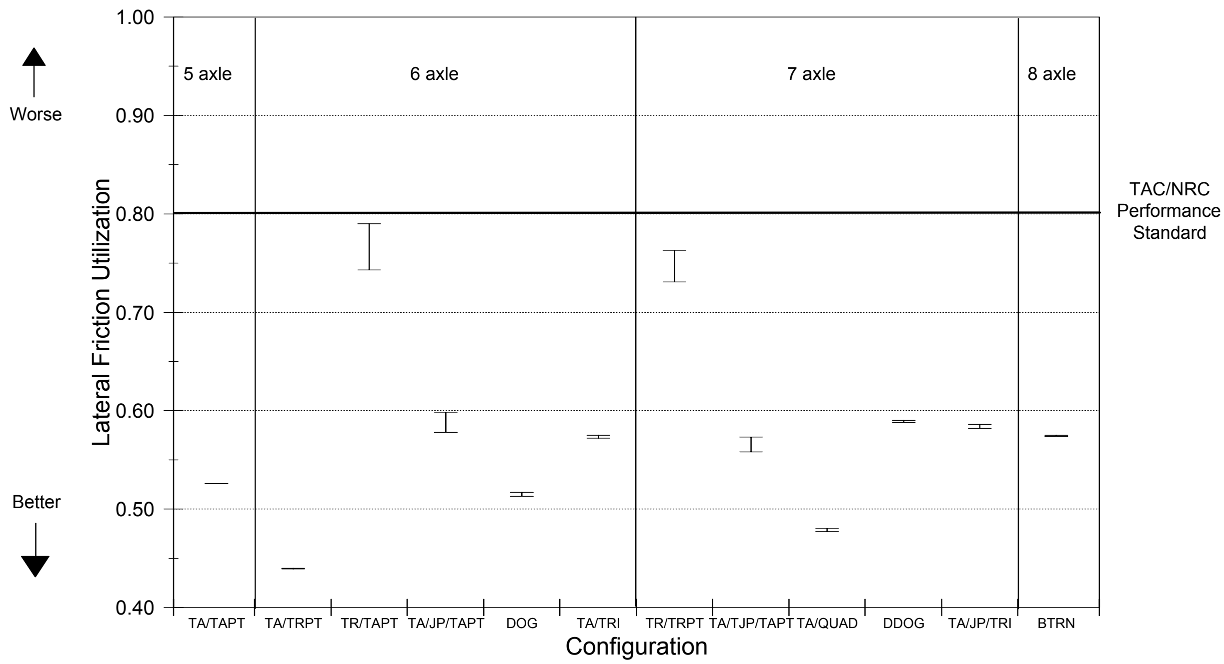


Figure 52. Lateral friction utilization - BC legal weights (with winter logging truck weight allowances).

i) Low speed offtracking (LSOT)

All configurations met the performance standard for low speed offtracking (Figure 53), and were much reduced relative to the reference TAC Super B-train (BTRN). The worst level of offtracking occurred for the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT), approximately 1 m less than the B-train, while the best level of LSOT occurred for the tandem tractor/triaxle trailer (TA/TRI).

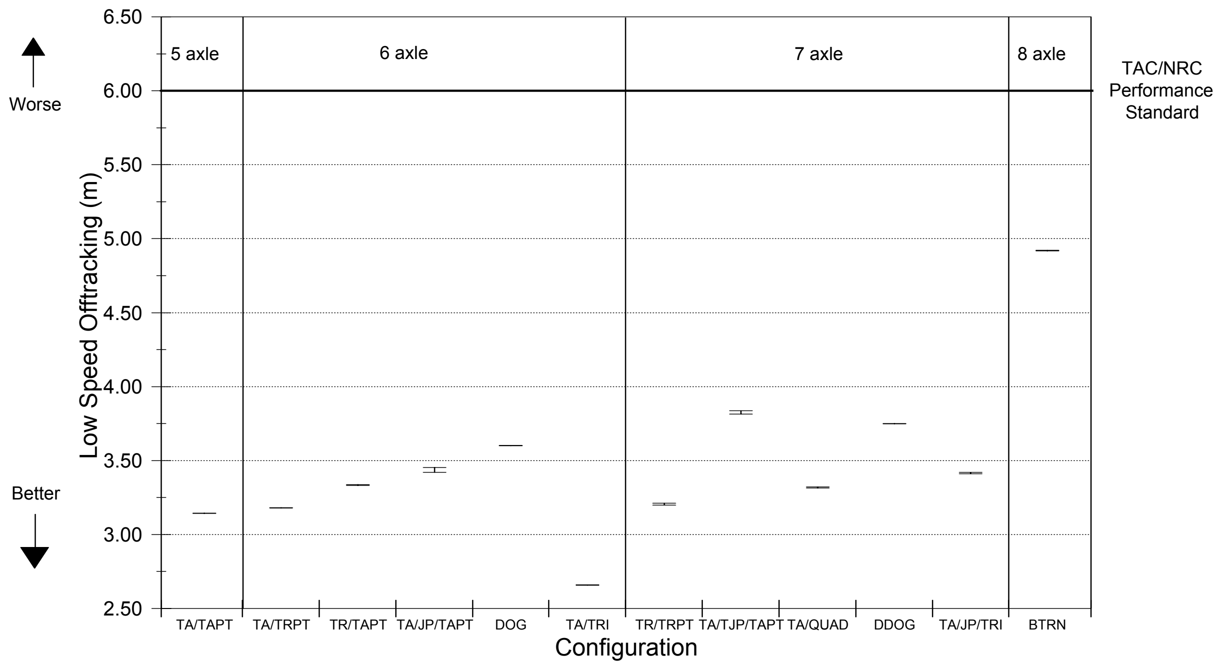


Figure 53. Low speed offtracking - BC legal weights (with winter logging truck weight allowances).

(ii) Individual Configuration Performance

5 axle configurations

a) Tandem tractor/tandem pole trailer

The tandem tractor/tandem pole trailer exhibited improved performance over the performance standards for all performance measures except high speed offtracking at low densities (Figure 54). Possible options for addressing this deficiency include using stiffer tires and reducing the hitch offset.

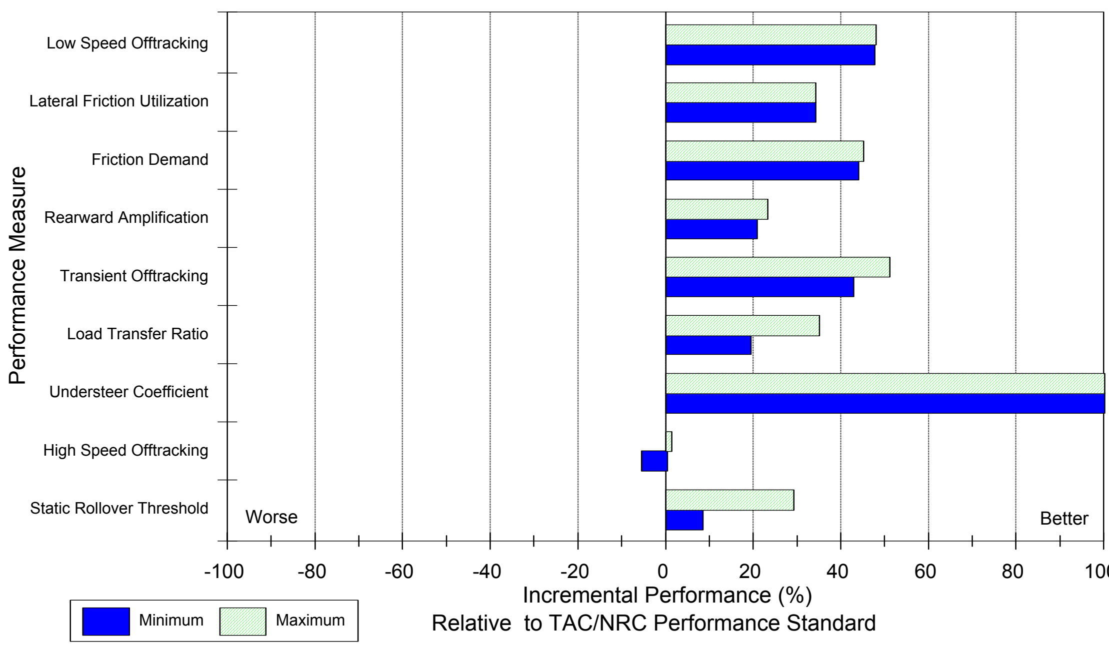


Figure 54. Tandem tractor/tandem pole trailer - BC legal weights (with winter logging truck weight allowances).

6 axle configurations

b) Tandem tractor/tridem pole trailer

The tandem tractor/tridem pole trailer exhibited a decrease in performance relative to the performance standards for two performance measures under all loading conditions: high speed offtracking and friction demand (Figure 55). Friction demand performance was degraded below the performance standard by up to 77%. Friction demand performance could be improved by reducing the hitch offset, increasing the inter-group spacing, and decreasing the trailer group spread. High speed offtracking performance could be improved by using stiffer tires and reducing the hitch offset.

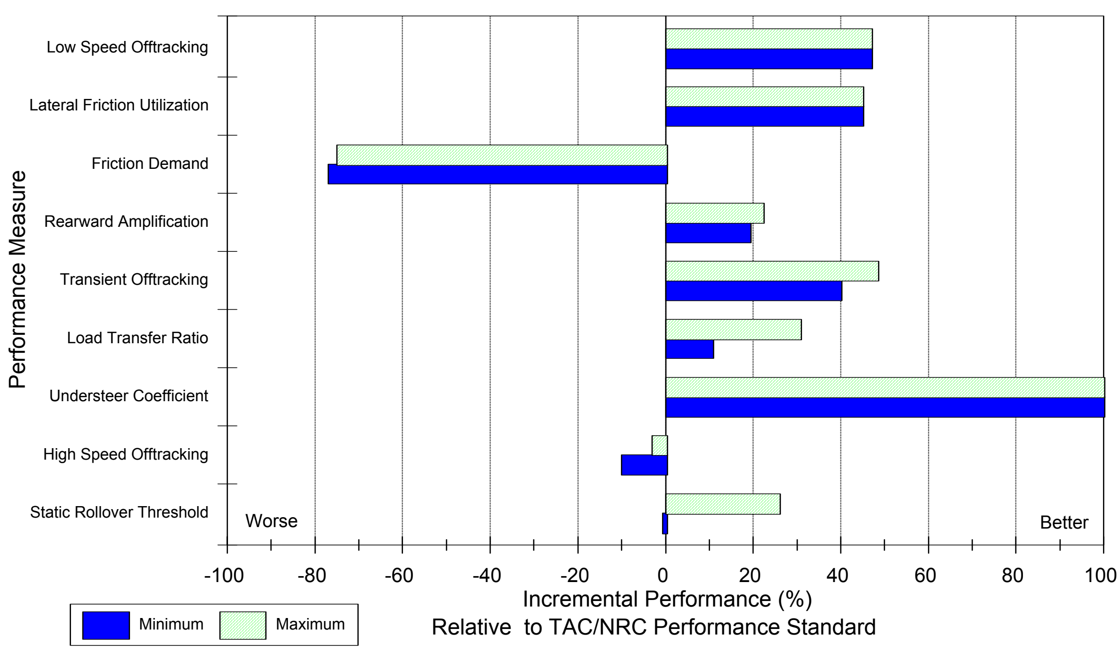


Figure 55. Tandem tractor/tridem pole trailer - BC legal weights (with winter logging truck weight allowances).

c) Tridem tractor/tandem pole trailer

The tridem tractor/tandem pole trailer exhibited improved performance over the performance standards for all performance measures except high speed offtracking (Figure 56). Possible options for addressing this deficiency include using stiffer tires and reducing the hitch offset.

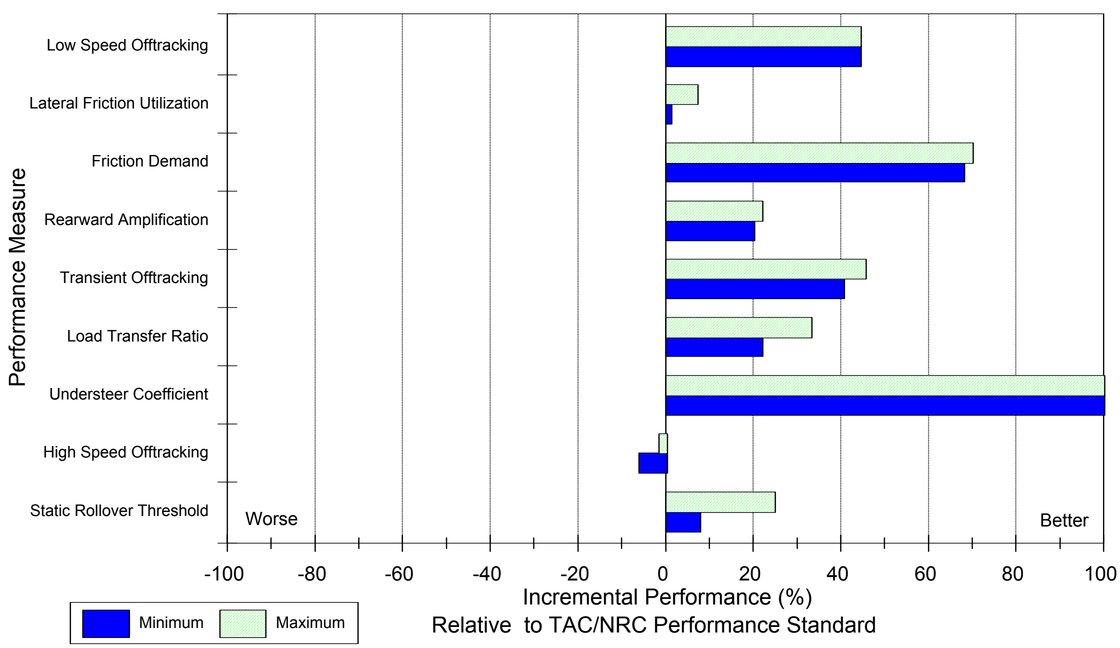


Figure 56. Tridem tractor/tandem pole trailer - BC legal weights (with winter logging truck weight allowances).

d) Tandem tractor/jeep/tandem pole trailer

The tandem tractor/jeep/tandem pole trailer exhibited improved performance relative to the performance standards for all performance measures except high speed offtracking (Figure 57). Possible options for addressing this deficiency include using stiffer tires, reducing the hitch offset, and minimizing the inter-group spacing between the drive group and the jeep and between the jeep and the trailer.

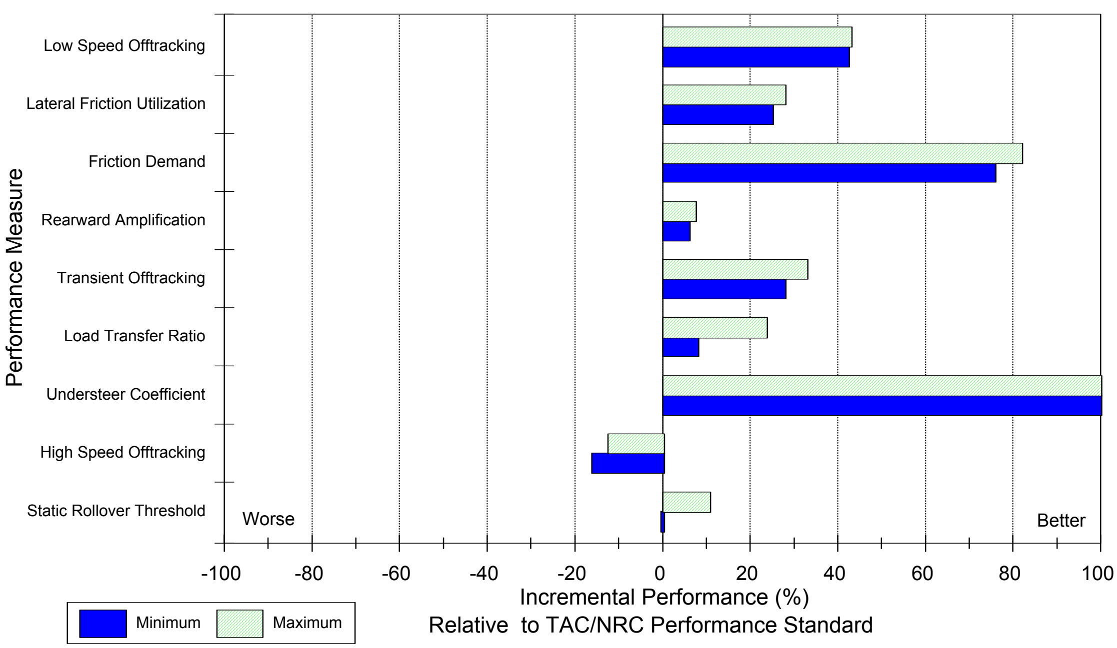


Figure 57. Tandem tractor/jeep/tandem pole trailer - BC legal weights (with winter logging truck weight allowances).

e) <u>Doglogger</u>

The doglogger exhibited a decrease in performance relative to the performance standard for high speed offtracking for all loading conditions and the static rollover threshold was degraded marginally when loaded with low density logs (Figure 58). The high speed offtracking was degraded by up to 32% from the performance standard. This deficiency could be addressed by using stiffer tires and reducing the hitch offset. The magnitude of these changes can only be determined by a detailed investigation and optimization of the configuration parameters.

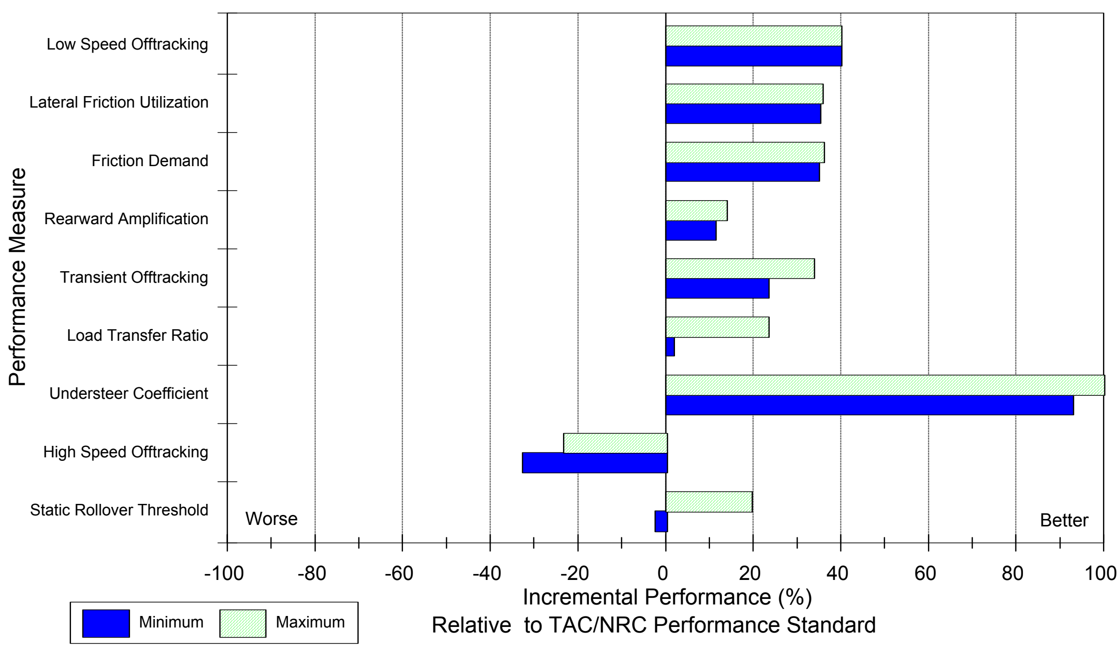


Figure 58. Doglogger - BC legal weights (with winter logging truck weight allowances).

f) <u>Tandem tractor/triaxle trailer</u>

The tandem tractor/triaxle trailer exhibited a decrease in performance relative to the performance standards for high speed offtracking for all loading conditions, and static rollover threshold and load transfer ratio performance when loaded with low density logs (Figure 59). These deficiencies will require a thorough investigation and optimization of the configuration parameters in order to meet the performance standards. However, it is likely that using stiffer tires will improve the majority of this configuration's deficiencies.

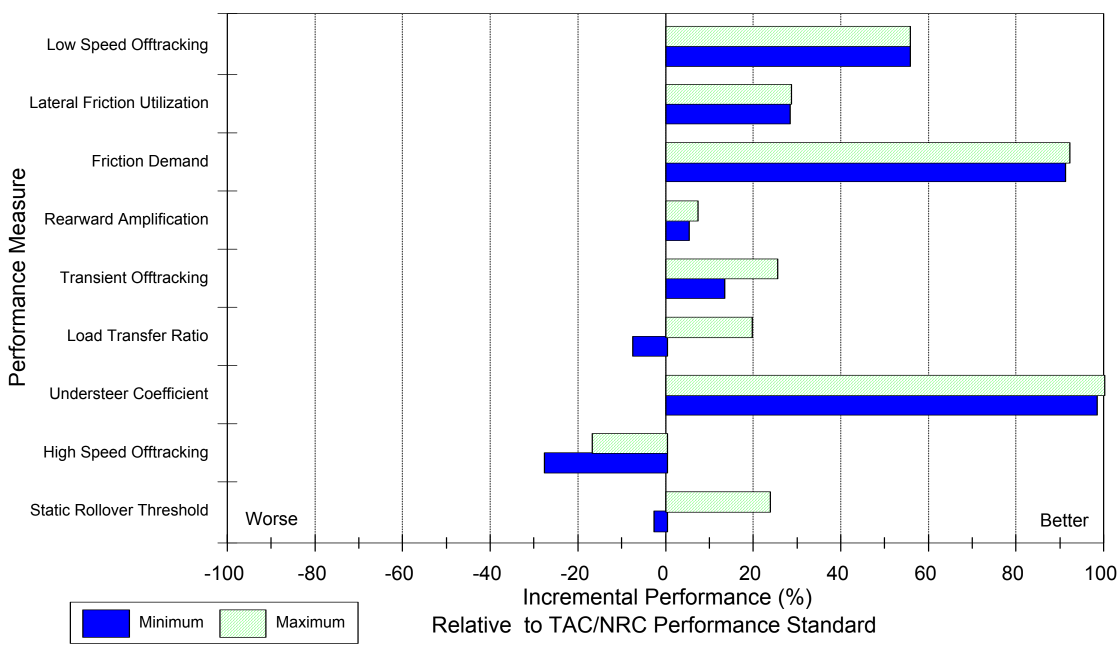


Figure 59. Tandem tractor/triaxle trailer - BC legal weights (with winter logging truck weight allowances).

7 axle configurations

g) Tridem tractor/tridem pole trailer

The tridem tractor/tridem pole trailer exhibited improved performance over the performance standards for all performance measures except high speed offtracking under all loading conditions, and except friction demand under some loading conditions (Figure 60). These deviations from the performance standards are minor (< 10%) and could be rectified by using stiffer tires, reducing the hitch offset and increasing the inter-group spacing.

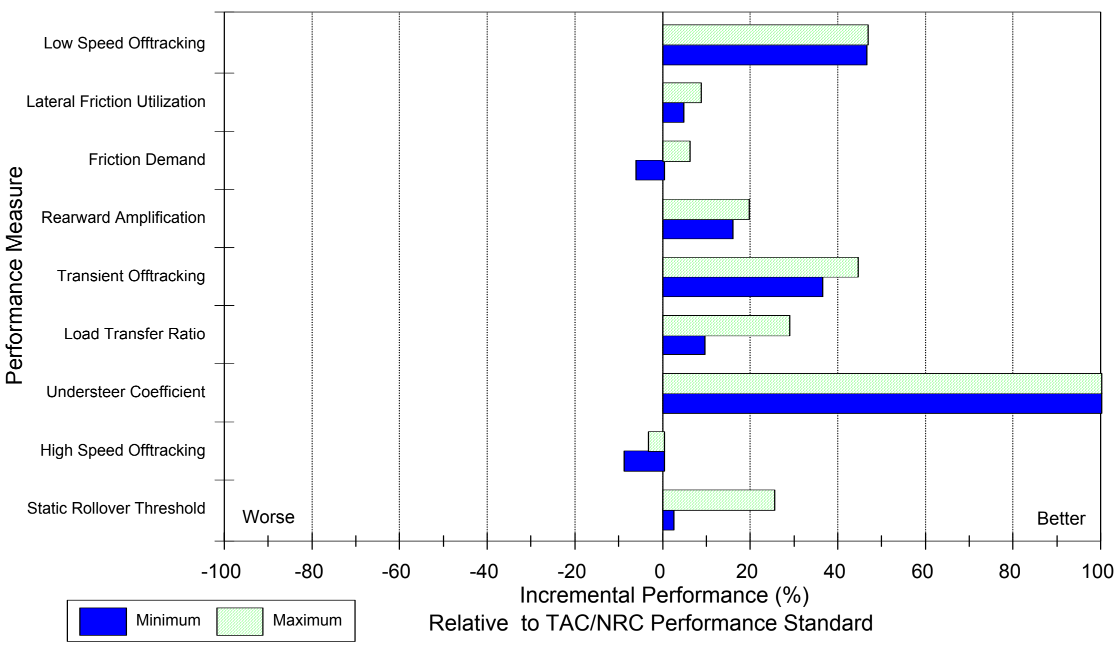


Figure 60. Tridem tractor/tridem pole trailer - BC legal weights (with winter logging truck weight allowances).

h) Tandem tractor/tandem jeep/tandem pole trailer

The tandem tractor/tandem jeep/tandem pole trailer exhibited a decrease in performance relative to the performance standards for two performance measures: high speed offtracking, and static rollover threshold under most loading conditions (Figure 61). These deficiencies will require a thorough investigation and optimization of the configuration parameters in order to meet the performance standards. It is likely that using stiffer tires will improve the high speed offtracking deficiencies. In order to improve the static rollover threshold, the cg height needs to be lowered or the roll resistance of the axles and suspensions increased.

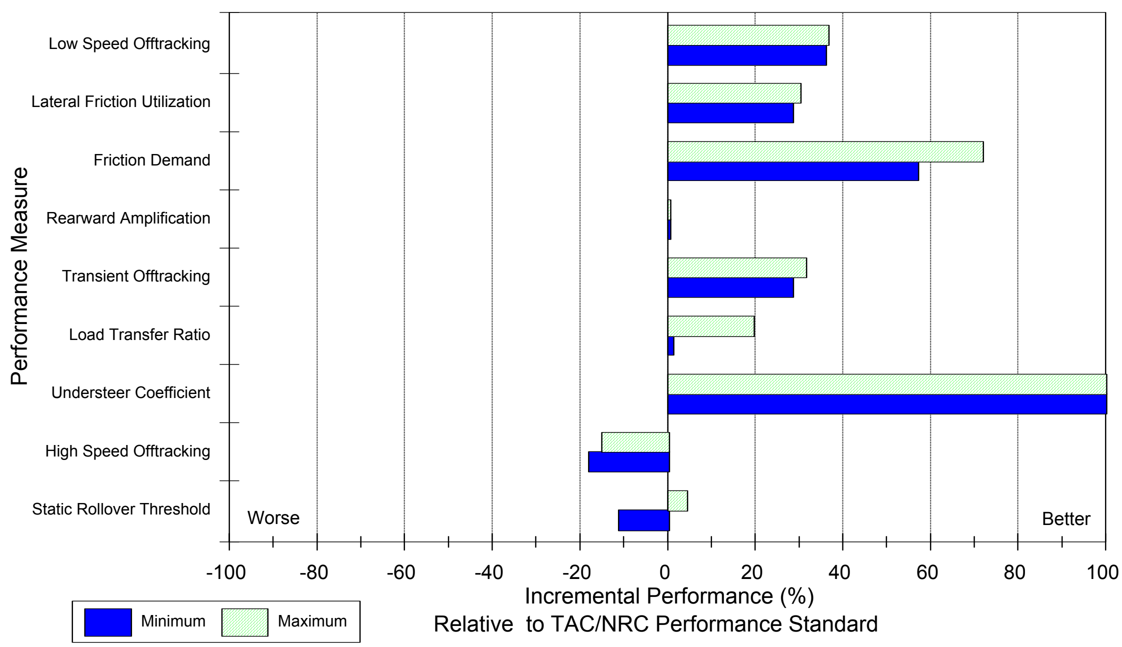


Figure 61. Tandem tractor/tandem jeep/tandem pole trailer - BC legal weights (with winter logging truck weight allowances).

i) Tandem tractor/quadaxle trailer

The tandem tractor/quadaxle trailer exhibited a decrease in performance relative to the performance standards for high speed offtracking under all loading conditions, and the performance standards were not achieved for another two performance measures: static rollover threshold and load transfer ratio at low load densities (Figure 62). The high speed offtracking performance was particularly poor with a performance up to 46% worse than the performance standard. These deficiencies will require a thorough investigation and optimization of the configuration parameters in order to meet the performance standards. However, a large proportion of this configuration's deficiencies should be met by minimizing the hitch offset and using stiffer tires.

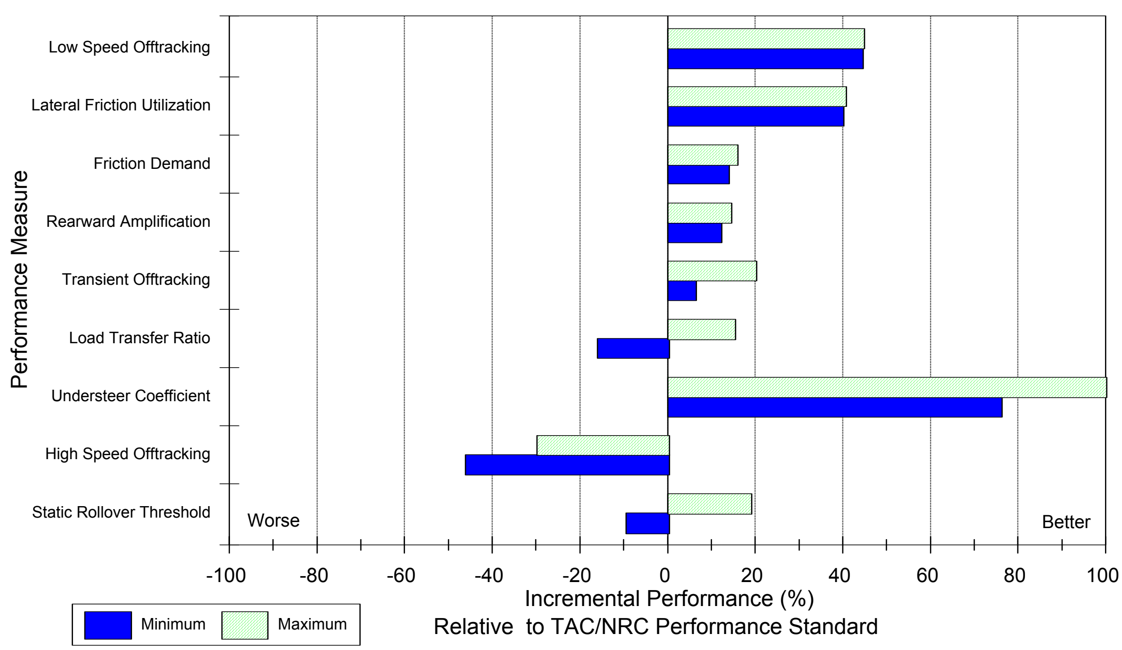


Figure 62. Tandem tractor/quadaxle trailer - BC legal weights (with winter logging truck weight allowances).

j) Double doglogger

The double doglogger exhibited a decrease in performance relative to the performance standards for three performance measures: high speed offtracking, static rollover threshold under most loading conditions, and load transfer ratio at low load densities (Figure 63). These deficiencies will require a thorough investigation and optimization of the configuration parameters in order to meet the performance standards. Possible options for improving this configuration's performance include using stiffer tires, reducing the hitch offset, reducing bunk height, and increasing individual axle and suspension roll stiffness.

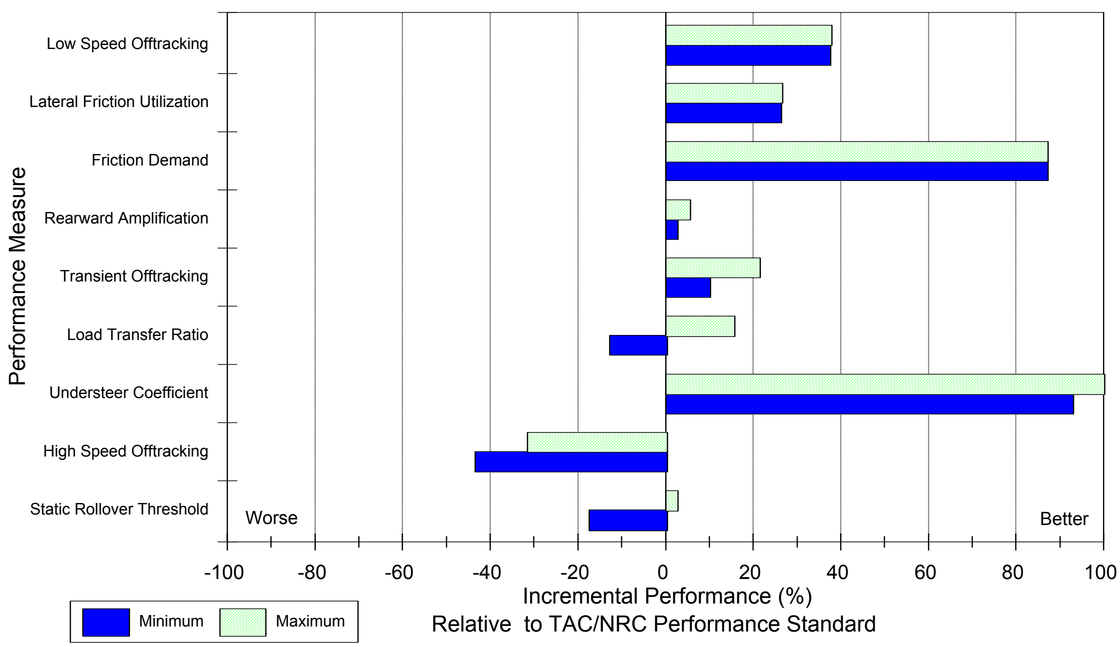


Figure 63. Double doglogger - BC legal weights (with winter logging truck weight allowances).

k) <u>Tandem tractor/jeep/triaxle trailer</u>

The tandem tractor/jeep/triaxle trailer exhibited a decrease in performance relative to the performance standards for three performance measures: high speed offtracking, static rollover threshold under most loading conditions, and load transfer ratio at low load densities (Figure 64). These deficiencies will require a thorough investigation and optimization of the configuration parameters in order to meet the performance standards. Possible options for improving this configuration's performance include using stiffer tires, reducing the hitch offset, reducing bunk height, and increasing individual axle and suspension roll stiffness.

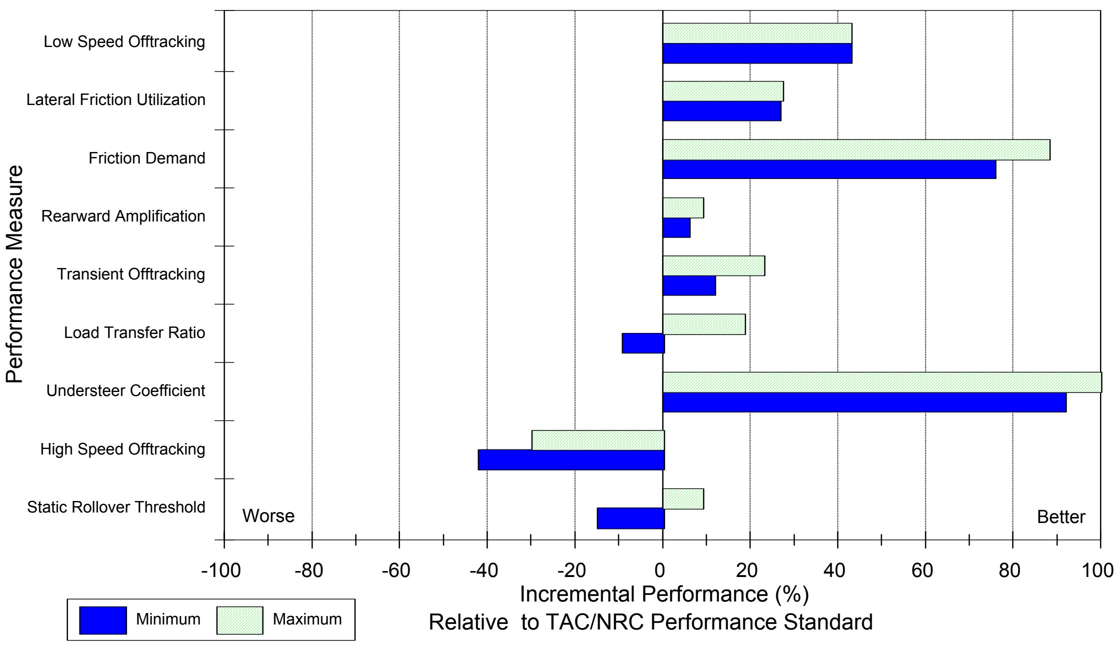


Figure 64. Tandem tractor/jeep/triaxle trailer - BC legal weights (with winter logging truck weight allowances).

8 axle configurations

l) Super B-train

The Super B-train is presented here for comparative purposes. The log-hauling Super B-train when equipped with 11R24.5 tires failed to meet the performance standards for only one performance measure at all load densities (high speed offtracking) (Figure 65). High speed offtracking is up to 35% worse, primarily due to the tire characteristics. All logging configurations with the exception of the tandem tractor/quadaxle trailer, the tandem tractor/jeep/triaxle trailer, and the double doglogger had an overall performance equivalent to, or better than, the TAC Super B-train.

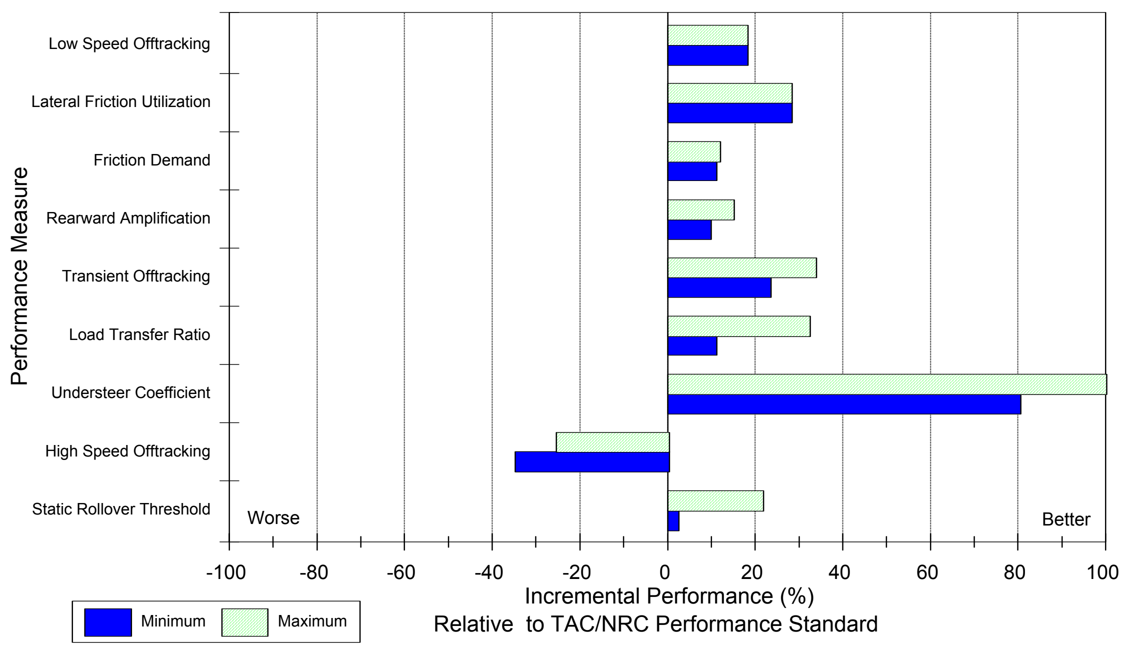


Figure 65. Super B-train - BC legal weights.

(iii) Ranking of Configurations

All of the 6-axle configurations, plus the 5-axle tandem tractor/tandem pole trailer (TA/TAPT), and the 7-axle tridem tractor/tridem pole trailer (TR/TRPT), achieved an equivalent or higher dynamic index than the reference TAC Super B-train (BTRN) (Figure 66). The 5-axle tandem tractor/tandem pole trailer performed the best overall with a dynamic index of 70.5. The best 6-axle and 7-axle configurations overall were the tridem tractor/tandem pole trailer (TR/TAPT) and the tridem tractor/tridem pole trailer (TR/TRPT) respectively. The configuration with the lowest dynamic index was the double doglogger (DDOG) with a value of 57.5. The dynamic index is influenced by payload (Figure 67), as well as the number of articulation points. The high payload capacity configurations tend to have a greater number of articulation points which results in lower dynamic indices, while the configurations with the lowest payload capacities (single articulation configurations) have the highest dynamic indices. All 6-axle configurations with the exception of the tridem tractor/tandem pole trailer have similar payload capacities, but the tandem tractor/jeep/tandem pole trailer (TA/JP/TAPT) has the highest dynamic index of these other configurations. Likewise, with the exception of tridem tractor/tridem pole trailer, the tandem tractor/tandem jeep/tandem pole trailer (TA/TJP/TAPT) exhibited the highest overall dynamic performance of the 7-axle configurations with a similar payload capacity. The tridem tractor/tridem pole trailer showed an improvement in overall performance relative to the tandem tractor/tridem pole trailer (TA/TRPT) at an increase in payload of approximately 4 500 kg. However, for the same increase in payload, the tridem tractor/tandem pole trailer showed a slight reduction in overall dynamic performance relative to the tandem tractor/tandem pole trailer.

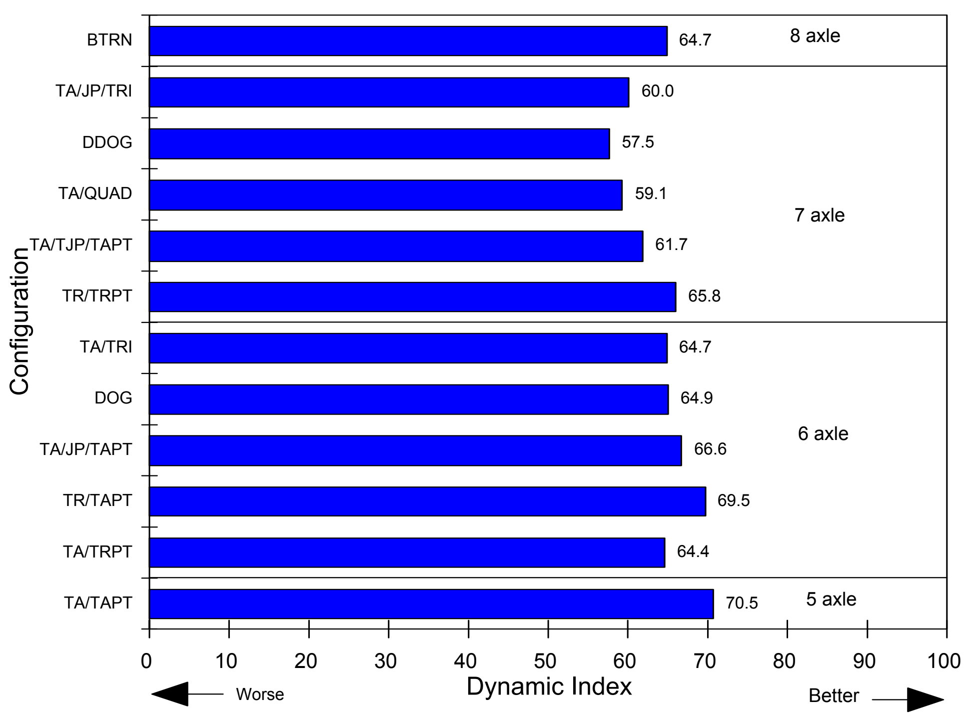


Figure 66. Dynamic indices - BC legal weights (with winter logging truck weight allowances).

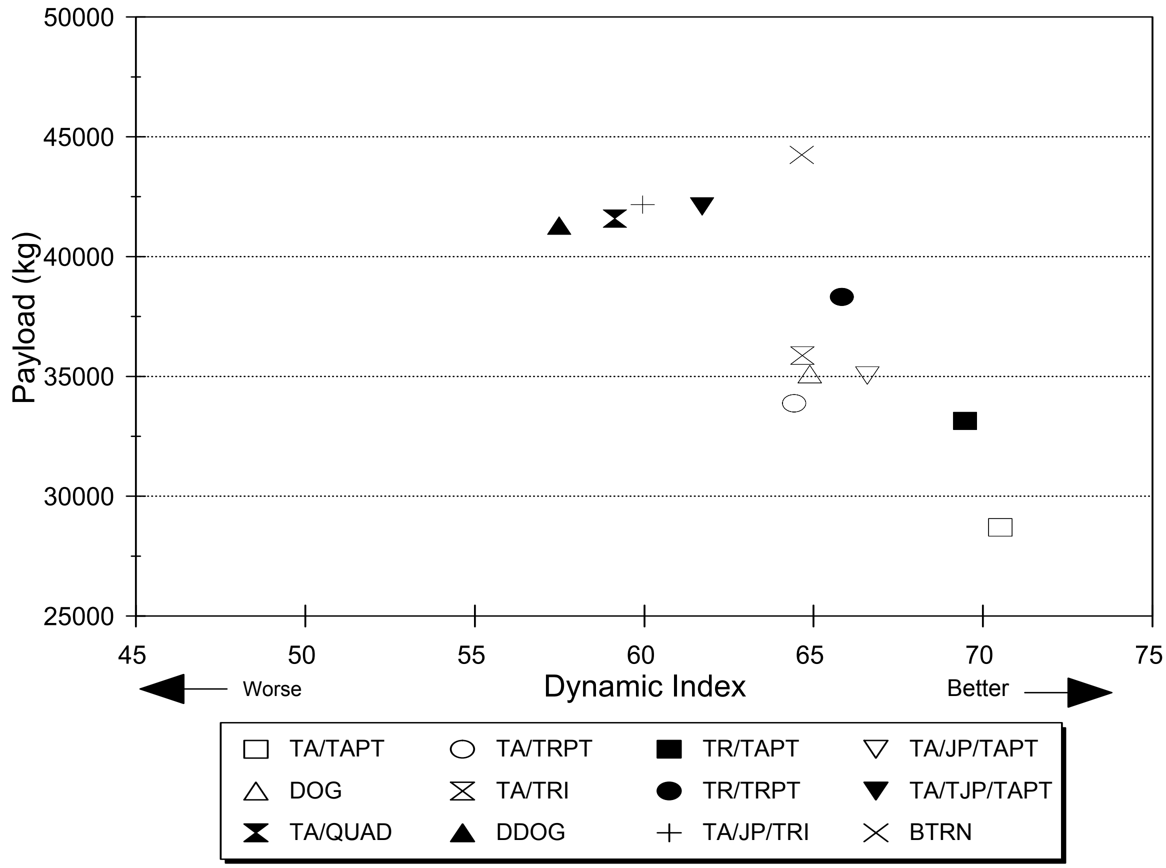


Figure 67. Overall performance - BC legal weights (with winter logging truck weight allowances).

V. Model Application to Explore Configuration Improvement Options

The dynamic performance of the existing fleet was determined by using the simulation models developed in this study. Should the results of this study prompt consideration for regulatory change, these models can be used to test various dynamic performance improvement options for some existing configurations. For example, this section presents an example of various options which could be implemented to improve the dynamic performance of the tandem tractor/tandem jeep/tandem pole trailer. This configuration was selected primarily due to its payload potential and popularity, but also due to its lower overall dynamic performance relative to most configurations, particularly under Alberta loading conditions.

1. Sensitivity Analysis

A sensitivity analysis (Table 2) showed that the variation of eight selected configuration parameters has a significant impact on the nine performance measure results. Of most interest was the effect of the configuration parameters on the following five performance measures: static rollover threshold, load transfer ratio, rearward amplification, high speed offtracking, and transient offtracking. These measures account for 75% of the dynamic index in its definition and are difficult for the configuration to meet. The baseline configuration failed to meet the performance standards, under at least a portion of the range of parameter variation, for all five of these performance measures. The baseline configuration had no difficulty meeting or exceeding the performance standards, over the full range of parameter variation for the remaining four performance measures: understeer coefficient, friction demand, lateral friction utilization, and low speed offtracking.

Of the five performance measures of particular interest, rearward amplification has the greatest sensitivity to parameter variation. A decrease in inter-group spacing by 20%, and an increase in the load bias forward by 20% resulted in increases in rearward amplification of 42.1% and 46.7%, respectively. Conversely, rearward amplification is minimized, and therefore performance is improved, by a longer inter-group spacing, a reduction in the load bias forward, a reduction in hitch offset, increased tire stiffness, increased jeep and trailer track widths, and a reduction in payload. Variation of the rear bunk width both above and below the baseline level results in an increase in rearward amplification, which suggests that the baseline bunk width is optimum.

Static rollover threshold is most influenced by payload, with the static rollover threshold increasing by 20.2% for a 20% reduction in the payload, as the cg height is reduced. Static rollover threshold is maximized, and therefore improved, at increased inter-group spacing, a decrease in load bias forward, an increase in rear bunk width, increased tire stiffness, increased jeep and trailer track widths, and a reduction in payload. Hitch offset has no effect on this performance measure.

Load transfer ratio is most influenced by payload and inter-group spacing, with the load transfer ratio increasing by 22.6% and 13.5% for a 20% increase in payload and a 20% reduction in the inter-group spacing, respectively. Load transfer ratio is minimized, and therefore improved by increased inter-group spacing, a decrease in load bias forward, a decrease in hitch offset, an increase in rear bunk width, increased tire stiffness, an increase in jeep and trailer track widths, and a reduction in payload.

Table 2. Sensitivity of Performance Measures To Various Configuration Parameters For A Tandem Tractor/Tandem Jeep/Tandem Pole Trailer Under Alberta Winter (green route) Loading Conditions

Performance Measure	Performance Measure Prior to Variation	Parameter Variation (%)	Change in Performance Measure Result Relative to Baseline (%)							
			Inter-group Spacing	Load Bias Forward	Hitch Offset	Rear Bunk Width	Tire Stiffness	Jeep Axle Track Width	Trailer Axle Track Width	Payload
Low Speed Offtracking	3.93	+ 20 - 20	+ 8.7 - 8.4	+ 2.3 - 4.1	- 3.8 + 3.6	0.0 0.0	+ 1.3 - 3.0	- 0.2 - 0.2	0.0 - 0.1	- 0.7 - 1.6
Lateral Friction Utilization	0.61	+ 20 - 20	+ 0.2 + 0.2	+ 9.9 - 4.3	- 0.2 - 0.3	0.0 - 0.2	+ 13.3 - 1.2	0.0 0.0	0.0 0.0	+ 12.4 - 5.8
Friction Demand	0.04	+ 20 - 20	+ 20.0 - 20.0	+ 22.9 - 34.3	- 11.4 + 25.7	+ 8.6 - 5.7	+ 14.3 - 11.4	+ 5.7 - 2.8	+ 5.7 - 8.6	+ 17.1 + 11.4
Rearward Amplification	2.51*	+ 20 - 20	- 10.8* + 42.1*	+ 46.7* - 8.2*	+ 1.8* - 6.0*	+ 1.0* + 5.3*	- 16.5 + 32.0*	- 3.4* + 5.1*	- 2.6* - 2.3*	+ 4.1* - 11.7*
Transient Offtracking	0.72	+ 20 - 20	- 9.5 + 14.6*	+ 26.5* - 15.6	+ 1.2 - 1.4	+ 2.6 + 13.3*	- 32.7 + 55.4*	- 4.4 + 5.8	- 3.4 + 3.0	+ 17.3* - 25.1
Load Transfer Ratio	0.61*	+ 20 - 20	- 9.5 + 13.5*	- 4.1 + 3.6*	+ 2.4* - 2.4	- 0.8* + 10.1*	- 7.0 + 7.0*	- 7.6 + 11.1*	- 7.3 + 10.9*	+ 22.6* - 19.7
Understeer Coefficient	1.33	+ 20 - 20	- 13.3 - 10.0	- 115.6 + 24.3	+ 2.1 + 3.0	- 13.8 - 54.8	+ 81.4 - 55.6	+ 12.2 - 58.9	+ 4.3 - 62.1	- 39.4 + 84.1
High Speed Offtracking	0.60*	+ 20 - 20	+ 4.3* - 3.7*	+ 0.3* - 3.3*	+ 0.8* - 1.0*	- 0.3* + 1.7*	- 21.4* + 36.5*	- 2.8* + 3.3*	- 4.1* + 2.8*	+ 13.1* - 14.6*
Static Rollover Threshold	0.31*	+ 20 - 20	+ 1.3* - 0.6*	- 3.5* + 5.8*	0.0* 0.0*	+ 1.6* - 4.8*	+ 3.2* - 1.9*	+ 8.3* - 8.0*	+ 6.7* - 6.7*	- 17.9* + 20.2

Asterisk (*) indicates performance standard not met

High speed offtracking is most influenced by tire stiffness and payload with high speed offtracking increasing by 36.5% and 13.1% for a 20% decrease in tire stiffness and 20% increase in payload respectively. High speed offtracking is minimized, and therefore improved by decreased inter-group spacing, a decrease in load bias forward, a decrease in hitch offset, an increase in rear bunk width, increased tire stiffness, increased jeep and trailer track widths, and a decreased payload.

The eight configuration parameters have a significant influence on transient offtracking, with the tire stiffness having the greatest impact (55.4% increase in transient offtracking for a 20% decrease in tire stiffness). Transient offtracking is minimized, and therefore improved, by increased inter-group spacing, a decrease in load bias forward, a decrease in hitch offset, increased tire stiffness, increased jeep and trailer track widths, and a decrease in payload. As for rearward amplification, variation of the rear bunk width both above and below the baseline level results in a degradation in performance, which suggests that the baseline bunk width is an optimum for this configuration and loading conditions.

The performance standards of the remaining four performance measures were easily met for all conditions investigated in the sensitivity analysis. Among the remaining performance measures, understeer coefficient is very sensitive to variations in the configuration parameters, but the configuration meets this performance standard for all conditions investigated, since the baseline configuration exceeds the performance standard by such a great margin. This also applies to friction demand and low speed offtracking. Lateral friction utilization is most affected by variations in load and tire characteristics.

Based on the results of this analysis, the overall performance of the tandem tractor/tandem jeep/tandem pole trailer will be optimized at increased inter-group spacing, decreased forward load bias (i.e., a decreased load on the jeep bunk and increased load on the trailer bunk), decreased hitch offset, increased rear bunk width, increased tire stiffness, increased jeep and trailer track widths, and decreased payload. However, the goal is to maintain as high a payload as possible, so payload should only be reduced as a last resort, where the other measures are unable to achieve the performance standards. It also may not be practical to increase the trailer track width beyond what is presently used, as the performance standard will have to be adjusted to maintain the high speed offtracking tolerance between the tires and lane edge, and the provinces have strict limits on overall vehicle width.

2. Optimization and Evaluation

Based on the sensitivity analysis, four possible versions of configurations incorporating a tandem jeep are presented as examples illustrating a combination of feasible changes rather than the arbitrary changes of the preceding section, which could be made to the tandem tractor/tandem jeep/tandem pole trailer, while retaining reasonable productivity. These versions include an optimized tandem tractor/tandem jeep/tandem pole trailer with butts forward load orientation, an optimized tandem tractor/tandem jeep/tandem pole trailer with mixed butts and tops, an optimized tandem tractor/tandem jeep/tridem pole trailer with butts forward load orientation, and an optimized tandem tractor/tandem jeep/tridem pole trailer with mixed butts and tops. The tridem pole trailer is incorporated into this optimization process to increase roll stability and payload simultaneously. The versions presented here should not be interpreted as the definitive solution but rather as examples of how the models developed in this study can be applied to improve configuration performance. The stakeholders will need to collectively determine the optimization parameters, a priority list of configurations to optimize, and the optimization criteria[10]. The examples presented in this section provide a framework for this process.

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[10] In the example presented in this section, the optimization criteria requires the performance standards must be met at all load densities for all performance measures.

A. Alberta Legal Weights

The configuration parameters were optimized (see Appendix V-a) by increasing the inter-group spacing (rear jeep axle to forward trailer axle) from 5.2 m to 5.5 m for the tandem pole trailer and from 5.2 to 6.0 m for the tridem pole trailer versions respectively, by decreasing the hitch offset from 1.86 m to 1.60 m, increasing the jeep axle width from 2.59 m to 3.05[11] m, and by changing the tires from 11R24.5 to 295/75R22.5 (low profile tires) for both tandem and tridem pole trailer configurations.

For the alternative configuration with a tridem trailer, the payload was increased relative to the baseline configuration, since the increased tridem group load capacity, allows a maximum GCW of 62 500 kg to be achieved. The load was moved rearward to obtain the appropriate axle loads and to reduce the proportion of the load on the forward bunk. The rear bunk width was increased from 2.31 m to 3.05 m for the mixed orientation loads. The trailer axle width was maintained at 2.59 m, since increasing the axle width at this location would require an increase in the high speed offtracking performance standard to maintain the tolerance between the outside tire and the edge of the lane. The inter-group spacing was minimized, and hitch offset was maximized as much as possible to minimize the low speed offtracking and maintain bush road manoeuvreability. The inter-group spacing is greater for the tridem pole trailer configuration relative to the tandem pole trailer configuration to ensure acceptable tight turning performance (as defined by LFU and FD). The use of 295/75R22.5 tires lowered the cg height by 3 cm and increased the cornering and vertical tire stiffness, which had a significant impact on the high speed offtracking performance.

All four optimizations resulted in a significant increase in the dynamic index relative to the baseline (Figure 68), as all performance measures were met at all load densities. The tridem pole trailer configuration allowed for an increase in payload of 4 000 kg. The tandem pole trailer's dynamic index increased from 57.3 to 67.1 and 69.4 as a result of optimization for the butts forward and mixed orientation loads respectively. The use of the tridem pole trailer with the tandem jeep resulted in dynamic index values of 66.5 and 68.7 for the butts forward and mixed orientation loads, respectively. The optimized tandem pole trailer configuration with a mixed load orientation achieved a slightly higher dynamic index than the optimized tridem pole trailer configuration loaded in the mixed orientation, but with decreased payload. Both configurations when loaded with butts ahead orientation exhibited lower dynamic indices relative to the configurations loaded in the mixed orientation, primarily because of a higher cg height resulting from a narrower rear bunk width. The increased payload capacity of the tridem pole trailer configuration relative to the optimized tandem pole trailer results primarily from the improved roll resistance of the additional axle.

[11] In Alberta the regulations allow for a maximum vehicle width of 3.2 m.

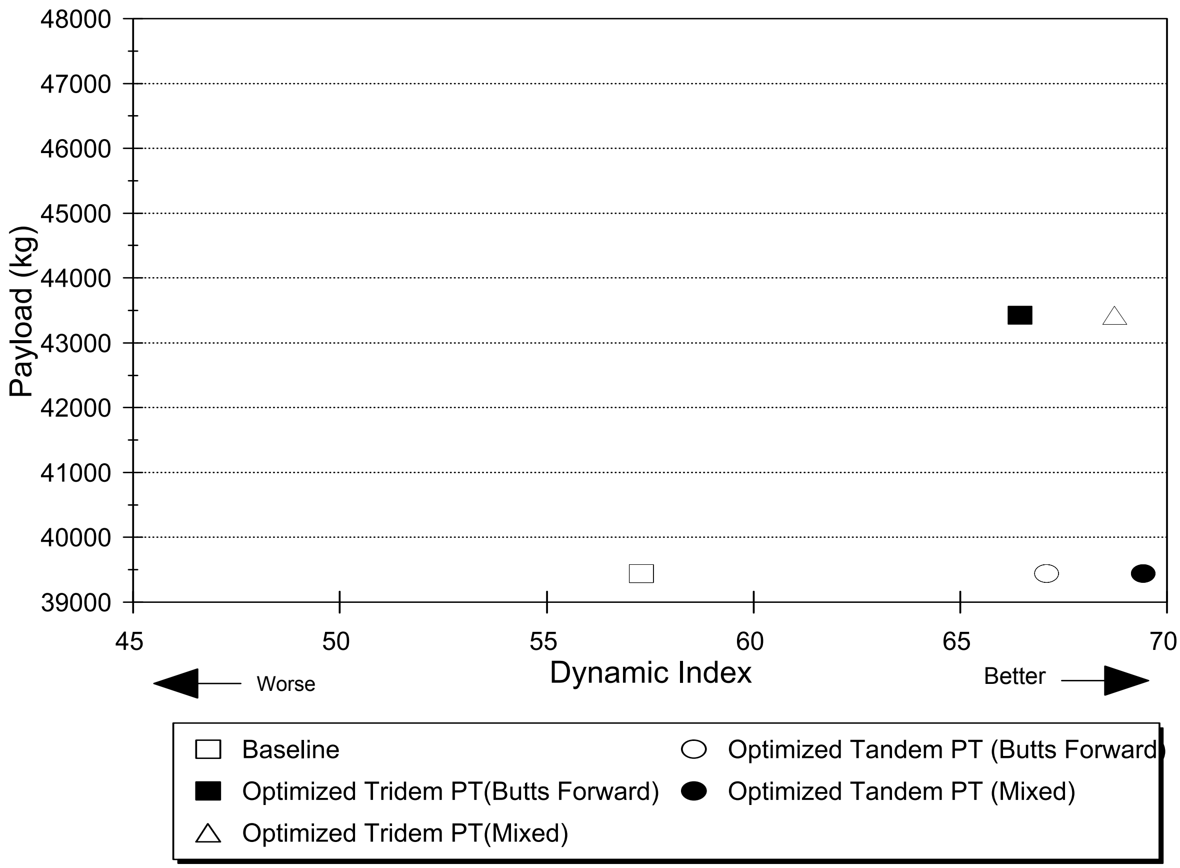

Figure 68. Overall performance tandem jeep configurations - Alberta legal weights.

B. Alberta Winter Weights

The four optimization options were explored for Alberta winter green route loads (see Appendix V-b). The configuration parameters were optimized by increasing the inter-group spacing (rear jeep axle to forward trailer axle) from 5.2 m to 5.5 m, decreasing the hitch offset from 1.86 m to 1.60 m, increasing the jeep axle width from 2.59 m to 3.05[12] m, changing the tires from 11R24.5 to 295/75R22.5, and distributing the load to blue route load regulations with the maximum tandem group not exceeding 20 000 kg, for both tandem and tridem pole trailer. The gross combination weight (GCW) was reduced for the tandem pole trailer configuration from 65 000 kg to 61 500 kg and 64 000 kg when loaded with butts forward orientation and mixed orientation, respectively, so that all the performance measures could be met at all load densities. All performance measures were met at all load densities for the tridem pole trailer configuration for both loading scenarios when the GCW was maintained at the maximum of 65 000 kg. However, the payload was reduced by 1 700 kg relative to the baseline configuration because of the increased tare weight of this configuration.

[12] In Alberta the regulations allow for a maximum vehicle width of 3.2 m.

All four optimizations resulted in improved dynamic performance relative to the baseline (Figure 69). The tandem pole trailer's dynamic index increased from 47.4 to 64.2 and 61.6 as a result of optimization for the butts forward and mixed orientation loads respectively. The use of the tridem pole trailer with the tandem jeep resulted in dynamic index values of 64.0 and 64.1 for the butts forward and mixed orientation loads, respectively. The performance standards were met for all performance measures at all load densities for optimized configurations (Appendix VII). The additional axle of the tridem trailer configuration enabled this configuration to increase its payload capacity relative to the optimized tandem pole trailer configuration, while maintaining the same overall dynamic performance. The increased productivity of this configuration shows good potential to reduce overall hauling costs and should be explored further.

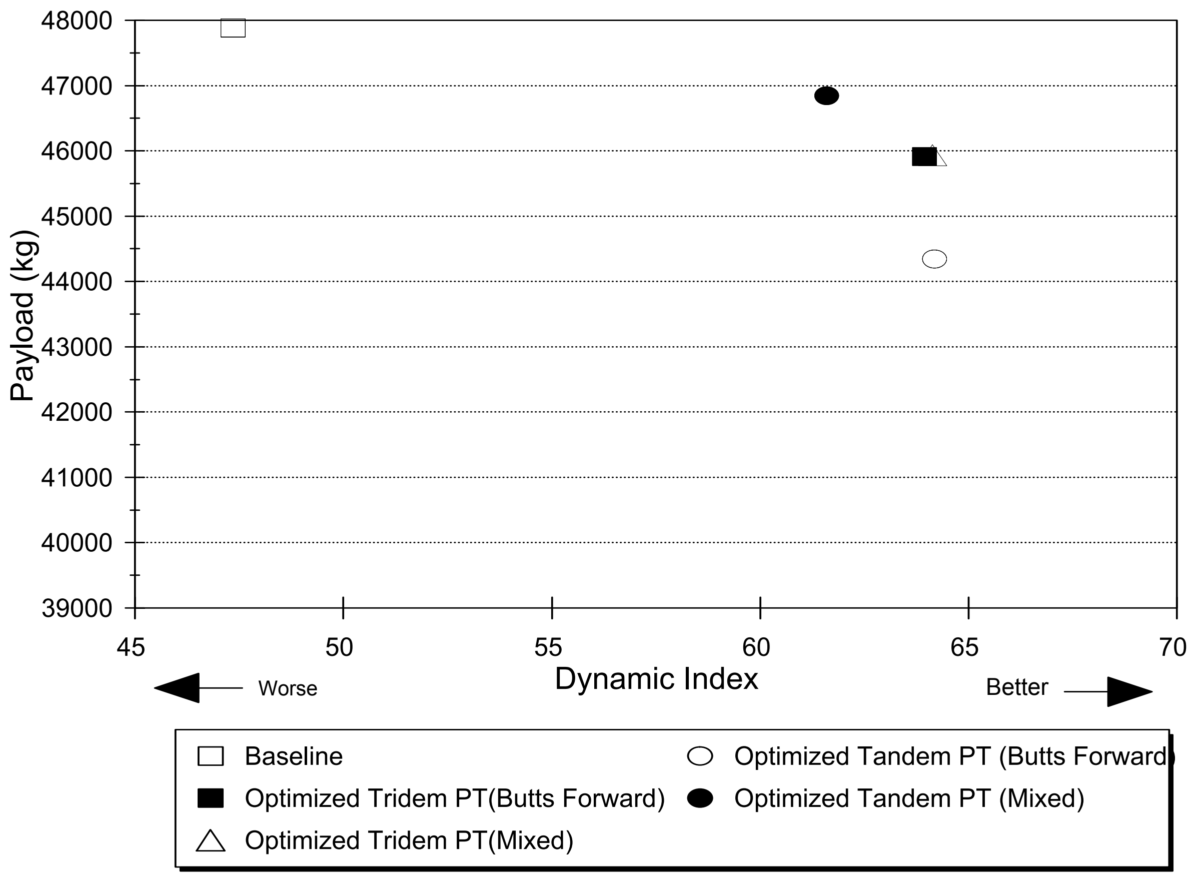

Figure 69. Overall performance tandem jeep configurations - Alberta winter weights.

C. British Columbia Legal Weights (including winter logging truck weight allowances)

Only the two optimization options with mixed load orientation were explored for BC loads since this is the predominant loading method employed in BC (see Appendix V-c). The configuration parameters were optimized by increasing the inter-group spacing (rear jeep axle to forward trailer axle) from 5.17 m to 5.5 m, decreasing the hitch offset from 1.86 m to 1.60 m, and changing the tires from 11R24.5 to 295/75R22.5 for both tandem and tridem pole trailer configurations. The jeep and trailer axle widths, and bunk widths were maintained at 2.59 m, which is the maximum vehicle width in BC. The payload capacity was reduced by approximately 2 500 kg for the tandem pole trailer configuration so that the performance standard could be achieved at all load densities. The use of the tridem pole trailer allowed the payload to be maintained while meeting all the performance standards at all load densities. Similar to the case for the Alberta optimizations, the inter-group spacing was minimized and hitch offset was maximized to minimize the low speed offtracking as much as possible and maintain bush road manoeuvreability. The closer tridem group spread allowed in BC made it unnecessary to increase the inter-group spacing for the tridem pole trailer configuration to ensure acceptable tight turning performance.

The optimization resulted in improvements in dynamic performance for both configurations relative to the unoptimized baseline configuration (Figure 70). The tandem pole trailer's dynamic index increased from 55.6 to 66.6 as a result of optimization. The use of the tridem pole trailer resulted in a lower dynamic index of 64.6, but an increased payload of approximately 2 500 kg relative to the optimized tandem pole trailer configuration. All the performance standards were met at all load densities (Appendix VII) for both configurations, with the static rollover threshold being the governing performance measure.

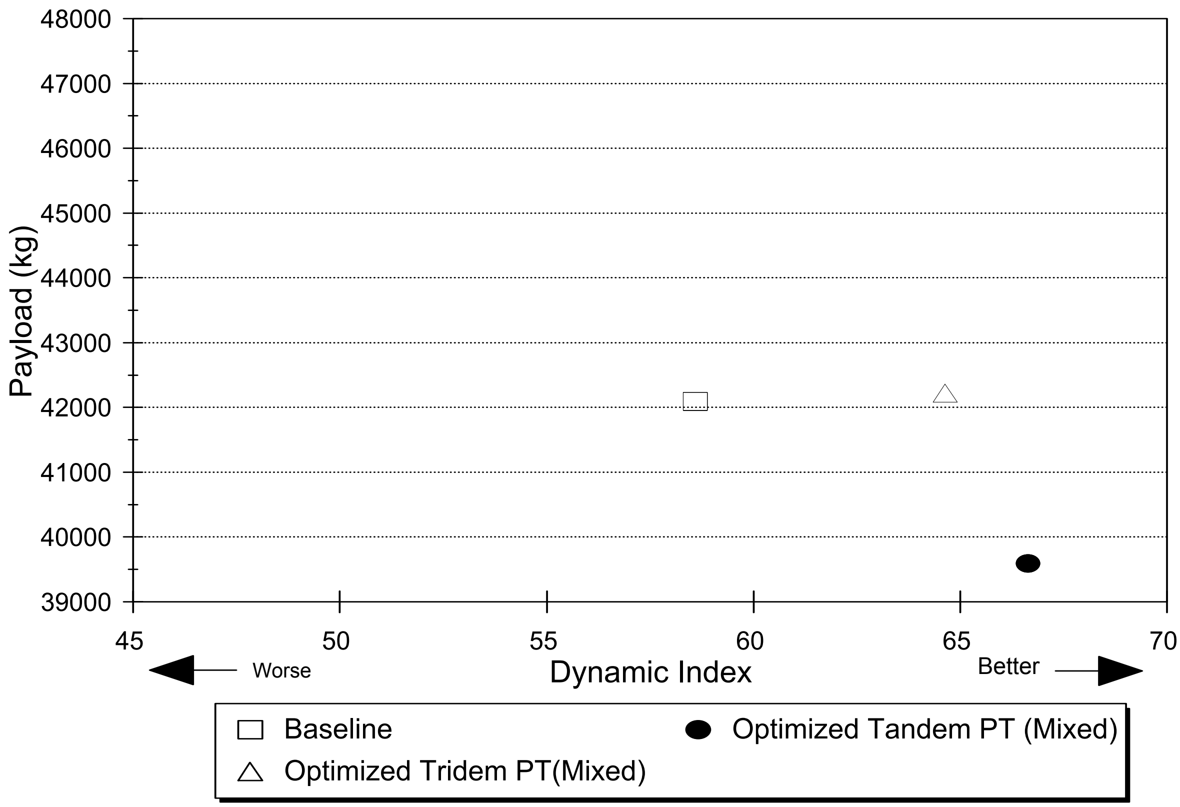

Figure 70. Overall Performance Tandem Jeep Configurations - British Columbia Legal Weights (with Winter logging truck weight allowances)

CONCLUSIONS

General

- A survey of the forest industry in Alberta and British Columbia was undertaken to determine future trends in log hauling practices. The trend is to increase the number of axles on logging configurations in an effort to maximize payload. There is also an increase in the proportion of dedicated shortlog configurations.

- A series of dynamic and static tests were conducted on a tandem tractor/tandem pole trailer and a tandem tractor/jeep/tandem pole trailer to provide reference data for computer simulation models designed to evaluate the dynamic behavior of log trucks.

- A yaw/roll computer simulation model was developed by the National Research Council and the University of Victoria to analyse the dynamic responses of western Canadian log truck configurations under different manoeuvres. The results obtained from this model were in good agreement with the field tests.

- Through the steering committee process a set of nine performance measures were identified with which to assess these specific log truck configurations. Eight of these measures come from the TAC weights and dimensions study and the ninth is NRC's lateral friction utilization performance measure. These nine measures were weighted according to their relative importance for these configurations and a relative ranking of configurations within the fleet was established.

- A survey of logging trailer manufacturers was undertaken to gather information on state-of-the-art designs and to gain insights on equipment improvement possibilities.

- Seven configurations were studied under two different regulatory weight and dimension regimes for Alberta (legal weghts, and winter (green route) weights), and 11 were studied under BC legal weights (including winter logging truck weight allowances).

- Of the nine performance measures examined in this study, the logging configurations had the greatest difficulty meeting the performance standard for high speed offtracking. This deficiency results primarily from the lower cornering stiffness of the 11R24.5 tires commonly used on these configurations. This deficiency can be safely tolerated with the following exceptions: doglogger, tandem tractor/tandem jeep/tandem pole trailer, and tandem tractor/jeep/tandem pole trailer under Alberta winter weights, and the double doglogger, tandem tractor/quadaxle trailer, and tandem tractor/jeep/triaxle trailer under BC legal weights (with winter logging truck weight allowances).

- Configurations with tridem pole trailers had difficulty meeting the friction demand performance standard. The tridem tractor/tridem pole trailer showed an improvement over the tandem tractor/tridem pole trailer for this performance measure. For BC loads, friction demand performance was further improved relative to Alberta loads primarily due to the shorter tridem spreads allowed in BC.

- Overall dynamic performance is strongly influenced by payload and number of articulation points, with configurations carrying less payload and with less articulation points tending to exhibit improved performance.

Alberta Legal Weights

- All configurations under all loading conditions examined met the performance standard for low speed offtracking, understeer coefficient, transient offtracking, load transfer ratio, and lateral friction utilization.

- Only the single articulated configurations met the performance standard for high speed offtracking.

- Only the tandem tractor/tandem jeep/tandem pole trailer failed to meet the performance standard for static rollover threshold and rearward amplification.

- Based on the dynamic index developed in this report, the best configuration in terms of overall dynamic performance was the tridem tractor/tandem pole trailer. The tandem tractor/tandem jeep/tandem pole trailer had the lowest overall performance, but still performed better than the reference TAC Super B-train, when loaded to Alberta legal weights.

- The use of tridem tractors with pole trailers resulted in an improvement in overall dynamic performance relative to tandem tractors, while increasing payload capacity.

Alberta Winter Weights (green route)

- All configurations under all loading conditions examined met the performance standard for low speed offtracking and understeer coefficient.

- None of the configurations met the performance standard for high speed offtracking.

- Lateral friction utilization is marginal only for tridem tractor configurations.

- Transient offtracking performance is a concern only for the doglogger and tandem tractor/tandem jeep/tandem pole trailer, when loaded with the lowest density logs.

- All configurations with the exception of the tridem tractor/tridem pole trailer have difficulty meeting the performance standard for static rollover threshold and load transfer ratio.

- The tandem tractor/tandem jeep/tandem pole trailer and the tandem tractor/tandem pole trailer failed to meet the performance standard for rearward amplification under most loading conditions. This is due to the extreme forward load bias for these configurations.

- Based on the dynamic index developed in this report, all configurations except for the tridem tractor/tridem pole trailer showed a reduction in overall dynamic performance relative to the legally loaded TAC Super B-Train. The tandem tractor/tandem jeep/tandem pole trailer had the lowest overall performance under this weight regime.

- The use of tridem tractors with pole trailers resulted in an improvement in overall dynamic performance relative to tandem tractors, at the same payload level for the tridem pole trailer and at a reduction in payload of 2 000 kg for the tandem pole trailer.

British Columbia Legal Weights (with winter logging truck weight allowances)

- All configurations under all of the loading conditions examined met the performance standard for low speed offtracking, understeer coefficient, transient offtracking, and lateral friction utilization.

- Only the tandem tractor/tandem pole trailer loaded with high density logs met the performance standard for high speed offtracking.

- The tandem tractor/tandem jeep/tandem pole trailer did not meet the performance standard for rearward amplification.

- The tandem tractor/quadaxle trailer, double doglogger, and tandem tractor/jeep/triaxle trailer were unable to meet the performance standard for load transfer ratio and static rollover threshold, when loaded with low density logs. In addition, the tandem tractor/triaxle trailer and tandem tractor/tandem jeep/tandem pole trailer were unable to meet the performance standard at low load densities for load transfer ratio and static rollover threshold, respectively.

- Based on the dynamic index developed in this report, all logging configurations, except for the tandem tractor/quadaxle trailer, double doglogger, tandem tractor/tandem jeep/tandem pole trailer, and tandem tractor/jeep/triaxle trailer, had an overall performance equivalent to or better than the legally loaded TAC Super B-Train. The best overall performance was achieved by the tandem tractor/tandem pole trailer and the worst by the double doglogger.

- The use of tridem tractors instead of tandem tractors improved overall dynamic performance for tridem pole trailers, but slightly decreased performance for tandem pole trailers, while increasing payload capacity by approximately 4 500 kg.

Configuration Improvement Options

- An example was explored to give the reader insight as to how the model could be applied to optimize existing configurations while maintaining acceptable productivity. Considering the results of a sensitivity analysis on the example configuration (tandem tractor/tandem jeep/tandem pole trailer), overall dynamic performance was optimized with increased inter-group spacing, decreased forward load bias, increased bunk width, increased tire stiffness, increased axle width, and decreased payload.

- It was found that, when the tandem pole trailer was replaced with a tridem pole trailer in the example configuration, significant improvements in dynamic performance resulted relative to the unoptimized baseline configuration. This optimized configuration (tandem tractor/tandem jeep/tridem pole trailer) allowed for an increase in payload capacity relative to the unoptimized tandem tractor/tandem jeep/tandem pole trailer, while meeting the performance standard at all load densities for Alberta legal weights. Under BC legal weights (with winter logging truck weight allowances), the payload was essentially maintained, while under Alberta winter loading conditions, it was necessary to reduce payload to meet the performance standard at all load densities.

- In order to meet the high speed offtracking performance standard, it was necessary to utilize stiffer low profile tires. Changing to stiffer tires that still have the off-road properties of 11R24.5 tires would be beneficial if such tires are available.

RECOMMENDATIONS

- Workshops should be held throughout Alberta and BC to disseminate the study results.

- Tires available with the stiffness characteristics of a 295/75R22.5 tire, and the off road attributes of an 11R24.5 tire should be investigated. If an acceptable tire can be sourced, its use should be encouraged.

- Within each province a task force should be established to address issues associated with the configurations that exhibit marginal performance and with the development of new or modified configurations. Using the tandem tractor/tandem jeep/tandem pole trailer example presented in this report to guide the optimization process, each task force will need to establish feasible optimization parameters, a priority list of configurations to investigate, and the optimization criteria.

- Significant differences exist between the provinces of Alberta and British Columbia in terms of the weight and dimension regulations that govern the operation of log trucks. Therefore, any action taken as a result of this study should be done in consultation with all the stakeholders of each respective province.

- Simulations of the log-hauling configurations not examined in this study (i.e. including short log configurations) should be done, using the same methodology used in this study, thereby allowing more informed decisions regarding the overall use of log-hauling configurations to be made.

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Appendix I - Project Steering Committee Members

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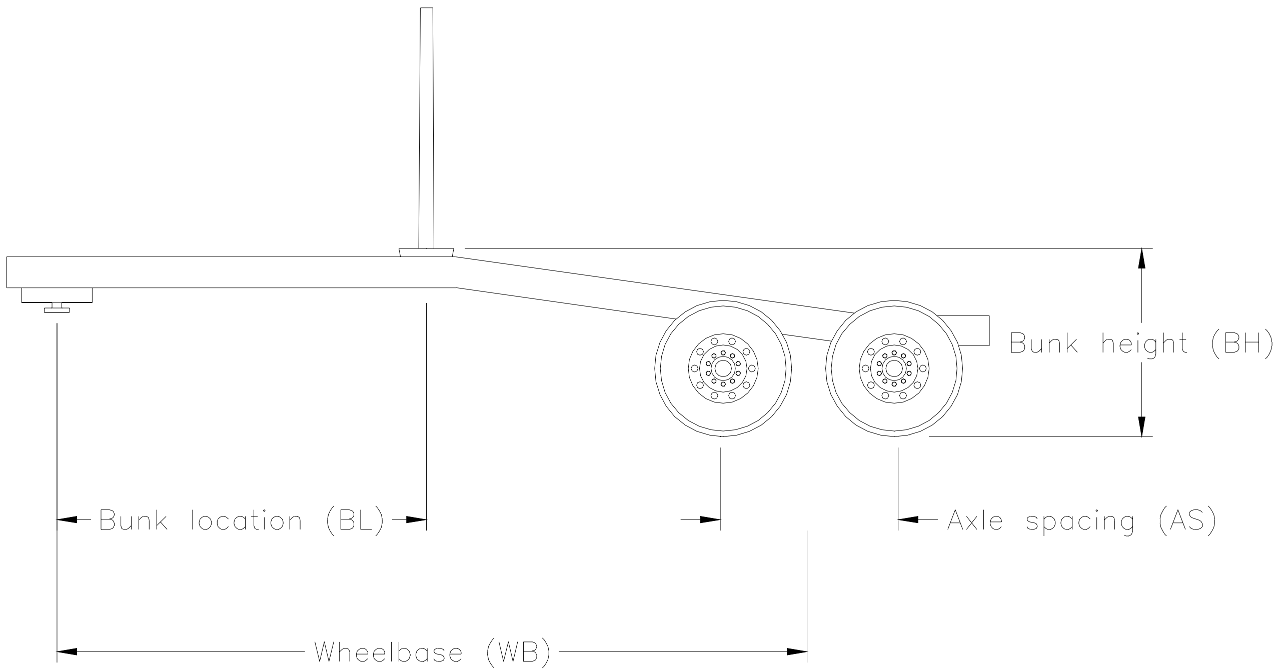
Ministry of Transportation
Government of Ontario
Downsview, Ontario

Appendix II - Trailer Specifications from Manufacturer Survey

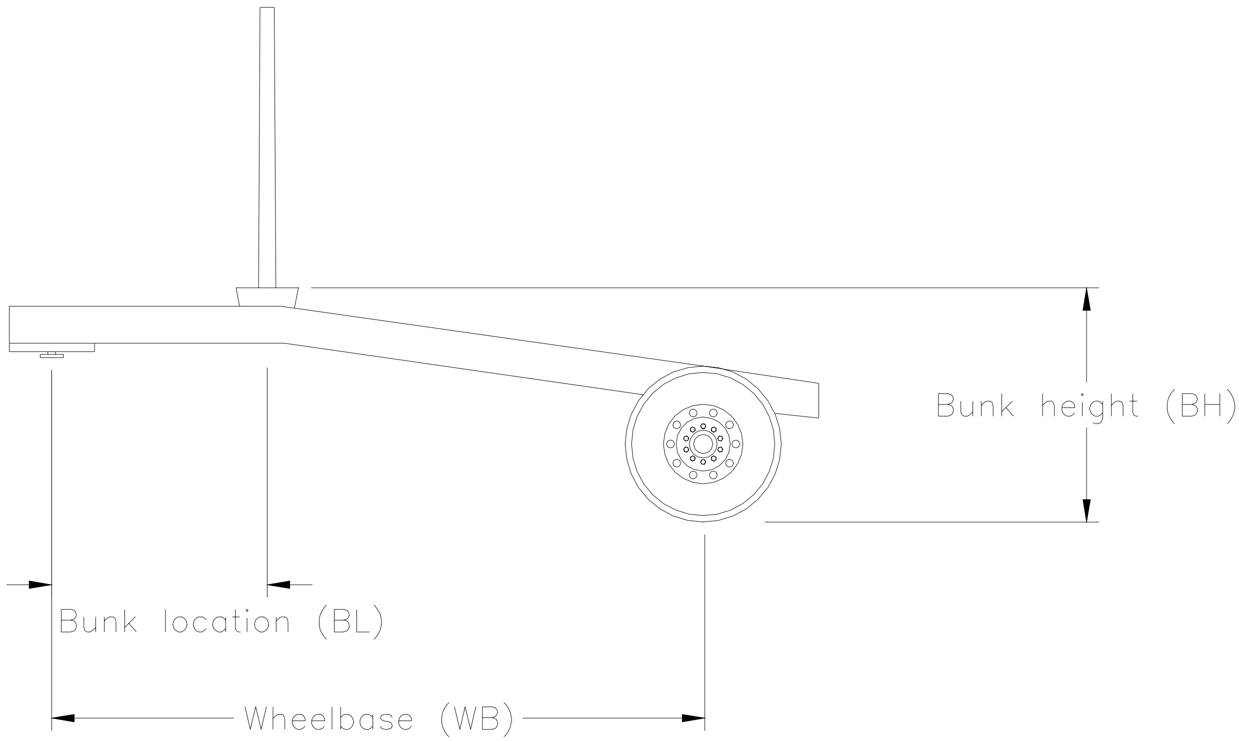
Tandem Axle Jeep



Manufacturer	Tare	WB	BL	BH (m)*		AS	Suspension		Track
	(kg)	(m)	(m)	Std	LP	(m)	Type	Width (m)	Width (m)
Anser Industries Inc.	4600	6.8	3.40	1.60	1.52	1.37	Walking beam	1.07	2.59
Peerless Ltd.	5000	6.9	3.30	1.73	1.62	1.37	Walking beam or air	1.12	2.59
Arctic Manufacturing Ltd.	5330	6.9	3.62	1.60	1.52	1.24	Spring walking beam	1.12	2.59

* Bunk height
Std = standard bunk
LP = low profile bunk

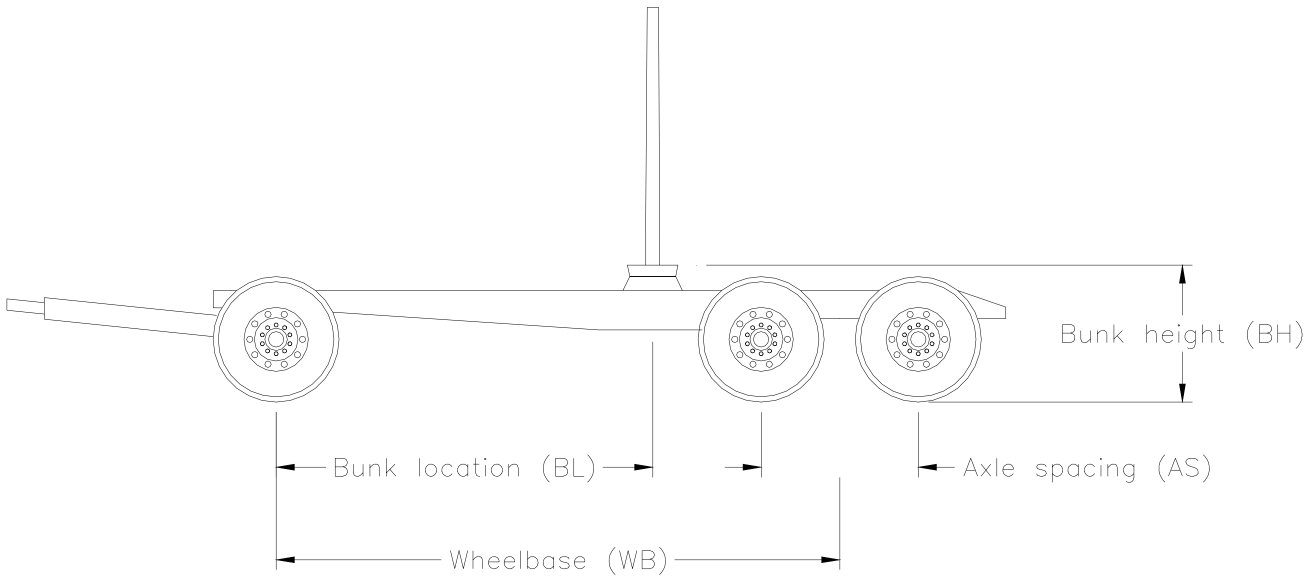
Single Axle Jeep



Manufacturer	Tare (kg)	WB (m)	BL (m)	BH (m)*		Suspension		Track
				Std	LP	Type	Width (m)	Width (m)
Anser Industries Inc.	3300	4.9	1.65	1.60	1.52	Air	1.02	2.59
Peerless Ltd.	3300	4.8	1.65	1.70	1.63	Air	1.04	2.59
Arctic Manufacturing Ltd.	3400	4.7	1.50	1.61	1.54	Air	0.86	2.59

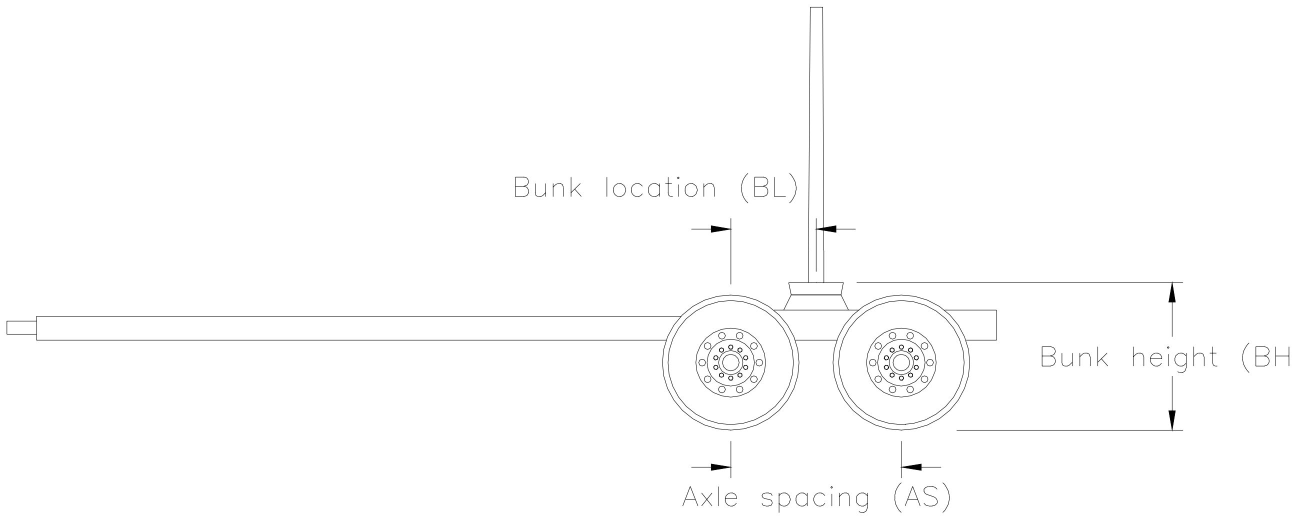
* Bunk height
Std = standard bunk
LP = low profile bunk

Triaxle Trailer



Manufacturer	Tare (kg)	WB (m)	BL (m)	BH (m) Std	AS (m)	Suspension Front	Suspension Rear	Width (m) Front	Width (m) Rear	Track Width (m)
Anser Industries Inc.	5300	4.3	2.95	1.45	1.37	Leaf spring	Walking beam	1.12	1.07	2.59
Arctic Manufacturing Ltd.	5050	3.6	2.16	1.44	1.37	Rubber block	Walking beam	1.12	1.12	2.59
Brodex Industries Ltd.	4900	4.3	3.08	1.32	1.37	Rubber block	Walking beam	0.76	0.76	2.59
Columbia Remtec Inc.	5125	4.6	3.15	1.42	1.38	Leaf spring	Walking beam	0.98	0.94	2.59
Peerless Ltd.	4990	4.6	3.13	1.45	1.37	Leaf spring	Walking beam	0.97	1.12	2.59

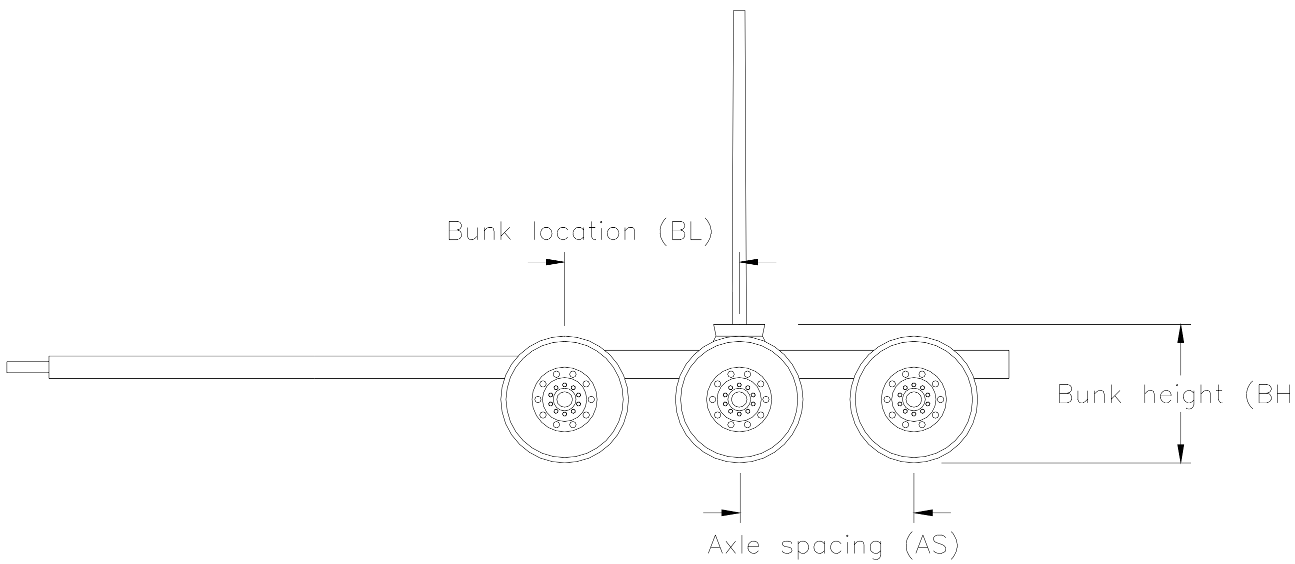
Tandem Axle Pole Trailer



Manufacturer	Tare (kg)	BL (m)	BH (m)*		AS (m)	Suspension		Track Width (m)
			Std	LP		Type	Width (m)	
Anser Industries Inc.	3150	0.69	1.57	1.50	1.37	Walking beam	1.09	2.59
Arctic Manufacturing Ltd.	3400	0.67	1.47	1.40	1.37	Walking beam	1.12	2.59
Columbia Remtec Inc.	3175	0.69	1.54	1.47	1.38	Walking beam	0.94	2.59
Peerless Ltd.	3175	0.69	1.45	1.37	1.37	Walking beam	1.12	2.59

* Bunk height
Std = standard bunk
LP = low profile bunk

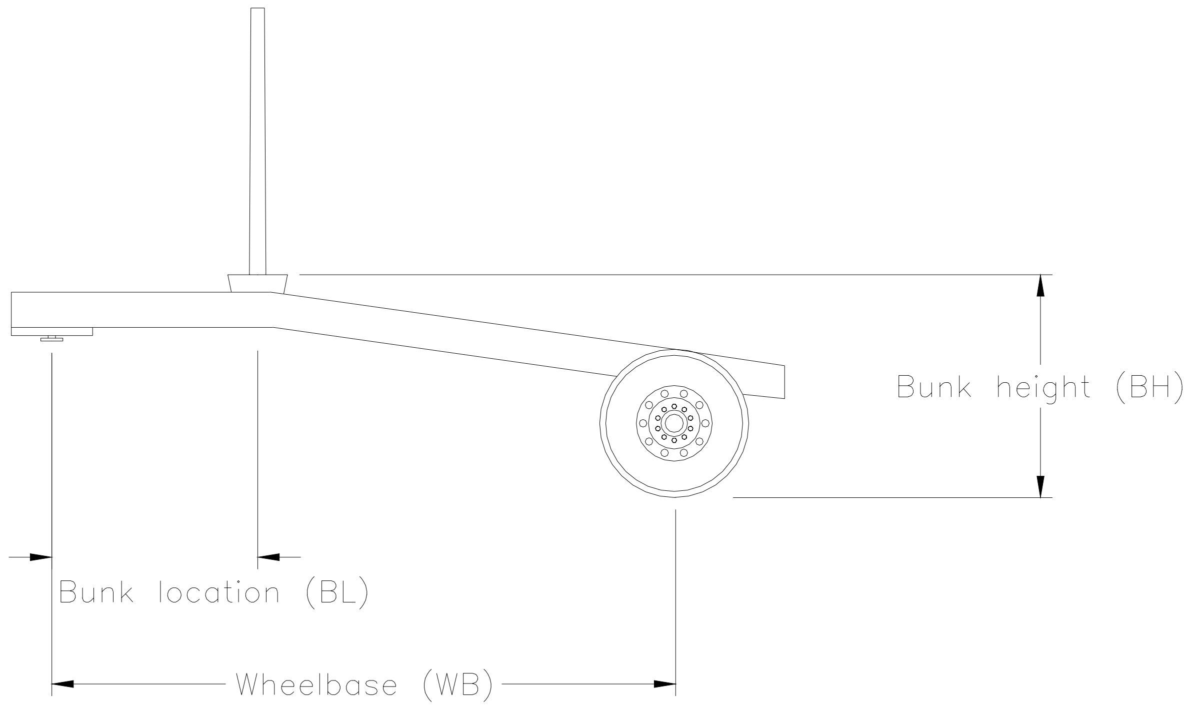
Tridem Axle Pole Trailer



Manufacturer	Tare (kg)	BL (m)	BH (m)*		AS (m)	Suspension		Track width (m)
			Std	LP		Type	Width (m)	
Anser Industries Inc.	5000	1.35	1.60	1.52	1.37	Walking beam	0.91	2.59
Arctic Manufacturing Ltd.	5000	1.35	1.49	1.42	1.37	Walking beam	0.97	2.59
Columbia Remtec Inc.	4850	1.35	1.59	1.52	1.40	Walking beam	0.99	2.59
Peerless Ltd.	4760	1.37	1.45	1.37	1.37	Walking beam	0.89	2.59

* Bunk height
Std = standard bunk
LP = low profile bunk

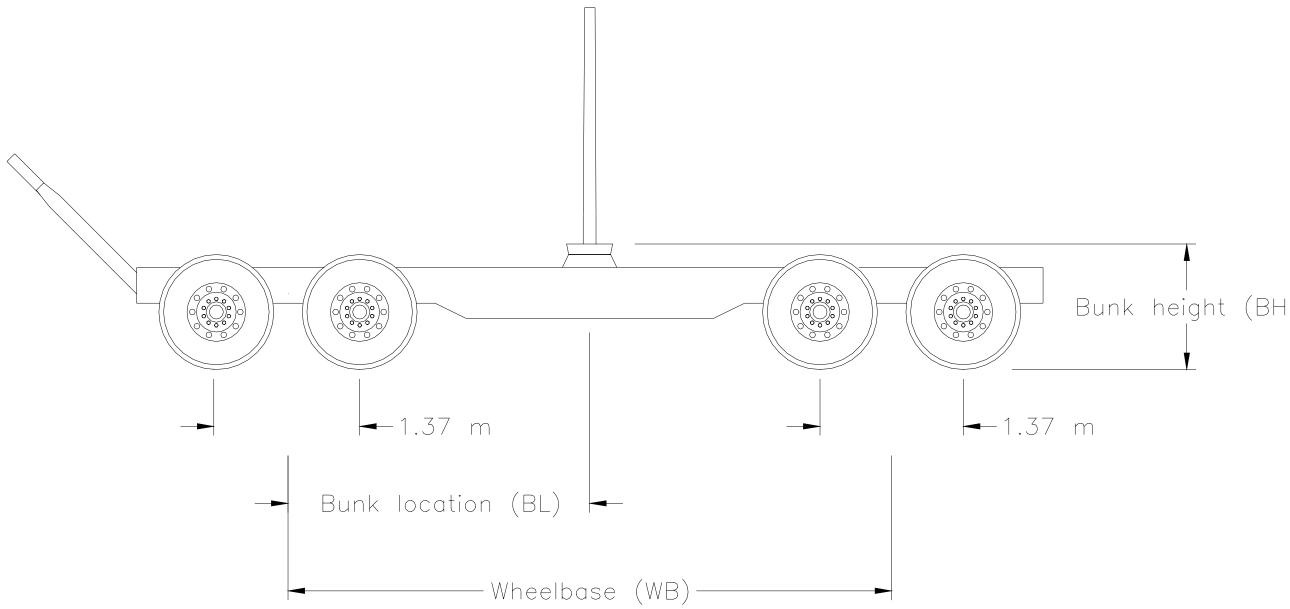
Doglogger



Manufacturer	Tare (kg)	WB (m)	BL (m)	BH (m)*		Suspension		Track Width (m)
				Std	LP	Type	Width (m)	
Anser Industries Inc.	2200	4.4	1.83	1.60	1.52	Rubber bushings	0.91	2.59
Arctic Manufacturing Ltd.	2450	3.6	1.40	1.65	1.57	Rubber bushings	0.97	2.59
Columbia Remtec Inc.	2450	3.6	1.55	1.69	1.63	Rubber bushings	0.89	2.59
Peerless Ltd.	2630	4.6	1.65	1.68	1.60	Rubber bushings	0.97	2.59

* Bunk height
Std = standard bunk
LP = low profile bunk

Quadaxle Trailer



Manufacturer	Tare (kg)	WB (m)	BL (m)	BH (m) Std	AS (m)	Suspension Front and Rear	Width (m) Front	Width (m) Rear	Track Width (m)
Arctic Manufacturing Ltd.	6300	6.3	2.61	1.39	1.37	Walking beam	0.97	1.12	2.59
Brodex Industries Ltd.	5990	5.5	2.75	1.32	1.37	Walking beam	0.76	0.76	2.59

Appendix III- Load Densities

Alberta

Sample Size :	65
Sample Mean:	448 kg/m^3
Sample Standard Deviation:	54 kg/m^3
Sample Confidence Interval (95%)[13]:	340 to 555 kg/m^3
Margin of Error:	13.03 kg/m^3

British Columbia

Sample Size :	105
Sample Mean:	520 kg/m^3
Sample Standard Deviation:	66 kg/m^3
Sample Confidence Interval (95%):	387 to 652 kg/m^3
Margin of Error:	12.64 kg/m^3

[13] The load density will be within this interval 95% of the time.

Appendix IV - Specifications Used in Simulations

Table IVa - Tractor and Trailer Specifications Used in Simulations[14]		
Tractor/Trailer Type	**Specifications**	
Tandem Drive Tractor	Wheelbase :	6.2 m
	Drive Axle Spacing:	1.37 m
	Bunk Height:	1.54 m
	Bunk Width (inside):	3.05 m (Alta) 2.31 m (BC)
	Hitch Offset:	1.60 m (Alta) 2.44 m (BC)
	Tare Weight:	9 700 kg
	Suspension	
	Steering Axle	
	Type:	Spring
	Axle Width:	2.02 m
	Lateral Spacing:	0.86 m
	Drive Group	
	Type:	Rubber Block
	Axle Width:	1.82 m
	Lateral Spacing:	0.90 m
Tridem Drive Tractor	Wheelbase :	6.6 m
	Drive Axle Spacing:	1.37 m
	Bunk Height:	1.54 m
	Bunk Width (inside):	3.05 m (Alta) 2.31 m (BC)
	Hitch Offset:	2.51 m
	Tare Weight:	12 800 kg
	Suspension	
	Steering Axle	
	Type:	Spring
	Axle Width:	2.02 m
	Lateral Spacing:	0.86 m
	Drive Group	
	Type:	Air
	Axle Width:	2.00 m
	Lateral Spacing:	0.90 m
Tandem Pole Trailer	Axle Spacing:	1.37 m
	Bunk Height:	1.37 m
	Bunk Width (inside):	2.31 m
	Tare Weight:	3 175 kg
	Suspension	
	Type:	Walking Beam
	Axle Width:	2.00 m
	Lateral Spacing:	1.12 m

[14] Tires used in simulations are 11R24.5.

Table IVa(cont) - Tractor and Trailer Specifications Used in Simulations[15]		
Tractor/Trailer Type	**Specifications**	
Tridem Pole Trailer	Axle Spacing:	1.51 m (Alta) 1.37 m (BC)
	Bunk Height:	1.42 m
	Bunk Width (inside):	2.31 m
	Tare Weight:	5 000 kg
	Suspension	
	Type:	Walking Beam
	Axle Width:	2.00 m
	Lateral Spacing:	0.96 m
Single Jeep	Wheelbase :	4.7 m
	Bunk Location (from 5th wheel)	1.5 m
	Bunk Height:	1.54 m
	Bunk Width (inside):	3.05 m (Alta) 2.31 m (BC)
	Hitch Offset:	0.90 m
	Tare Weight (w/o Bunk):	2 900 kg
	Suspension	
	Type:	Air
	Axle Width:	2.00 m
	Lateral Spacing:	0.86 m
Tandem Jeep	Wheelbase :	6.91 m
	Axle spacing :	1.37 m
	Bunk Location (from 5th wheel)	3.66 m
	Bunk Height:	1.62 m
	Bunk Width (inside):	3.05 m (Alta) 2.31 m (BC)
	Hitch Offset:	1.86 m
	Tare Weight (w/o Bunk):	3 600 kg
	Suspension	
	Type:	Walking Beam
	Axle Width:	2.00 m
	Lateral Spacing:	1.12 m

[15] Tires used in simulations are 11R24.5.

Table IVa(cont) - Tractor and Trailer Specifications Used in Simulations[16]		
Tractor/Trailer Type	**Specifications**	
Doglogger Jeep Addition to Tandem Pole Trailer	Wheelbase : Bunk Location (from 5th wheel) Bunk Height: Bunk Width (inside): Tare Weight (w/o Bunk): Suspension Type: Axle Width: Lateral Spacing:	4.6 m 2.0 m 1.60 m 2.31 m 2 600 kg None 2.00 m 0.98 m
Triaxle Trailer	Wheelbase : Axle Spacing: Bunk Location (from dolly): Bunk Height: Bunk Width (inside): Tare Weight : Suspension Dolly Type: Axle Width: Lateral Spacing: Trailer Type: Axle Width: Lateral Spacing:	4.6 m 1.37 m 3.13 m 1.37 m 2.31 m 5 000 kg Spring 2.00 m 0.98 m Walking Beam 2.00 m 1.12 m
Quadaxle Trailer	Wheelbase : Dolly Axle Spacing: Trailer Axle Spacing: Bunk Location (from dolly) Bunk Height: Bunk Width (inside): Tare Weight : Suspension Dolly Type: Axle Width: Lateral Spacing: Trailer Type: Axle Width: Lateral Spacing:	6.3 m 1.37 m 1.51 m 3.30 m 1.40 m 2.31 m 6 300 kg Walking Beam 2.00 m 0.96 m Walking Beam 2.00 m 1.12 m

[16] Tires used in simulations are 11R24.5.

Table IVa(cont) - Tractor and Trailer Specifications Used in Simulations[17]	
Tractor/Trailer Type	**Specifications**
B-train	Lead Trailer Wheelbase: 8.64 m Axle Spacing: 1.51 m (Alta) 1.37 m (BC) Bunk Height: 1.47 m Bunk Width (inside): 2.31 m Tare Weight: 5 545 kg Suspension Type: Air Axle Width: 2.00 m Lateral Spacing: 1.08 m Rear Trailer Wheelbase: 6.40 m Axle Spacing: 1.37 m Bunk Height: 1.42 m Bunk Width (inside): 2.31 m Tare Weight: 4 000 kg Suspension Type: Air Axle Width: 2.00 m Lateral Spacing: 1.08 m

[17] Tires used in simulations are 11R24.5.

Table IVb - Configuration Loading Conditions Used in Simulations										
Configuration	Load Density (kg/m^3)	Fifth Wheel Offset (m)	Axle Group Loads[18] (kg)					Inter-Group Axle Spacing[19] (m)		
			Group1	Group2	Group3	Group4	Group5	Group 2 to 3	Group 3 to 4	Group 4 to 5
Alberta Legal										
Tandem Tractor /Tandem Pole Trailer	340	0.36	5 600	17 000	17 000	NA	NA	7.0	NA	NA
	555	0.36	5 600	17 000	17 000	NA	NA	7.0	NA	NA
Tandem Tractor /Tridem Pole Trailer	340	0.36	5 600	17 000	23 000	NA	NA	7.0	NA	NA
	555	0.36	5 600	17 000	23 000	NA	NA	7.0	NA	NA
Tridem Tractor/Tandem Pole Trailer	340	0.22	6 100	21 000	17 000	NA	NA	7.0	NA	NA
	555	0.22	6 100	21 000	17 000	NA	NA	7.0	NA	NA
Tandem Tractor/Jeep/Tandem Pole Trailer	340	0.34	5 600	17 000	8 600	17 000	NA	3.7	7.0	NA
	555	0.34	5 600	17 000	8 600	17 000	NA	3.7	7.0	NA
Doglogger	340	0.36	5 600	17 000	17 000	9 050	NA	7.0	3.9	NA
	555	0.36	5 600	17 000	17 000	9 050	NA	7.0	3.9	NA
Tridem Tractor /Tridem Pole Trailer	340	0.23	6 100	21 000	23 000	NA	NA	7.0	NA	NA
	555	0.23	6 100	21 000	23 000	NA	NA	7.0	NA	NA
Tandem Tractor/Tandem Jeep/Tandem Pole Trailer	340	0.34	5 600	16 950	17 000	17 000	NA	5.2	5.2	NA
	555	0.34	5 600	16 950	17 000	17 000	NA	5.2	5.2	NA
B-train	340	0.29	5 500	17 000	23 000	17 000	NA	6.1	5.7	NA
	350	0.29	5 500	17 000	23 000	17 000	NA	6.1	5.7	NA
	555	0.29	5 500	17 000	23 000	17 000	NA	6.1	5.7	NA
Alberta Winter (green route)										
Tandem Tractor /Tandem Pole Trailer	340	0.22	5 530	23 050	25 000	NA	NA	7.0	NA	NA
	555	0.22	5 600	25 000	25 000	NA	NA	7.0	NA	NA
	340	0.22	5 600	25 000	25 000	NA	NA	7.0	NA	NA

[18] Group number starts at front of configuration (i.e., Group1 for steering axle).

[19] Distance from centre of rear axle in forward group to centre of forward axle in rearward group.

Table IVb (cont) - Configuration Loading Conditions Used in Simulations											
Configuration	Load Density (kg/m^3)	Fifth Wheel Offset (m)	Axle Group Loads[20] (kg)					Inter-Group Axle Spacing[21] (m)		
			Group1	Group2	Group3	Group4	Group5	Group 2 to 3	Group 3 to 4	Group 4 to 5
Alberta Winter (green route)										
Tandem Tractor /Tridem Pole Trailer	450	0.22	5 600	25 000	27 000	NA	NA	7.0	NA	NA
	555	0.22	5 600	25 000	27 000	NA	NA	7.0	NA	NA
Tridem Tractor/Tandem Pole Trailer	340	0.16	6 100	27 000	25 000	NA	NA	7.0	NA	NA
	355	0.16	6 100	27 000	25 000	NA	NA	7.0	NA	NA
Tandem Tractor/Jeep/Tandem Pole Trailer	555	0.23	5 460	19 415	9 650	25 000	NA	3.8	7.0	NA
	340	0.23	5 600	23 000	11 400	25 000	NA	3.8	7.0	NA
	555	0.23	5 600	23 000	11 400	25 000	NA	3.8	7.0	NA
Doglogger	340	0.22	5 580	24 340	22 230	11 985	NA	7.0	3.9	NA
	355	0.22	5 600	25 000	22 350	12 050	NA	7.0	3.9	NA
	555	0.22	5 600	25 000	22 350	12 050	NA	7.0	3.9	NA
Tridem Tractor /Tridem Pole Trailer	340	0.16	6 100	27 000	26 900	NA	NA	7.0	NA	NA
	555	0.16	6 100	27 000	26 900	NA	NA	7.0	NA	NA
Tandem Tractor/Tandem Jeep/Tandem Pole Trailer	340	0.26	5 600	20 800	21 350	17 250	NA	5.3	7.0	NA
	555	0.26	5 600	20 800	21 350	17 250	NA	5.3	7.0	NA
British Columbia Legal (with winter logging truck weight allowances)										
Tandem Tractor /Tandem Pole Trailer	387	0.34	5 600	18 500	18 000	NA	NA	8.5	NA	NA
	652	0.34	5 600	18 500	18 000	NA	NA	8.5	NA	NA
Tandem Tractor /Tridem Pole Trailer	387	0.34	5 600	18 500	25 000	NA	NA	8.1	NA	NA
	652	0.34	5 600	18 500	25 000	NA	NA	8.1	NA	NA

[20] Group number starts at front of configuration (i.e., Group1 for steering axle).

[21] Distance from centre of rear axle in forward group to centre of forward axle in rearward group.

Table IVb (cont) - Configuration Loading Conditions Used in Simulations										
Configuration	Load Density (kg/m^3)	Fifth Wheel Offset (m)	Axle Group Loads[22] (kg)					Inter-Group Axle Spacing[23] (m)		
			Group1	Group2	Group3	Group4	Group5	Group 2 to 3	Group 3 to 4	Group 4 to 5
British Columbia Legal (with winter logging truck weight allowances)										
Tridem Tractor/Tandem Pole Trailer	387	0.18	6 030	22 855	18 500	NA	NA	7.8	NA	NA
	479	0.18	6 100	25 500	18 000	NA	NA	7.8	NA	NA
	652	0.18	6 100	25 500	18 000	NA	NA	7.8	NA	NA
Tandem Tractor/Jeep/Tandem Pole Trailer	387	0.30	5 530	17 160	8 560	18 490	NA	3.7	6.1	NA
	505	0.30	5 600	18 500	9 220	18 000	NA	3.7	6.1	NA
	652	0.30	5 600	18 500	9 220	18 000	NA	3.7	6.1	NA
Doglogger	387	0.33	5 600	18 500	17 600	9 390	NA	7.7	3.9	NA
	652	0.33	5 600	18 500	17 600	9 390	NA	7.7	3.9	NA
Tandem Tractor /Triaxle Trailer	387	0.32	5 600	18 500	8 850	18 000	NA	5.8	3.9	NA
	652	0.32	5 600	18 500	8 850	18 000	NA	5.8	3.9	NA
Tridem Tractor /Tridem Pole Trailer	387	0.18	6 050	23 630	25 500	NA	NA	7.0	NA	NA
	451	0.18	6 100	25 500	25 000	NA	NA	7.0	NA	NA
	652	0.18	6 100	25 500	25 000	NA	NA	7.0	NA	NA
Tandem Tractor/Tandem Jeep/Tandem Pole Trailer	387	0.31	5 550	17 010	16 775	16 850	NA	5.2	5.2	NA
	522	0.31	5 600	18 000	17 920	17 580	NA	5.2	5.2	NA
	652	0.31	5 600	18 000	17 920	17 580	NA	5.2	5.2	NA
Tandem Tractor /Quadaxle Trailer	387	0.32	5 600	18 500	15 910	17 040	NA	5.5	4.9	NA
	397	0.32	5 600	18 500	16 410	17 590	NA	5.5	4.9	NA
	652	0.32	5 600	18 500	16 410	17 590	NA	5.5	4.9	NA
Double doglogger	387	0.30	5 600	18 500	9 120	15 940	8 400	3.7	5.0	3.9
	415	0.30	5 600	18 500	9 120	17 650	9 350	3.7	5.0	3.9
	652	0.30	5 600	18 500	9 120	17 650	9 350	3.7	5.0	3.9

[22] Group number starts at front of configuration (i.e., Group1 for steering axle).

[23] Distance from centre of rear axle in forward group to centre of forward axle in rearward group.

Table IVb (cont) - Configuration Loading Conditions Used in Simulations										
Configuration	Load Density (kg/m³)	Fifth Wheel Offset (m)	Axle Group Loads[24] (kg)					Inter-Group Axle Spacing[25] (m)		
			Group1	Group2	Group3	Group4	Group5	Group 2 to 3	Group 3 to 4	Group 4 to 5
British Columbia Legal										
Tandem Tractor /Jeep/Triaxle Trailer	387	0.30	5 600	18 500	9 200	8 300	16 850	3.7	3.5	3.9
	414	0.30	5 600	18 500	9 200	8 890	18 100	3.7	3.5	3.9
	652	0.30	5 600	18 500	9 200	8 890	18 100	3.7	3.5	3.9
B-train	387	0.29	5 500	17 000	24 000	17 000	NA	6.3	5.6	NA
	450	0.29	5 500	17 000	24 000	17 000	NA	6.3	5.6	NA
	652	0.29	5 500	17 000	24 000	17 000	NA	6.3	5.6	NA

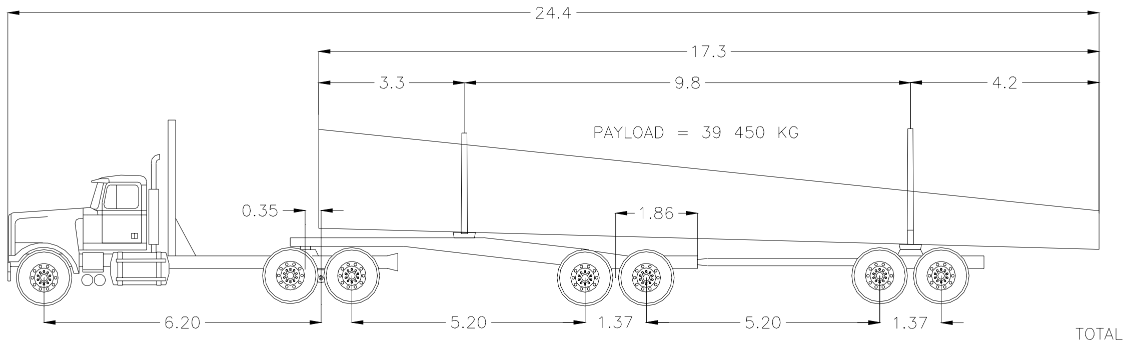
[24] Group number starts at front of configuration (i.e., Group1 for steering axle).

[25] Distance from centre of rear axle in forward group to centre of forward axle in rearward group.

Appendix V - Optimization of Tandem Tractor/Tandem Jeep/Pole Trailer Configuration Details

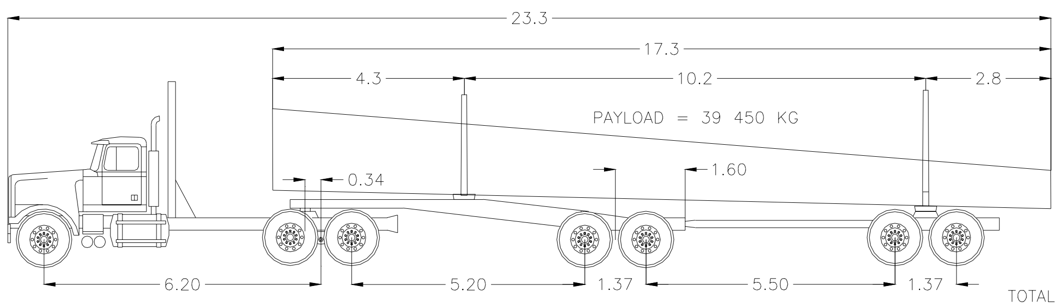
APPENDIX V-a : Alberta Legal

Baseline Configuration



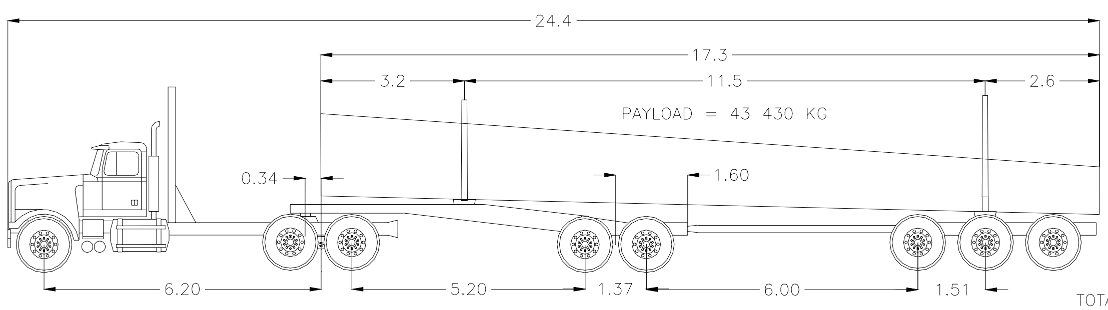
					TOTAL
5 600	LOAD (KG)	17 000	17 000	17 000	56 600
2.02	TRACK WIDTH	1.82	2.00	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tandem Pole Trailer Configuration (Butts Forward Orientation)



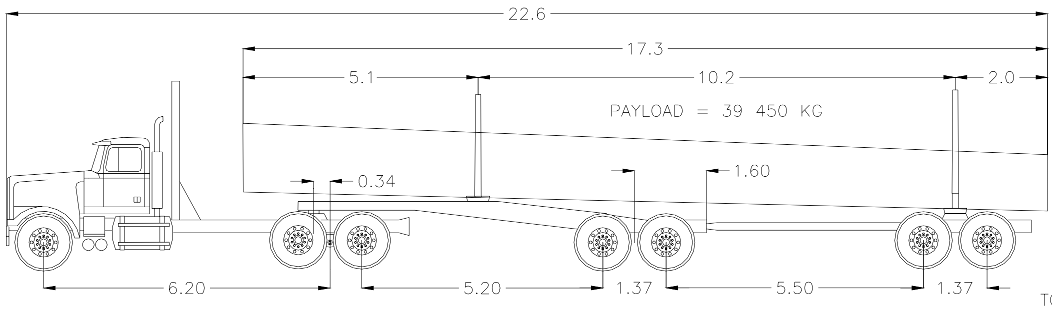
					TOTAL
5 600	LOAD (KG)	17 000	17 000	17 000	56 600
2.02	TRACK WIDTH	2.00	2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tridem Pole Trailer Configuration (Butts Forward Orientation)



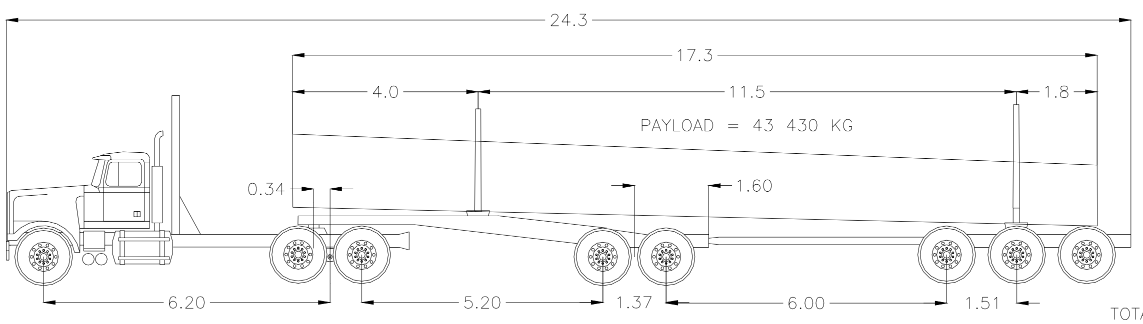
					TOTAL
5 600	LOAD (KG)	17 000	17 000	22 900	62 500
2.02	TRACK WIDTH	2.00	2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tandem Pole Trailer Configuration (Mixed orientation)



						TOTAL
5 600	LOAD (KG)	17 000		17 000	17 000	56 600
2.02	TRACK WIDTH	2.00		2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		3.05		3.05	

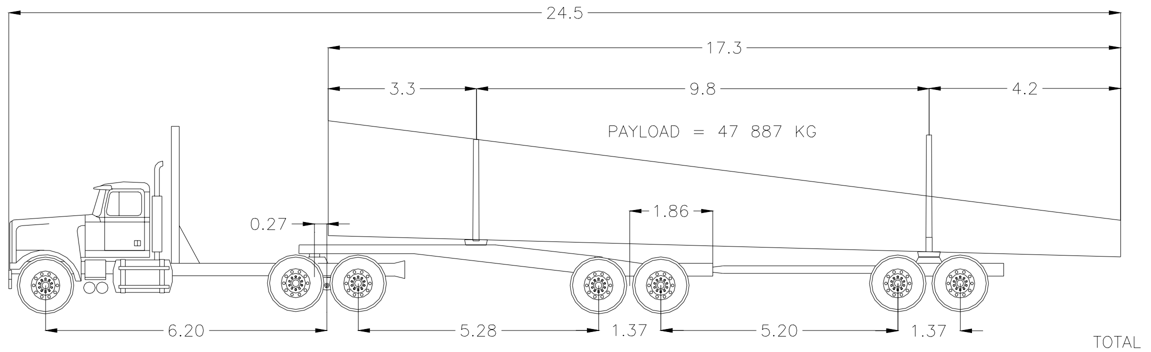
Optimized Tridem Pole Trailer Configuration (Mixed Orientation)



						TOTAL
5 600	LOAD (KG)	17 000		17 000	22 900	62 500
2.02	TRACK WIDTH	2.00		2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		3.05		3.05	

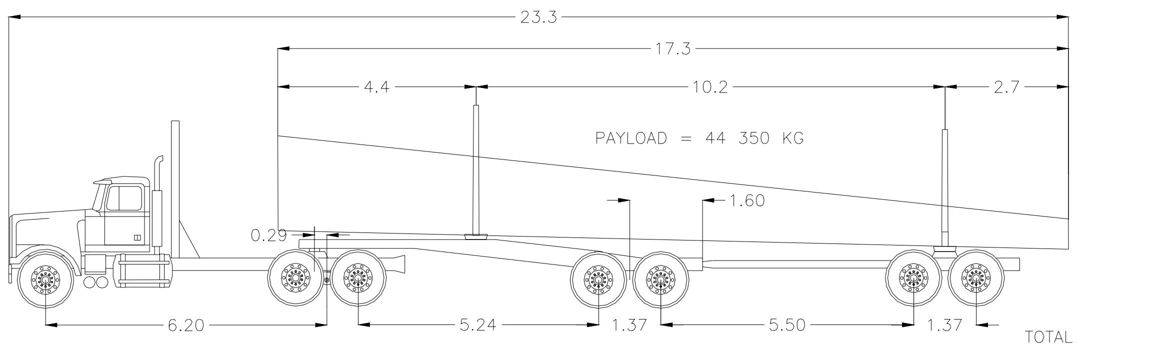
APPENDIX V-b : Alberta Winter (green route)

Baseline Configuration



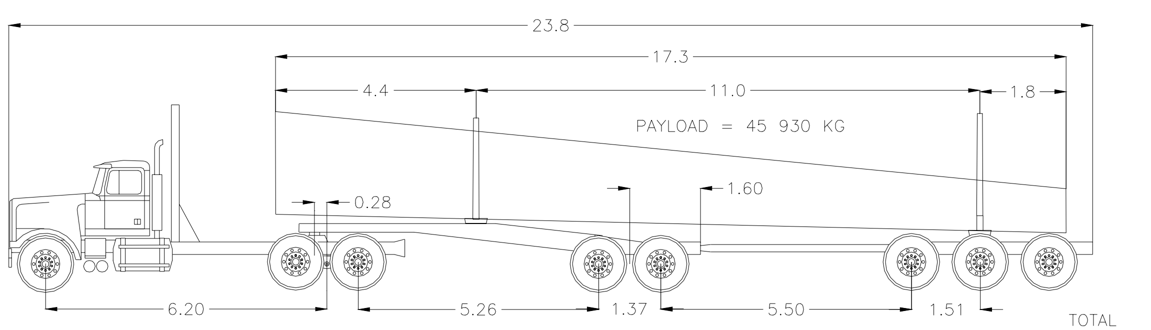
5 600	LOAD (KG)	20 800	21 350	17 250	65 000
2.02	TRACK WIDTH	1.82	2.00	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tandem Pole Trailer Configuration (Butts Forward Orientation)



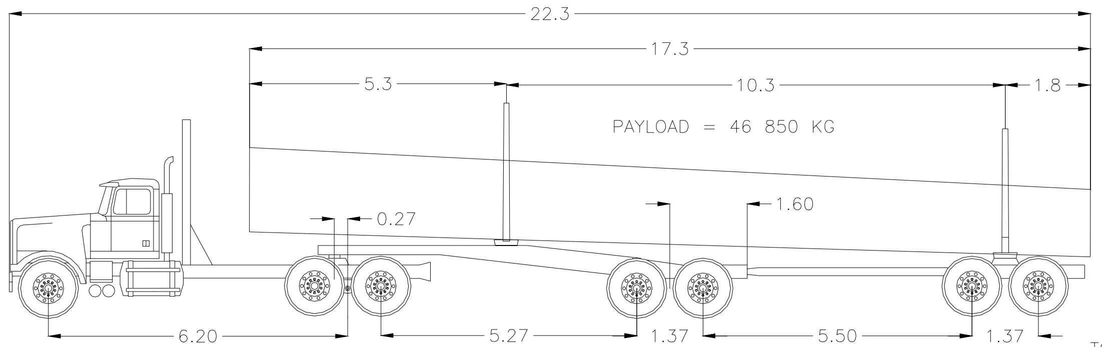
5 600	LOAD (KG)	18 800	18 465	18 635	61 500
2.02	TRACK WIDTH	2.00	2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tridem Pole Trailer Configuration (Butts Forward Orientation)



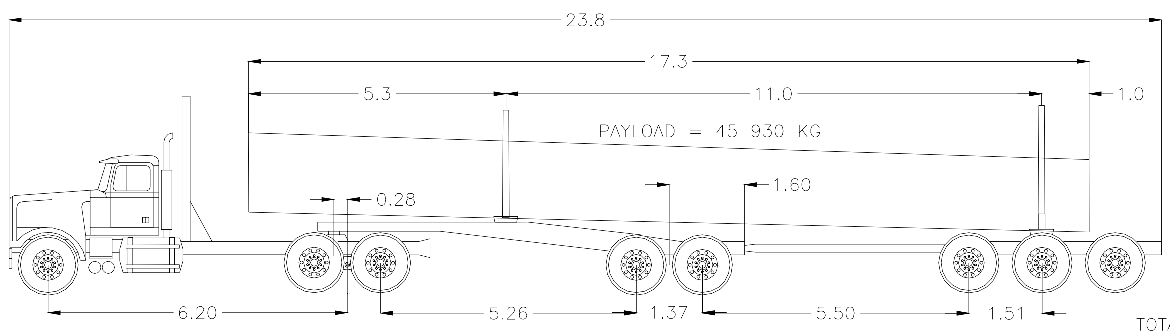
5 590	LOAD (KG)	19 980	19 900	19 520	65 000
2.02	TRACK WIDTH	2.00	2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK	WALKING BEAM	WALKING BEAM	
	BUNK WIDTH	3.05		2.31	

Optimized Tandem Pole Trailer Configuration (Mixed Orientation)



						TOTAL
5 600	LOAD (KG)	19 985		19 750	18 665	64 000
2.02	TRACK WIDTH	2.00		2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		3.05		3.05	

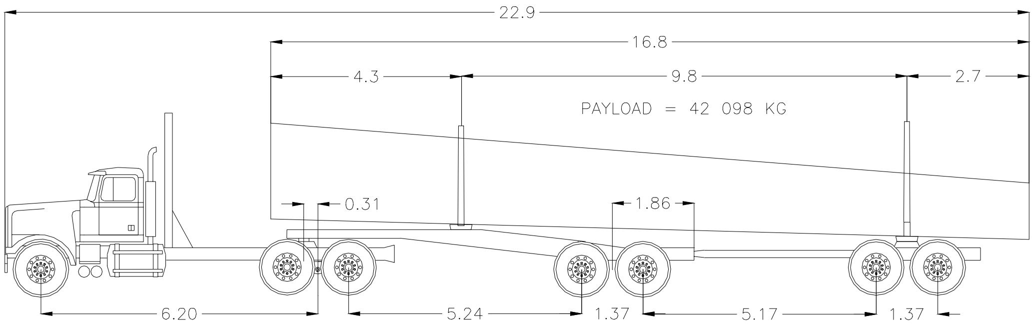
Optimized Tridem Pole Trailer Configuration (Mixed Orientation)



						TOTAL
5 590	LOAD (KG)	19 980		19 900	18 665	65 000
2.02	TRACK WIDTH	2.00		2.46	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		3.05		3.05	

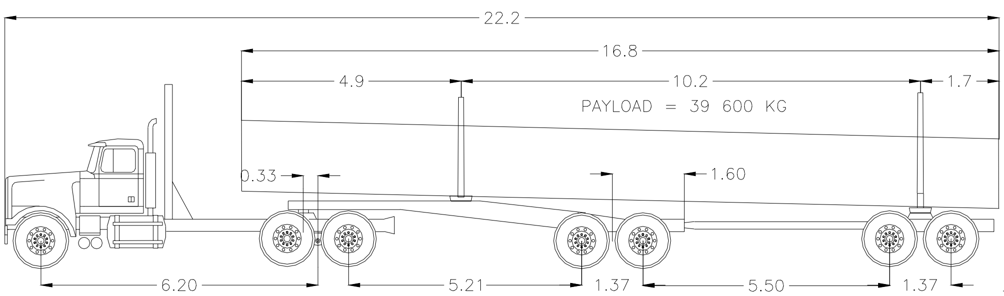
APPENDIX V-c : British Columbia Legal Weights (with winter logging truck weight allowances)

Baseline Configuration



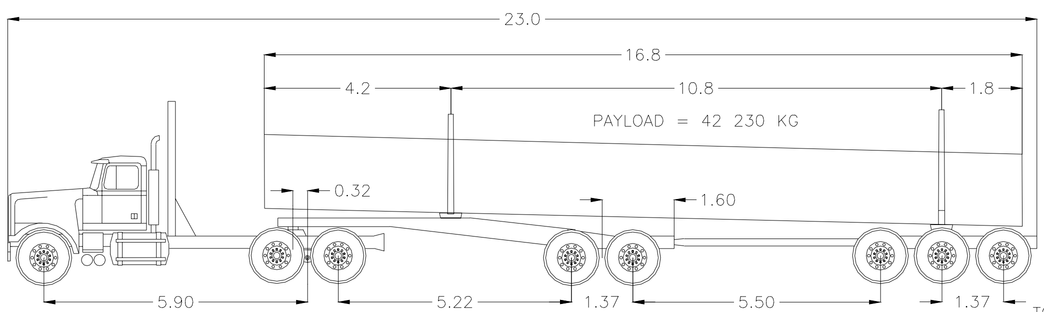
						TOTAL
5 600	LOAD (KG)	18 000		17 925	17 575	59 100
2.02	TRACK WIDTH	1.82		2.00	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		2.31		2.31	

Optimized Tandem Pole Trailer Configuration (Mixed Orientation)



						TOTAL
5 600	LOAD (KG)	16 800		16 800	17 400	56 600
2.02	TRACK WIDTH	2.00		2.00	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		2.31		2.31	

Optimized Tridem Pole Trailer Configuration (Mixed Orientation)



						TOTAL
5 600	LOAD (KG)	16 850		16 750	22 000	61 200
2.02	TRACK WIDTH	2.00		2.00	2.00	
SPRING	SUSPENSION	RUBBER BLOCK		WALKING BEAM	WALKING BEAM	
	BUNK WIDTH		2.31		2.31	

Appendix VI - Simulation Results

Table VI-a1 -STATIC ROLLOVER THRESHOLD (SRT) Alberta Legal (Performance Standard > 0.35g)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.40	0.45
Tandem tractor /tridem pole trailer	0.38	0.46
Tridem tractor/tandem pole trailer	0.42	0.49
Tandem tractor/jeep/tandem pole trailer	0.35	0.44
Doglogger	0.36	0.44
Tridem tractor /tridem pole trailer	0.40	0.49
Tandem tractor/tandem jeep/tandem pole trailer	0.32*	0.34*
B-train	0.33*	0.40

Table VI -a2 - HIGH SPEED OFFTRACKING (HSOT) Alberta Legal (Performance Standard < 0.46 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.41	0.44
Tandem tractor /tridem pole trailer	0.42	0.44
Tridem tractor/tandem pole trailer	0.40	0.42
Tandem tractor/jeep/tandem pole trailer	0.49*	0.52*
Doglogger	0.51*	0.55*
Tridem tractor /tridem pole trailer	0.43	0.45
Tandem tractor/tandem jeep/tandem pole trailer	0.52*	0.54*
B-train	0.59*	0.64*

asterisk (*) indicates performance standard not met

Table VI-a3 -UNDERSTEER COEFFICIENT (USC)
Alberta Legal
(Performance Standard > -4.51deg/g (tandem tractor)
> -4.85 deg/g (tridem tractor))

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	1.91	2.50
Tandem tractor /tridem pole trailer	2.37	3.34
Tridem tractor/tandem pole trailer	4.56	5.03
Tandem tractor/jeep/tandem pole trailer	2.00	2.99
Doglogger	0.36	1.87
Tridem tractor /tridem pole trailer	4.64	5.33
Tandem tractor/tandem jeep/tandem pole trailer	2.78	2.94
B-train	-2.34	-0.63

Table VI -a4 - LOAD TRANSFER RATIO (LTR)
Alberta Legal
(Performance Standard <0.60)

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.48	0.49
Tandem tractor /tridem pole trailer	0.40	0.51
Tridem tractor/tandem pole trailer	0.37	0.45
Tandem tractor/jeep/tandem pole trailer	0.39	0.49
Doglogger	0.44	0.57
Tridem tractor /tridem pole trailer	0.37	0.47
Tandem tractor/tandem jeep/tandem pole trailer	0.54	0.59
B-train	0.44	0.62*

asterisk (*) indicates performance standard not met

Table VI -a5 -TRANSIENT OFFTRACKING (TOT) Alberta Legal (Performance Standard < 0.80 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.43	0.50
Tandem tractor /tridem pole trailer	0.38	0.44
Tridem tractor/tandem pole trailer	0.37	0.42
Tandem tractor/jeep/tandem pole trailer	0.43	0.50
Doglogger	0.49	0.56
Tridem tractor /tridem pole trailer	0.38	0.43
Tandem tractor/tandem jeep/tandem pole trailer	0.57	0.58
B-train	0.57	0.68

Table VI -a6 - REARWARD AMPLIFICATION (RWA) Alberta Legal (Performance Standard < 2.20)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	1.73	1.77
Tandem tractor /tridem pole trailer	1.63	1.70
Tridem tractor/tandem pole trailer	1.71	1.79
Tandem tractor/jeep/tandem pole trailer	1.81	1.89
Doglogger	1.79	1.87
Tridem tractor /tridem pole trailer	1.68	1.74
Tandem tractor/tandem jeep/tandem pole trailer	2.24*	2.27*
B-train	1.77	1.84

asterisk (*) indicates performance standard not met

Table VI -a7 - FRICTION DEMAND (FD) Alberta Legal (Performance Standard < 0.10)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.06	0.07
Tandem tractor /tridem pole trailer	0.18*	0.18*
Tridem tractor/tandem pole trailer	0.03	0.03
Tandem tractor/jeep/tandem pole trailer	0.02	0.02
Doglogger	0.06	0.06
Tridem tractor /tridem pole trailer	0.13*	0.14*
Tandem tractor/tandem jeep/tandem pole trailer	0.03	0.04
B-train	0.11*	0.11*

Table VI -a8 - LATERAL FRICTION UTILIZATION (LFU) Alberta Legal (Performance Standard <0.80)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.50	0.50
Tandem tractor /tridem pole trailer	0.41	0.41
Tridem tractor/tandem pole trailer	0.70	0.70
Tandem tractor/jeep/tandem pole trailer	0.57	0.57
Doglogger	0.50	0.50
Tridem tractor /tridem pole trailer	0.67	0.67
Tandem tractor/tandem jeep/tandem pole trailer	0.56	0.56
B-train	0.56	0.57

asterisk (*) indicates performance standard not met

Table VI -a9 - LOW SPEED OFFTRACKING (LSOT) Alberta Legal (Performance Standard < 6.00 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	2.92	2.93
Tandem tractor /tridem pole trailer	3.21	3.21
Tridem tractor/tandem pole trailer	2.98	2.98
Tandem tractor/jeep/tandem pole trailer	3.80	3.82
Doglogger	3.74	3.74
Tridem tractor /tridem pole trailer	3.24	3.25
Tandem tractor/tandem jeep/tandem pole trailer	3.83	3.86
B-train	4.90	4.91

asterisk (*) indicates performance standard not met

Table VI -b1 - STATIC ROLLOVER THRESHOLD (SRT)
Alberta Winter (Green Route)
(Performance Standard > 0.35g)

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.28*	0.33*
Tandem tractor /tridem pole trailer	0.28*	0.36
Tridem tractor/tandem pole trailer	0.29*	0.37
Tandem tractor/jeep/tandem pole trailer	0.26*	0.30*
Doglogger	0.24*	0.32*
Tridem tractor /tridem pole trailer	0.32*	0.40
Tandem tractor/tandem jeep/tandem pole trailer	0.27*	0.32*

Table VI-b2 - HIGH SPEED OFFTRACKING (HSOT)
Alberta Winter (Green Route)
(Performance Standard < 0.46 m)

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.54*	0.56*
Tandem tractor /tridem pole trailer	0.54*	0.60*
Tridem tractor/tandem pole trailer	0.52*	0.56*
Tandem tractor/jeep/tandem pole trailer	0.64*	0.68*
Doglogger	0.69*	NA[1]
Tridem tractor /tridem pole trailer	0.52*	0.57*
Tandem tractor/tandem jeep/tandem pole trailer	0.60*	0.65*

1. Steady state not achieved with low density load

asterisk (*) indicates performance standard not met

Table VI -b3 - UNDERSTEER COEFFICIENT (USC)
Alberta Winter (Green Route)
(Performance Standard > -4.51deg/g (tandem tractor)
> -4.85 deg/g (tridem tractor))

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	-1.75	-0.26
Tandem tractor /tridem pole trailer	-1.18	0.87
Tridem tractor/tandem pole trailer	-0.73	1.67
Tandem tractor/jeep/tandem pole trailer	-1.39	-0.02
Doglogger	-2.68	-1.11
Tridem tractor /tridem pole trailer	1.10	2.51
Tandem tractor/tandem jeep/tandem pole trailer	0.45	1.09

Table VI -b4 - LOAD TRANSFER RATIO (LTR)
Alberta Legal
(Performance Standard <0.60)

Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.65*	0.78*
Tandem tractor /tridem pole trailer	0.53	0.74*
Tridem tractor/tandem pole trailer	0.56	0.72*
Tandem tractor/jeep/tandem pole trailer	0.59	0.72*
Doglogger	0.65*	0.87*
Tridem tractor /tridem pole trailer	0.47	0.60
Tandem tractor/tandem jeep/tandem pole trailer	0.59	0.73*

asterisk (*) indicates performance standard not met

Table VI-b5 - TRANSIENT OFFTRACKING (TOT) Alberta Winter (Green Route) (Performance Standard < 0.80 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.66	0.73
Tandem tractor /tridem pole trailer	0.58	0.71
Tridem tractor/tandem pole trailer	0.56	0.66
Tandem tractor/jeep/tandem pole trailer	0.63	0.67
Doglogger	0.74	0.82*
Tridem tractor /tridem pole trailer	0.50	0.58
Tandem tractor/tandem jeep/tandem pole trailer	0.69	0.81*

Table VI -b6 - REARWARD AMPLIFICATION (RWA) Alberta Winter (Green Route) (Performance Standard < 2.20)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	2.00	2.60*
Tandem tractor /tridem pole trailer	1.89	1.95
Tridem tractor/tandem pole trailer	1.96	2.07
Tandem tractor/jeep/tandem pole trailer	1.92	2.09
Doglogger	1.86	2.06
Tridem tractor /tridem pole trailer	1.84	1.95
Tandem tractor/tandem jeep/tandem pole trailer	2.45*	2.65*

asterisk (*) indicates performance standard not met

Table VI-b7 - FRICTION DEMAND (FD) Alberta Winter (Green Route) (Performance Standard < 0.10)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.05	0.05
Tandem tractor /tridem pole trailer	0.14*	0.14*
Tridem tractor/tandem pole trailer	0.03	0.03
Tandem tractor/jeep/tandem pole trailer	0.01	0.02
Doglogger	0.05	0.05
Tridem tractor /tridem pole trailer	0.11*	0.12*
Tandem tractor/tandem jeep/tandem pole trailer	0.04	0.04

Table VI -b8 - LATERAL FRICTION UTILIZATION (LFU) Alberta Winter (Green Route) (Performance Standard <0.80)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.59	0.61
Tandem tractor /tridem pole trailer	0.50	0.51
Tridem tractor/tandem pole trailer	0.81*	0.81*
Tandem tractor/jeep/tandem pole trailer	0.63	0.70
Doglogger	0.59	0.61
Tridem tractor /tridem pole trailer	0.79	0.79
Tandem tractor/tandem jeep/tandem pole trailer	0.61	0.61

asterisk (*) indicates performance standard not met

Table VI-b9 - LOW SPEED OFFTRACKING (LSOT) Alberta Winter (Green Route) (Performance Standard < 6.00 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	2.92	2.92
Tandem tractor /tridem pole trailer	3.22	3.24
Tridem tractor/tandem pole trailer	2.96	2.97
Tandem tractor/jeep/tandem pole trailer	3.74	3.74
Doglogger	3.72	3.73
Tridem tractor /tridem pole trailer	3.25	3.26
Tandem tractor/tandem jeep/tandem pole trailer	3.93	3.93

asterisk (*) indicates performance standard not met

Table VI-c1 -STATIC ROLLOVER THRESHOLD (SRT) British Columbia Legal (winter logging truck weight allowances) (Performance Standard > 0.35g)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.38	0.45
Tandem tractor /tridem pole trailer	0.35	0.44
Tridem tractor/tandem pole trailer	0.38	0.44
Tandem tractor/jeep/tandem pole trailer	0.35	0.39
Doglogger	0.34*	0.42
Tandem tractor /triaxle trailer	0.34*	0.43
Tridem tractor /tridem pole trailer	0.36	0.44
Tandem tractor/tandem jeep/tandem pole trailer	0.31*	0.37
Tandem tractor /quadaxle trailer	0.32*	0.42
Double doglogger	0.29*	0.36
Tandem tractor /jeep/triaxle trailer	0.30*	0.38
B-train	0.36	0.43

Table VI-c2 -HIGH SPEED OFFTRACKING (HSOT) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 0.46 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.45	0.48*
Tandem tractor /tridem pole trailer	0.47*	0.51*
Tridem tractor/tandem pole trailer	0.47*	0.49*
Tandem tractor/jeep/tandem pole trailer	0.52*	0.53*
Doglogger	0.57*	0.61*
Tandem tractor /triaxle trailer	0.54*	0.59*
Tridem tractor /tridem pole trailer	0.47*	0.50*
Tandem tractor/tandem jeep/tandem pole trailer	0.53*	0.54*
Tandem tractor /quadaxle trailer	0.60*	0.67*
Double doglogger	0.61*	0.66*
Tandem tractor /jeep/triaxle trailer	0.60*	0.65*
B-train	0.58*	0.62*

asterisk (*) indicates performance standard not met

Table VI-c3 -UNDERSTEER COEFFICIENT (USC) British Columbia Legal (winter logging truck weight allowances) (Performance Standard > -4.51deg/g (tandem tractor) > -4.85 deg/g (tridem tractor))		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	1.33	2.18
Tandem tractor /tridem pole trailer	1.04	2.28
Tridem tractor/tandem pole trailer	3.12	3.56
Tandem tractor/jeep/tandem pole trailer	1.17	2.08
Doglogger	-0.65	0.88
Tandem tractor /triaxle trailer	-0.41	1.35
Tridem tractor /tridem pole trailer	2.93	3.70
Tandem tractor/tandem jeep/tandem pole trailer	2.24	2.69
Tandem tractor /quadaxle trailer	-1.41	0.54
Double doglogger	-0.65	0.81
Tandem tractor /jeep/triaxle trailer	-0.70	0.96
B-train	-1.22	0.27

Table VI -c4 -LOAD TRANSFER RATIO (LTR) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 0.60)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.40	0.47
Tandem tractor /tridem pole trailer	0.43	0.54
Tridem tractor/tandem pole trailer	0.39	0.48
Tandem tractor/jeep/tandem pole trailer	0.46	0.55
Doglogger	0.46	0.59
Tandem tractor /triaxle trailer	0.48	0.64*
Tridem tractor /tridem pole trailer	0.42	0.54
Tandem tractor/tandem jeep/tandem pole trailer	0.48	0.59
Tandem tractor /quadaxle trailer	0.51	0.70*
Double doglogger	0.51	0.68*
Tandem tractor /jeep/triaxle trailer	0.49	0.66*
B-train	0.40	0.53

asterisk (*) indicates performance standard not met

Table VI-c5 -TRANSIENT OFFTRACKING (TOT) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 0.80 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.39	0.46
Tandem tractor /tridem pole trailer	0.41	0.48
Tridem tractor/tandem pole trailer	0.44	0.48
Tandem tractor/jeep/tandem pole trailer	0.54	0.58
Doglogger	0.53	0.61
Tandem tractor /triaxle trailer	0.60	0.69
Tridem tractor /tridem pole trailer	0.44	0.51
Tandem tractor/tandem jeep/tandem pole trailer	0.55	0.58
Tandem tractor /quadaxle trailer	0.64	0.75
Double doglogger	0.63	0.72
Tandem tractor /jeep/triaxle trailer	0.61	0.70
B-train	0.53	0.61

Table VI-c6 -REARWARD AMPLIFICATION (RWA) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 2.20)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	1.69	1.75
Tandem tractor /tridem pole trailer	1.71	1.78
Tridem tractor/tandem pole trailer	1.71	1.76
Tandem tractor/jeep/tandem pole trailer	2.04	2.07
Doglogger	1.89	1.95
Tandem tractor /triaxle trailer	2.04	2.09
Tridem tractor /tridem pole trailer	1.77	1.85
Tandem tractor/tandem jeep/tandem pole trailer	2.19	2.19
Tandem tractor /quadaxle trailer	1.88	1.90
Double doglogger	2.08	2.14
Tandem tractor /jeep/triaxle trailer	2.00	2.07
B-train	1.87	1.99

asterisk (*) indicates performance standard not met

Table VI-c7 -FRICTION DEMAND (FD) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 0.10)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.05	0.06
Tandem tractor /tridem pole trailer	0.17*	0.18*
Tridem tractor/tandem pole trailer	0.03	0.03
Tandem tractor/jeep/tandem pole trailer	0.02	0.02
Doglogger	0.06	0.06
Tandem tractor /triaxle trailer	0.01	0.01
Tridem tractor /tridem pole trailer	0.09	0.11*
Tandem tractor/tandem jeep/tandem pole trailer	0.04	0.04
Tandem tractor /quadaxle trailer	0.09	0.09
Double doglogger	0.01	0.01
Tandem tractor /jeep/triaxle trailer	0.01	0.02
B-train	0.09	0.09

Table VI-c8 -LATERAL FRICTION UTILIZATION (LFU) British Columbia Legal (winter logging truck weight allowances) (Performance Standard <0.80)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	0.53	0.53
Tandem tractor /tridem pole trailer	0.44	0.44
Tridem tractor/tandem pole trailer	0.74	0.79
Tandem tractor/jeep/tandem pole trailer	0.58	0.60
Doglogger	0.51	0.52
Tandem tractor /triaxle trailer	0.57	0.57
Tridem tractor /tridem pole trailer	0.73	0.76
Tandem tractor/tandem jeep/tandem pole trailer	0.56	0.58
Tandem tractor /quadaxle trailer	0.48	0.48
Double doglogger	0.59	0.59
Tandem tractor /jeep/triaxle trailer	0.58	0.59
B-train	0.57	0.57

asterisk (*) indicates performance standard not met

Table VI -c9 -LOW SPEED OFFTRACKING (LSOT) British Columbia Legal (winter logging truck weight allowances) (Performance Standard < 6.00 m)		
Configuration	Performance Measure Range	
	Minimum	Maximum
Tandem tractor /tandem pole trailer	3.14	3.14
Tandem tractor /tridem pole trailer	3.18	3.18
Tridem tractor/tandem pole trailer	3.33	3.34
Tandem tractor/jeep/tandem pole trailer	3.42	3.45
Doglogger	3.60	3.60
Tandem tractor /triaxle trailer	2.66	2.66
Tridem tractor /tridem pole trailer	3.20	3.21
Tandem tractor/tandem jeep/tandem pole trailer	3.83	3.91
Tandem tractor /quadaxle trailer	3.32	3.32
Double doglogger	3.75	3.75
Tandem tractor /jeep/triaxle trailer	3.41	3.42
B-train	4.92	4.92

asterisk (*) indicates performance standard not met

Appendix VII - Simulation Results Optimization of Sample Configuration

TABLE VII-a - SIMULATION RESULTS FOR OPTIMIZED TANDEM JEEP CONFIGURATIONS - ALBERTA LEGAL WEIGHTS (BUTTS FORWARD ORIENTATION)					
Performance Measure	Performance Standard	With Tandem Pole Trailer		With Tridem Pole Trailer	
		Minimum	Maximum	Minimum	Maximum
Static Rollover Threshold	> 0.35 g	0.376	0.458	0.373	0.456
High Speed Offtracking	< 0.46 m	0.367	0.390	0.393	0.415
Understeer Coefficient	> - 4.51 deg /g	5.486	5.526	5.454	5.654
Load Transfer Ratio	< 0.60	0.352	0.452	0.332	0.431
Transient Offtracking	< 0.80 m	0.294	0.342	0.278	0.315
Rearward Amplification	< 2.2	1.731	1.796	1.595	1.672
Friction Demand	< 0.10	0.090	0.091	0.041	0.048
Lateral Friction Utilization	< 0.80	0.560	0.562	0.747	0.766
Low Speed Offtracking	< 6.0 m	3.993	4.001	4.768	4.782

TABLE VII-b - SIMULATION RESULTS FOR OPTIMIZED TANDEM JEEP CONFIGURATIONS - ALBERTA LEGAL WEIGHTS (MIXED ORIENTATION)					
Performance Measure	Performance Standard	With Tandem Pole Trailer		With Tridem Pole Trailer	
		Minimum	Maximum	Minimum	Maximum
Static Rollover Threshold	> 0.35 g	0.400	0.489	0.395	0.480
High Speed Offtracking	< 0.46 m	0.364	0.382	0.390	0.407
Understeer Coefficient	> - 4.51 deg /g	5.354	5.626	5.424	5.650
Load Transfer Ratio	< 0.60	0.337	0.420	0.316	0.399
Transient Offtracking	< 0.80 m	0.286	0.324	0.274	0.302
Rearward Amplification	< 2.2	1.719	1.767	1.589	1.637
Friction Demand	< 0.10	0.095	0.095	0.045	0.045
Lateral Friction Utilization	< 0.80	0.560	0.561	0.758	0.765
Low Speed Offtracking	< 6.0 m	3.991	3.991	4.772	4.834

TABLE VII-c - SIMULATION RESULTS FOR OPTIMIZED TANDEM JEEP CONFIGURATIONS - ALBERTA WINTER WEIGHTS (Green Route) (BUTTS FORWARD ORIENTATION)					
Performance Measure	Performance Standard	With Tandem Pole Trailer		With Tridem Pole Trailer	
		Minimum	Maximum	Minimum	Maximum
Static Rollover Threshold	> 0.35 g	0.345	0.429	0.353	0.447
High Speed Offtracking	< 0.46 m	0.402	0.433	0.421	0.446
Understeer Coefficient	> - 4.51 deg /g	4.500	4.984	4.345	4.792
Load Transfer Ratio	< 0.60	0.383	0.517	0.356	0.470
Transient Offtracking	< 0.80 m	0.342	0.418	0.329	0.337
Rearward Amplification	< 2.2	1.739	1.915	1.726	1.828
Friction Demand	< 0.10	0.052	0.056	0.058	0.061
Lateral Friction Utilization	< 0.80	0.586	0.588	0.616	0.617
Low Speed Offtracking	< 6.0 m	4.071	4.075	4.779	4.787

TABLE VII-d - SIMULATION RESULTS FOR OPTIMIZED TANDEM JEEP CONFIGURATIONS - ALBERTA WINTER WEIGHTS (Green Route) (MIXED ORIENTATION)					
Performance Measure	Performance Standard	With Tandem Pole Trailer		With Tridem Pole Trailer	
		Minimum	Maximum	Minimum	Maximum
Static Rollover Threshold	> 0.35 g	0.346	0.430	0.374	0.460
High Speed Offtracking	< 0.46 m	0.419	0.449	0.418	0.440
Understeer Coefficient	> - 4.51 deg /g	4.274	4.631	4.641	4.965
Load Transfer Ratio	< 0.60	0.379	0.504	0.342	0.439
Transient Offtracking	< 0.80 m	0.361	0.435	0.324	0.362
Rearward Amplification	< 2.2	1.836	1.941	1.720	1.806
Friction Demand	< 0.10	0.074	0.076	0.060	0.064
Lateral Friction Utilization	< 0.80	0.600	0.601	0.616	0.618
Low Speed Offtracking	< 6.0 m	4.049	4.071	4.776	4.781

TABLE VII-e - SIMULATION RESULTS FOR OPTIMIZED TANDEM JEEP CONFIGURATIONS - BRITISH COLUMBIA LEGAL WEIGHTS (with winter logging truck weight allowances)					
Performance Measure	Performance standard	With Tandem Pole Trailer		With Tridem Pole Trailer	
		Minimum	Maximum	Minimum	Maximum
Static Rollover Threshold	> 0.35 g	0.345	0.419	0.345	0.426
High Speed Offtracking	< 0.46 m	0.378	0.407	0.397	0.423
Understeer Coefficient	> - 4.51 deg /g	5.348	5.779	4.949	5.395
Load Transfer Ratio	< 0.60	0.386	0.501	0.380	0.490
Transient Offtracking	< 0.80 m	0.293	0.352	0.290	0.335
Rearward Amplification	< 2.2	1.711	1.808	1.653	1.724
Friction Demand	< 0.10	0.040	0.042	0.037	0.038
Lateral Friction Utilization	< 0.80	0.552	0.553	0.563	0.564
Low Speed Offtracking	< 6.0 m	4.050	4.090	4.540	4.553