TECHNICAL PROCESS OF TRANSPORTATION POLICY CHANGE AND IMPLEMENTATION

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Abstract

Canadian resources, such as forest products, are generally transported to mills by trucks using road sections that are under the jurisdiction of provincial governments. Trucks, therefore, must comply with weight & dimension regulations governed by these administrations. While there are interprovincial conventions, each province has its own regulations, restrictions, and trucking programs. There is a need for transportation competitiveness to ensure the sustainability of industries in each province. To do so, there are several ways to promote transport efficiency, such as implementing a new truck configuration; implementing or increasing winter weight premiums; reducing the length or severity of spring road restrictions, etc. This paper describes the technical process used in Canada to improve transportation efficiency while preserving road user safety and the integrity of affected infrastructure. This process involves the five following phases:

1. Defining the need for transportation efficiency. Evaluating the need from the industry, selecting the champion and stakeholders, analyzing preliminary economic impact for all parties involved.
2. Feasibility study and strategy. Study provincial administration regulations, incorporating government priorities, etc.
3. Scientific methodology and technical approach. Infrastructure data acquisition, study impact of proposed change on infrastructure, safety, economy, environment.
4. Presentation of study results to responsible transportation officials.
5. Implementation. Process of changing transport policy.

A practical case that illustrates this process is highlighted in this paper, namely the introduction of a 9-axle tandem-drive truck in Ontario.

Introduction

FPInnovations is a not-for-profit research institute that seeks to enhance the competitiveness, safety, environmental impacts, and sustainability of the entire value chain of forest products in Canada. The transportation and infrastructure group of FPInnovations has a rich history with research and development of new, safer, and more efficient truck configurations and trucking policies in Canada. Many of the high efficiency log hauling truck configurations used in Canada have been developed, refined, and implemented with input from FPInnovations (Figure 1).

Figure 1. 9-axle log B-trains have been introduced to British Columbia with technical support from FPInnovations.

Canadian resources, such as forest products, are generally transported to mills by trucks using roadways that are regulated by provincial governments. Log hauling trucks must comply with the weight & dimension regulations established and enforced by these administrations. While there are interprovincial conventions, each province has its own regulations, restrictions, and trucking programs. There is a need for transportation competitiveness to ensure the sustainability of truck-based industries in each province. To do so, there are various ways to promote transport efficiency, including implementing new truck configurations; implementing or increasing winter weight premiums; or reducing the length or severity of spring road restrictions. This paper describes the general process used in Canada to improve the efficiency of truck-based transportation while preserving road user safety and the integrity of affected infrastructure. The latter part of the paper presents an example case study of a recently completed project in Ontario that followed this process as it sought to introduce a new high efficiency log truck configuration.

Economic, safety, and environmental benefits

Increases in log payload generate numerous ongoing benefits for truck-based industries, and by extension, to government and the public. A general rule-of-thumb developed from various truck configuration studies by FPInnovations is that a 10% payload increase generates approximately 5% in additional haul cost savings and 6.7% in fuel savings. Higher truck payloads result in fewer truck trips needed to haul the same log volume – reducing traffic congestion and the likelihood of collisions, and alleviating issues caused by persistent driver shortages. Typically, new highway configurations meet or exceed provincial safety and pavement damage thresholds and so are both safer and more road friendly than older configurations.

Lower trucking costs improve the competitiveness and sustainability of truckers, forestry companies, and forestry communities. Introduction of tridem-drive 9-axle B-trains in BC increased payloads by 18% compared to 8-axle B-trains and this is estimated to generate $50,000 in hauling savings per truck per year. Lower trucking costs also increase access to wood and log utilization by making it more economic to transport over longer distances and to transport lower value smaller logs. Because of the reduced fuel consumption, there is a comparable reduction in greenhouse gas emissions (i.e., -6.7% for each 10% increase in payload)(Bradley and Sinnett 2020).

Process for developing and implementing high efficiency log truck configurations in Canada

Initial steps

The initial steps of the process are to define project stakeholders, objectives and economics, applicable approval process, and terms of reference (Figure 2).

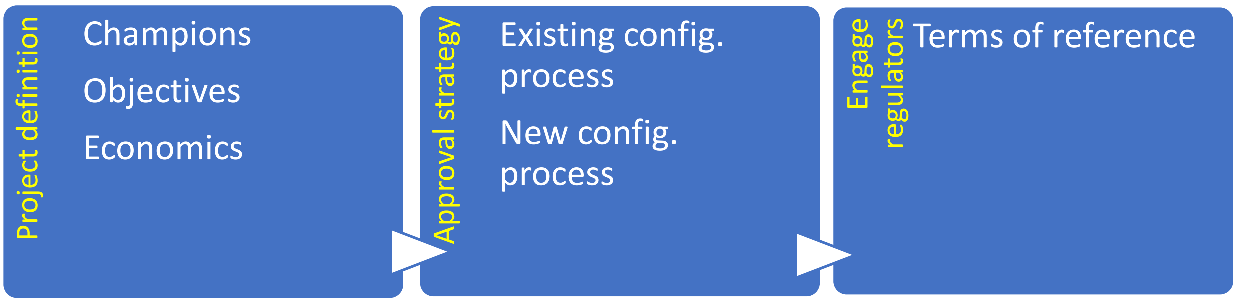

Figure 2. Initial steps to the general process for introducing high efficiency log truck configurations in Canada.

1. Project definition: Identify industry champions and determine the objectives for the implementation of a new or refined truck configuration. The initial step in the process is to prepare an economic case for implementing the new configuration based on estimated costs and benefits, and the market size (number of trucks implemented). The selection of a new truck configuration takes into consideration a number of factors including current or future preferred log sizes, hauling terrain and road network (adverse grades and curve widths), hauling season, size and weight limitations of loading/unloading equipment, existing regional operating practices, and the province of implementation.

2. Approval strategy: Select the government approval process that is most likely to meet the project objectives, which very much depends on the province of implementation. Determine whether the new configuration is already in regulations, but proposed weights or dimensions exceed regulated limits or if it is a new configuration not in regulation.
    - Approval of increased weights or dimensions for an existing configuration can be relatively quick and simple to obtain through an internal policy action that grants permits to haulers subject to specific terms and conditions (e.g., seasonal, or time-of-day constraints, designated routes, operator driving record, monitoring, compliance record). Prior to making the policy change the regulator will typically consider vehicle safety, potential infrastructure impacts, concerns from local District staff or municipalities, overall benefits, and alignment with government objectives.
    - Approval of a new configuration not already in regulations is more time consuming, involved, and requires more resources.
        i. If the configuration is to be used by truckers throughout the province without restriction, it will have to be approved into legislation. Prior to this, regulators will need to be assured that the general safety performance, impact on all provincial

infrastructure, the environmental impacts, and the economic benefits of the configuration meet present and future government objectives.

ii. If the configuration is to operate under a permit (letter of authorization), the Ministry can implement this with a policy subject to terms and conditions. This process is generally less time consuming than the legislation route. Regulators may be more willing to approve a permit because it is easier to create, and there is limited risk due to the smaller numbers of vehicles, stakeholders, municipalities, and structures involved. If the permits are targeted for the entire province, they may be issued on a route-by-route basis subject to bridge and route evaluations (e.g., B.C. 9-axle log B-trains) or they may be issued for all public highways at once (e.g., quad-axle semi-trailers in Alberta).

3. Engage regulators: Proponents engage with the regulators who are responsible for guiding and approving new vehicle proposals. This usually involves regulators from the vehicle compliance department and from the pavements and infrastructure departments. New vehicle proposals must be prepared in accordance with the province's established terms of reference. If these do not exist, proponents will need to co-create, with regulators, a process and set of performance thresholds for the proposal. It is important to obtain clear direction from regulators at this initial stage to determine the evaluation requirements and procedures—this will help to manage expectations, budgets, and bring the project to a timely conclusion. It can be challenging to work with multiple departments and individuals, and requires a shared vision, respectful collaboration, and attentive project management.

Technical assessments

Three technical assessments typically are used to optimize vehicle safety and performance and to minimize the impact on public roads and infrastructure. These evaluations are inter-related and comprise dynamic performance evaluations, estimates of network pavement impacts and bridge demands, and estimates of the road geometry requirements (Figure 3).

Figure 3. Technical evaluations for assessing vehicle safety, network impacts, and geometric requirements.

4. Dynamic performance evaluation. This is usually the first process in configuration development because of its implications for vehicle safety. The dynamic performance evaluation process generally adheres to the following steps, in the given order:

- Establish the necessary dynamic performance measures and the accepted performance thresholds. Typically, these will be some or all of the 12 TAC/NRC[1] dynamic performance measures and each of these has recommended performance standards; however, each province may define its own performance measure or modify the performance standard to suit their purposes.
- Select dimensions for the new configuration, as much as possible, that match those of tractors and trailers currently used by industry. This will help the new configuration to meet existing dimension regulations and may reduce the cost of implementation if trucking contractors can utilize in-service tractors or trailers for part of the new configuration.
- Use an appropriate dynamics simulation software to model the new configuration's dynamic performance and adjust dimensions and loading, as needed, to meet the required performance standards. The UMTRI Yaw/Roll model is commonly used for North American on-highway configurations while FPInnovations has a comparable model specifically developed for evaluating log hauling trucks.
- Consult with the provincial champions to resolve any subpar performance values.
- Conduct a sensitivity analysis to define ranges for vehicle dimensions that still allow the configuration to have acceptable dynamic performance and can be used by designers to manufacture new trailers.
- Assess the horsepower requirement for the truck or tractor unit to have acceptable acceleration from a stop (e.g., in B.C. this is 1 HP per 150 kg) and to climb highway grades under winter (low) traction conditions. Check that the manufacturer's axle weight ratings are not exceeded (to ensure braking capacity is sufficient).
- Additional preliminary testing may be required if novel or non-standard technology is specified in order for the configuration to meet the dynamic performance requirements (e.g., the B.C. requirement to test and demonstrate the function of a roll-coupled hitch that FPInnovations had proposed for use with a new 5-axle log hauling trailer).

5. The next step in configuration development typically is to evaluate the potential impact of the vehicle on provincial roads and infrastructure. Apart from unsafe configurations, regulators usually are not receptive of configurations that have greater infrastructure impacts than trucks contained in regulation. Allowing trucks with greater impacts to operate on public highways, without charging incremental road damage fees, would in effect create an industry subsidy. Quite the reverse is true, and some regulators use this process to encourage the development of new configurations that are less damaging than the status quo. The process for road and bridge impact assessments varies between provinces and some prefer to do the bridge assessment themselves while others have processes for proponents to use. For those provinces that have a bridge evaluation process for proponents to use, it may look like the following:
   - A preliminary or screening evaluation is conducted for a range of spans and arrangements of culverts and bridges in the proposed haul corridor or in the province. This evaluation

[1] TAC Transportation Association of Canada developed original performance measures in the 1980s during its landmark Canadian study of heavy vehicle safety (RTAC 1986). NRC – National Research Council built on these performance measures following the study.

compares the relative structural force effects generated by the proposed configuration and by a baseline configuration(s) (e.g., a worst-case, legally loaded, truck configuration).

- If the proposed configuration generates higher force effects, the regulators may still accept the results if the bridges and culverts are understood to have sufficient reserve capacity. Alternately, the regulators may require detailed evaluations be conducted on representative bridges or each bridge of concern to demonstrate that they have sufficient reserve capacity (Figure 4).
- Although much less common, regulators also may require evaluations of the impact of the proposed configuration on bridge serviceability and(or) bridge fatigue.

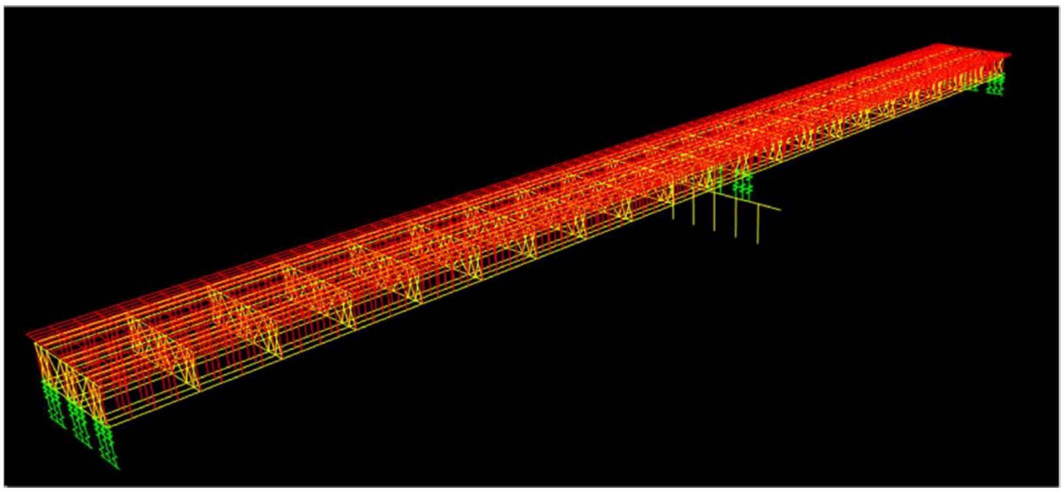

Figure 4. A 3-D model used in a detailed evaluation of Bailey trusses in a bridge superstructure.

If the results of any of the bridge analysis are rejected, the proposed truck's loading and(or) dimensions must be altered to create a more bridge-friendly configuration (back to step 4), and then the bridge analyses repeated.

Pavement analyses are typically done by the proponent. The process of pavement impact evaluation may involve an ESAL[2] comparison, pavement damage modeling, or both. This analysis is intended to assess how the population of new trucks would impact pavement service life and maintenance costs. While the ESAL analysis is relatively easy (a comparison of ESALs per tonne payload of the proposed truck versus a baseline truck), it is a dated calculation (and cannot account for truck axle spacing, pavement structure and condition, subgrade soil type, freezing or thaw-weakening, or other site-specific conditions. One relatively recent development came when FPInnovations developed ESAL formulae that are based on the original RTAC study (RTAC 1986) and account for a range of popular North American tire sizes (Bradley and Thiam 2020).

Modern layered elastic pavement analysis software can account for axle and tire size configurations and for many seasonal and site conditions using field data and(or) representative inputs provided in the mechanistic-empirical pavement design guide (MEPDG 2020). Further, the

[2] ESAL – Equivalent Single Axle Load, representing theoretical long-term damage to a typical pavement (RTAC 1986, AASHTO 1993).

instantaneous strain results from modeling can be used to estimate pavement service life using published strain-based transformations (Asphalt Institute 1982).

6. Additional geometric analyses also may be required to assess the proposed vehicle's road fit and accessibility (usually at low speed):
    - If the configuration utilizes non-regulation axle widths and(or) non-regulation bunk widths to attain satisfactory dynamic performance, its fit to highway lane widths may need to be assessed or its use on older, narrow, 2-lane highways may be restricted.
    - If local District staff or municipalities express concern about specific tight curves or intersections, the proponent may need to assess the swept path requirements of the unit through these curves. This is accomplished using software tools.[3]
    - If there are concerns about the new configuration's gradeability, this can be assessed relative to other configurations currently operating on the affected route or can be directly compared with the road grade. It may be advisable to consider both traction-limited and power-limited gradeability as these may form operating constraints under different weather conditions.
    - If there are concerns about the new configuration's downhill braking, this can be assessed using custom-built models. Some types of configurations also may be analyzed using FPInnovations' Steep Grade Descent Calculator (Parker 2016).

<u>Additional steps</u>

After the technical assessment of a new configuration has been completed and accepted by regulators, additional steps are needed before a new configuration can be introduced (Figure 5).

Figure 5. Field testing, regulation or policy creation, and final steps to implement a new truck configuration.

7. Field testing may be required by regulators to provide added assurance of the configuration's safety and performance. For field testing to be possible, one or more units must be created. This can normally be accomplished by combining existing tractors and trailers, and(or) modifying an existing trailer (e.g., adding an additional axle). In some cases, a trailer manufacturer will be enlisted to prepare a design and manufacture a prototype. The manufacturer's decision to

[3] AutoTURN is a CAD software compatible with Microsoft Windows OS, available in 2-D and 3-D versions.

produce a prototype typically depends on the economic case (step 1) but can also be influenced by assurances from regulators and the proponents.

Field testing can be conducted in the form of a technical test (i.e., to evaluate some aspect of performance under actual field conditions) or of a pilot trial with a limited group of trucks on defined route(s). Pilots are intended to comprehensively evaluate the performance of a configuration under real-life operating conditions, and this can take one year or longer. Pilots involve the monitoring of compliance with government-dictated terms and conditions (e.g., quarterly summaries of mill scale weight records; data from GPS-linked on-board dataloggers to monitor lift-axle deployment when on-highway). Pilots also may include gauging the stakeholder concerns and acceptance through surveys of drivers, other road users, enforcement officers, and local District staff. If issues or concerns arise, efforts to resolve these through dialogue, information sharing, or additional monitoring may be necessary. The pilot is concluded when either the regulator is satisfied that stakeholder issues or concerns have been resolved or if these issues and concerns cannot be resolved. A summary report about the pilot typically is prepared by the regulator, with input from the proponents.

8. At this point the province must develop the regulatory framework for supporting the use of the new configuration. This may involve drafting amendments to an Act and(or) the provincial weights & dimensions regulations to include the new configuration. This process is time consuming and requires the amendment to be passed by the legislative assembly. Alternately, regulators may create a program, and supporting policy, to allow use of the configuration on public highways in a way not covered by the Act and(or) Regulation (i.e., through a special use permit). Neighboring jurisdictions typically are consulted, especially where memorandums of understanding exist, and efforts made to harmonize weights & dimensions. Proponents are not normally involved in these actions.

9. If a new configuration is included in regulation, it can be implemented throughout the province subject to the same requirements that apply to all other regulated configurations. If a new configuration policy was created, however, this will stipulate when, where, and how the configuration can be used. The operating program for the configuration issues an annual permit or letter of authorization (LOA) to each participant and this must be carried in the vehicle as proof of authorization. These special programs typically have increased carrier safety and performance requirements (e.g., good driver records, on-board monitoring hardware, monthly reporting, less tolerance for non-compliance); regulators judge the increased program requirements are justified by the additional risks of operating larger trucks and by the economic advantages of participation. Some negotiation with proponents may occur to ensure program requirements are necessary, fair, and don’t impose undue hardship on participants. To minimize additional work for enforcement resources, industry proponents may be engaged by regulators to self-police the program. Permits/ LOAs can be revoked from those participants who cannot meet the program requirements.

   Proposed new log hauling configurations generally involve pairing existing tractor designs with new or improved trailer(s). (Tractor manufacturers are generally resistant to developing or refining tractors specifically for log hauling service because of the relatively small size of this market.) The new trailer configuration must be supplied at a competitive price and without undue delay to fill orders. For this reason, having multiple, local, trailer manufacturers to supply the new trailers is preferable. Proponents and FPInnovations (or other engineering support) may need to introduce the new configuration to these manufacturers and support the development of designs and pricing by supplying information about the projected benefits, application, and accepted dimensional ranges.

Another important aspect of implementation is the purchase of new configurations by trucking contractors. Progressive contractors may be willing to accept additional risks associated with purchasing a new truck configuration. Industry proponents should consider sharing this risk by offering incrementally higher and time-limited haul rates for first adopters. Timing of the new configuration's implementation is critical. The general economic climate of a forest company's operations can stop or severely impede implementation efforts. If a regional economic downturn is occurring, haul rates have been depressed, or the forest company has recently requested/ required its contractors to purchase new equipment, these trucking companies may lack the capital to purchase new equipment. In the case of implementing 9-axle log B-trains in BC, implementation efforts have been slowed by trucking contractors' resistance to purchasing new trailers until enough routes in their operating areas have been authorized for use.

Process Example: case study of the introduction of 9-axle B-trains to a haul corridor in Ontario

As previously stated, there are various ways to promote transport efficiency, including implementing new truck configurations, implementing or increasing winter weight premiums, and reducing the length or amount of spring road restrictions. The following is an example case study of a recently completed project in Ontario that sought to introduce a new high efficiency log truck configuration using this process. While this discussion is focused on raw forest products the process is applicable to the transport of many products by trucks carrying divisible loads.

In 2019, and on behalf of its forest industry members operating in Ontario, FPInnovations proposed to introduce a high efficiency 9-axle log hauling configuration to operate on specific routes (corridor) under permit. Although new to Ontario, 9-axle B-trains have been operating in BC, Alberta, and Saskatchewan since 2009. This year the Ontario Ministry of Transportation (MTO) created a permit program to allow the use of tandem-drive 9-axle log B-trains. This case study provides an overview of the process used to implement these configurations and references the 9-step process described above.

Per steps 1 and 2 of the process the proponent was a major Canadian forest company with sawmills in Thunder Bay, Sapawe and Ignace. The MTO regulators initially involved with the proposal were with the Carrier Program Development Office, Carrier Safety and Enforcement Branch, Pavements and Foundations Section, and the Bridge Management Section. The MTO advised that the most expedient method to implement a new truck configuration would be to create a policy and program specific to its use and limit the area of use to a hauling corridor. A review of forest operations in the Thunder Bay area and an assessment of the feasibility and economics of 9-axle log B-trains were described by Michaelsen (2019) and summarized below.

The objective of the proposal was to introduce a safe, high efficiency, log hauling truck configuration to Ontario. The general benefits expected from this new configuration include haul cost savings and associated improved competitiveness and sustainability of local industry, improved road safety, reduced greenhouse gas emissions, and reduced pavement maintenance requirements. Specific to the forest company and its trucking contractors, anticipated benefits include fewer trips and improved hauling safety, smaller fleet requirements, and more reliable access to wood.

The annual log hauling season typically lasts 51 weeks with 7 to 10 weeks, depending on weather, loaded to Ontario winter weight premiums, 4 weeks at spring road restrictions, and the balance at NOLTA Agreement weights.[4] Approximately 78% of the annual volume of logs transported is trucked at NOLTA Agreement weights and about 22% transported at winter weights; no volume is normally hauled during the spring load restriction period. Compared with the typical 7-axle log trucks in the area the 72.5-t tandem-drive 9-axle B-trains will increase payloads by 7.4 t (+17%) in the summer and 4.6 t (+10%) in the winter for an annual payload increase of approximately 6.8 t (+15.5%). Based on previous projects FPInnovations estimates a haul savings of about 8% per truck per year and reductions in fuel use and GHG emissions of approximately 10%.

The average harvest volume in the forest company's managed woodland is fixed over each 10 year-long planning period. For this reason, use of higher efficiency trucks for log hauling results in fewer truck trips and this will reduce traffic congestion and improve public safety. If all the forest company's log hauling trucks were replaced with 9-axle tandem-drive B-trains, the result is estimated to be a reduction in log truck trips of about 2500 trips per year (13%) and would help with the driver shortages faced by the Canadian forest industry. High efficiency log trucks increase the amount of wood available to a mill by allowing forest companies to economically access smaller diameter wood (improved utilization) and wood from further distances. Transporting more wood per trip with fewer trucks also allows mills to reduce mill yard inventory volumes and the associated costs (land rental, insurance, etc.). Finally, reducing the number of trucks in contractor fleets will reduce fixed fleet costs (license and insurance), some operating costs (e.g., fuel and tires), and ease fleet maintenance requirements.

Figure 6 illustrates the approved routes within the 9-axle log hauling corridor. The corridor totals 753 km of public highway with segments of Ontario highways 17, 61 and 61B, 130, 516, 599, 622 and 623 (3 km only), and 642.

[4] Under the Northwestern Ontario Log Transportation Association (NOLTA) Agreement log trucks may be loaded up to 105% of legal highway GVW. Under the Ontario raw forest product winter weight program log trucks may be loaded up to 10% of legal highway GVW. Ontario spring road restrictions typically restrict loadings to 5 t per axle.

Figure 6. Proposed highway sections in the 9-axle log B-train corridor (Google map image).

The truck configuration described in this case study is a 72.5-tonne 9-axle tandem-drive log B-train with wide-spread tridem axles on the trailer. The steering axle carries 5,500 kg, and the tandem-axle drive group carries a maximum of 17,800 kg. Maximum loading of 24,600 kg is carried on both the lead and rear trailer tridem-axle groups, respectively. The configuration's allowable gross vehicle weight (AGVW) is 72,500 kg (711 kN) and the maximum payload will be 51,000 kg; this AGVW applies all year with no increase for winter. The overall length of the unit is 27.5 m while the base-length (distance from first to last axle) is 25.30 m. Figure 7 presents a weight & dimension schematic and Figure 8 illustrates a comparable unit operating in AB.

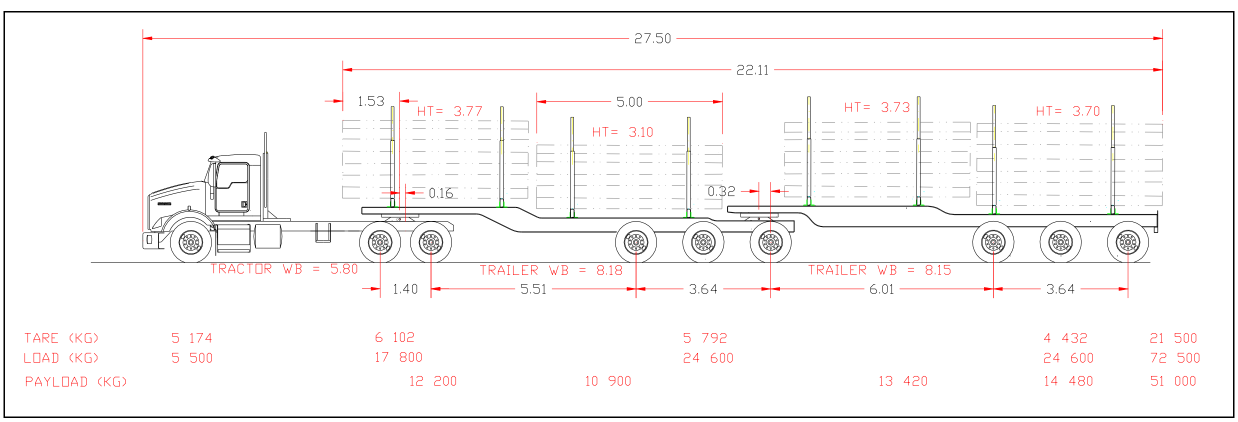

Figure 7. Proposed 9-axle tandem-drive log B-train weights and dimensions (in metres).

Figure 8. Example of tandem-drive 9-axle B-train operating in Alberta.

The tandem-drive tractor configuration uses a tractor with dimensions common to Ontario Forestry operations. This will allow trucking contractors wishing to participate in the 9-axle corridor program to use existing tractors and limit their capital investment in new equipment.

Vehicle Dynamics. Per steps 4 to 6, FPInnovations undertook a series of technical analyses to assess the dynamic performance, pavement impacts, and infrastructure impacts (bridge and culvert impacts); these analyses are summarized in the following sections but described in detail in (Bonsi and Parker 2021), (Thiam and Bober 2021), and (Bradley 2021), respectively.

FPInnovations evaluated the dynamic performance of a 72.5-t tandem drive 9-axle B-train and, in consultation with MTO, a reference configuration was selected for comparison that was representative of the heaviest current log hauling trucks used in the Thunder Bay region—a 63.5-t tandem-drive 8-axle B-train (Figure 9).

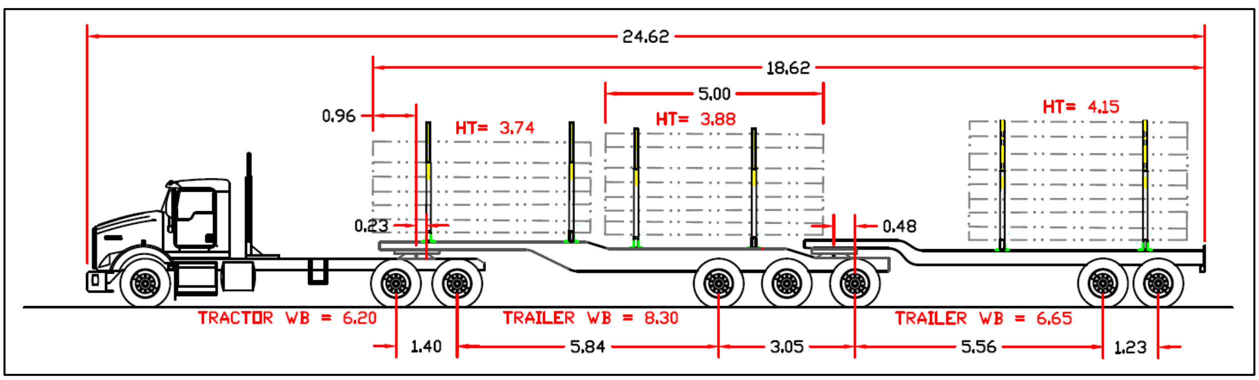

Figure 9. An 8-axle log B-train was the reference configuration for the vehicle dynamics evaluation (all dimensions in metres).

Dynamic simulations were conducted with the UMTRI yaw/roll model and eight standard performance measures. During this analysis, the sensitivity of dynamic performance was analyzed by changing key dimensions and weights. The parameters that were varied included dimensions (tractor wheelbase, trailer wheelbases, drive axle group spread, trailer axle group spreads, and bunk width) and payload distribution. Table 1 summarizes the dynamic performance results (results in **bold** did meet the performance standard).

Results showed that the proposed 72.5-t tandem drive 9-axle B-train compared favorably to the 63.5-t 8-axle log B-train. The proposed 9-axle configuration exhibited improved stability and dynamic performance characteristics. Despite the tandem drive 9-axle having increased Low-Speed Off-Tracking (LSOT) and High-Speed Off-Tracking (HSOT) compared to the reference vehicle, all results met the performance threshold except for the HSOT at 110 km/h and the Friction Demand (FD). While the excess friction demand was minor and not judged to be a concern, a follow-up analysis of 9-axle off-tracking was conducted to assess the impact of the increased LSOT. The off-tracking results indicated that the 9-axle tandem-drive B-train had comparable turning requirements to log trucks currently operated in the Thunder Bay region. With respect to the HSOT, limiting travel speeds for this configuration to 100 km/h was recommended to help ensure safe operation. Overall, the proposed 9-axle configuration compared favorably with the reference 8-axle B-train configuration.

Table 1. Dynamic Dynamics Results by Performance Measure

Performance Measure	Performance threshold	Baseline (63.5-t 8-axle B-train)	Proposed 72.5-t tandem-drive 9-axle B-train
1) Static Rollover Threshold	> 0.4 g's	**0.376**	0.402
2) Load Transfer Ratio (90 – 110 km/h)	< 0.60	0.479 – 0.530	0.425 – 0.493
3) Friction Demand (8.85 km/h)	< 0.10	**0.114**	**0.149**
4) Low-Speed Off-tracking (8.85 km/h)	< 5.6 m	4.911	5.159
5) Lateral Friction Utilization (8.85 km/h)	< 0.80	0.613	0.649
6) Rear Outswing (8.85 km/h)	< 0.2 m	0.087	0.118
7) High-Speed Off-tracking (90 – 100 km/h)	< 0.46 m	0.359 – 0.425	0.409 – 0.460
7) High-Speed Off-tracking (110 km/h)	< 0.46 m	0.425	**0.489**
8) Transient Off-tracking (90 – 110 km/h)	< 0.80 m	0.445 – 0.664	0.479 - 737

*Results in **bold** do not meet performance standard.*

Pavement Impacts. FPInnovations conducted two comparative pavement analyses to characterize and quantify impacts from the proposed 9-axle configuration. First, a load equivalency factor (LEF) analysis was performed to estimate long-term pavement impacts in terms of equivalent single axle loads (ESALs). Project terms of reference required the ESAL analysis to utilize the AASHTO (1993) definition; however, supplemental analyses also were presented using both TAC (1986) and FPInnovations (2018) ESAL definitions because these definitions account for single (steering) axles and are based on Canadian pavement structures. Secondly, advanced pavement modelling was performed to quantify the spontaneous responses and long-term impacts to the various pavement structures within the corridor (both surface-treated and asphalt concrete pavements). The 9-axle tandem-drive B-train results were compared to those from two log truck configurations currently operating in the corridor (a 63.5-t 8-axle B-train and a 62-t 7-axle tractor/ quad-axle trailer).

The load equivalency comparison found that the 9-axle tandem-drive B-train is much more pavement-friendly than current log hauling trucks. Using TAC load equivalencies, the 9-axle tandem-drive B-train generated 16% and 24% fewer ESALs per tonne of payload than the reference 8-axle B-train and 7-axle tractor/quad-axle trailer log hauling configurations. Of the 750,000 tonnes of logs to be hauled annually in the corridor by the forest company's trucking contractors 78%, on average, of this will be hauled under unfrozen conditions and these truck loads will generate approximately 98,130 ESALs. If the fleet were to be replaced with tandem-drive 9-axle B-trains, the result would be a net reduction of 16,790 ESALs (17%).

Available pavement data from the MTO Asset Management System was assembled for the highways in the corridor; data was available for 720 km (93%) of the total 753 km of corridor highway. It was determined that there were too many variations in pavement structure and that some simplification was needed for the advanced pavement modeling. Accordingly, the pavements were sorted according to pavement type and strength (Table 2). All of the surface-treated pavements had granular base equivalent thicknesses (GBE) of 600 - 625 mm and very thin to thin surface treatments. All of the hot mix asphalt "King's highway" pavements had thicker surface mats and GBE of 600 - 625 or 700 - 870 mm. Table 2 presents this pavement data arranged into 4 groups. One worst case structure was selected to conservatively represent each group—these pavements had the smallest GBE and were somewhat representative (i.e., >5% of their group's combined length) (Table 3).

Table 2. Pavement Structure Groupings

Highway	**Total length (km)**	**MTO rating**	**Subgrade type**	**Subgrade modulus (MPa)***	**Subbase (mm)**	**Base (mm)**	**Pavement type**	**Surface (mm)**	**GBE (mm)**
642, 599	89	Fair - good	Granular, sandy silt	41	710 - 715	80-85	Surface-Treated	20	600
622, 599, 516	316	Fair - good	Granular, sandy silt	35 - 41	260 - 740	22 - 240	Surface-Treated	30-92	600-625
623, 622, 130, 61, 17	80	Fair - good	Sandy silt	35 - 50	110 -	165 - 235	Thin AC	50 - 145	600-625
130, 61, 17	236	Good	Sandy silt	35 - 50	170 - 575	50 - 310	AC	130 - 190	700-870

* *Subgrade modulus was conservatively estimated in consideration of AMS data, MTO studies, and other published data*

Table 3. Representative Conservative Pavement Structures Used for Modeling

Pavement Structure	**Length of representative section (km)**	**Subgrade modulus (MPa)***	**Subbase (mm)**	**Base (mm)**	**Pavement type**	**Surface (mm)**	**GBE (mm)**
1	52	41	710	85	Surface-Treated	20	600
2	45	41	743	22	Surface-Treated	40	600
3	19	35	112	235	Thin AC	145	600
4	19	35	567	50	AC	135	700

Once grouped, the four pavement structures were modeled with the pavement analysis program WinJULEA. Instantaneous strains were calculated for each of the wheel assemblies on the three trucks and compared. Next, using Asphalt Institute (1982) damage relations these strains were transformed into estimates of the number of truck passes that would create a failed condition in either rutting or in bottom-up fatigue cracking, respectively.

The smallest number of truck passes to reach a failed condition in either rutting or fatigue cracking governs; and the governing results for each pavement were compared for the three trucks (Figures 10 and 11). Finally, a sensitivity analysis was performed on additional structures from each grouping to confirm that the representative worst-case structures were, indeed, the weakest structures within their respective groups and that all other sections had equal or better performance.

From an advanced pavement modelling standpoint, the 9-axle tandem-drive B-train generated lower critical strains and this, theoretically, should result in longer pavement life (climate and other traffic not withstanding). Considering the sensitivity analysis results, the lives of the surface-treated pavements in the corridor were predicted to be extended by 24% - 38% while the life of asphalt pavement structures would be extended by 2% - 6%. These results indicate that, with the introduction of the new trucks, pavement damage rates in the corridor should be reduced and this should generate considerable pavement maintenance benefits in the corridor on King's and, especially, surface-treated highways.

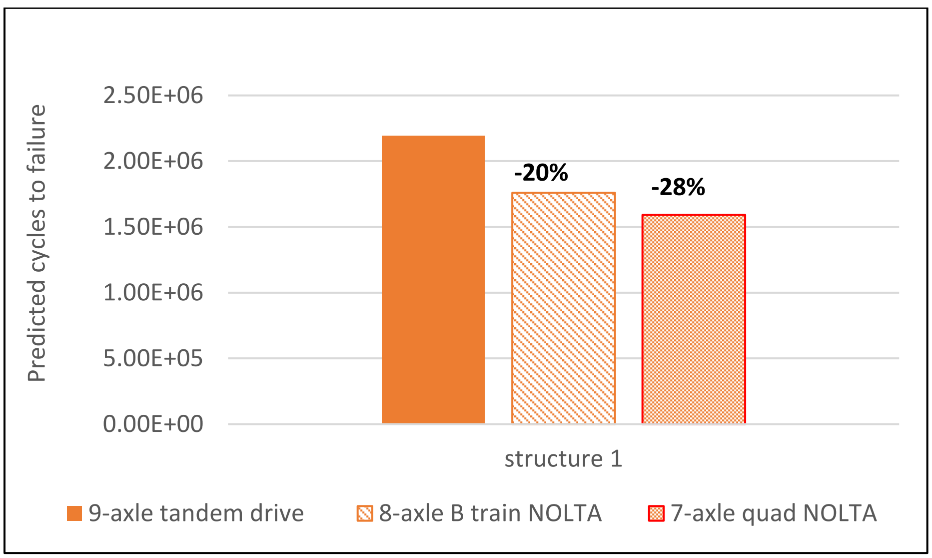

Figure 10. Predicted cycles to a failed condition in rutting for structure 1 (weak, surface-treated).

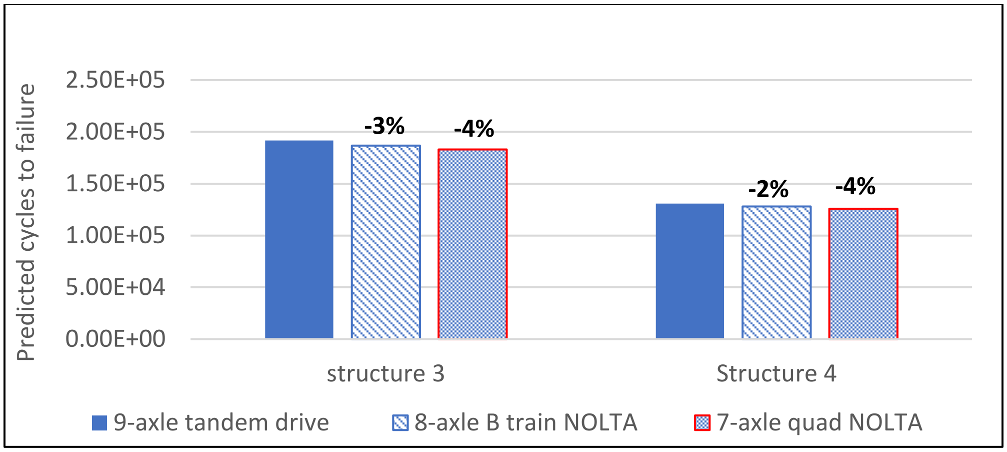

Figure 11. Predicted cycles to a failed condition in fatigue cracking for structures 3 and 4 (hot mix asphalt).

Bridge and culvert impacts. FPInnovations conducted a general bridge impact analysis using the MTO equivalent base-length methodology applied to the proposed 72.5-t 9-axle B-train and to the 8-axle B-train reference at winter and summer loading. To gain additional insight other analyses also were completed: a screening evaluation of each corridor bridge and at-grade culvert, detailed evaluations of two of the longest bridges in the corridor, and an assessment of forces acting on buried culvert structures.

An equivalent base-length analysis plots the load and equivalent base-length of every possible grouping of adjacent axles of a truck configuration. The analysis characterizes the potential bridge impacts of the truck configuration by comparing it to the same type of values generated by the Ontario Bridge Formula (which has a known demand on MTO bridge designs). The number of equivalent base-length axle groupings varies with the number of truck axles and was 37 and 29 for the 9-axle and 8-axle log B-trains, respectively. Figure 12 illustrates a plot of load-equivalent base-length values for the 72.5-t 9-axle B-train relative to the Ontario Bridge Formula and to an adjacent curve, offset by 100 kN, that is referred to as the “maximum observed load” curve. The analysis compared how many and by how much the equivalent base-length values of the 9-axle tandem-drive B-train and the two reference trucks exceeded the Ontario Bridge Formula Curve. Compared to the 8-axle B-train, the 9-axle B-train had a comparable number of values exceeding the Ontario Bridge Formula curve and the amounts by which they exceeded the Ontario Bridge Formula curve also were comparable.

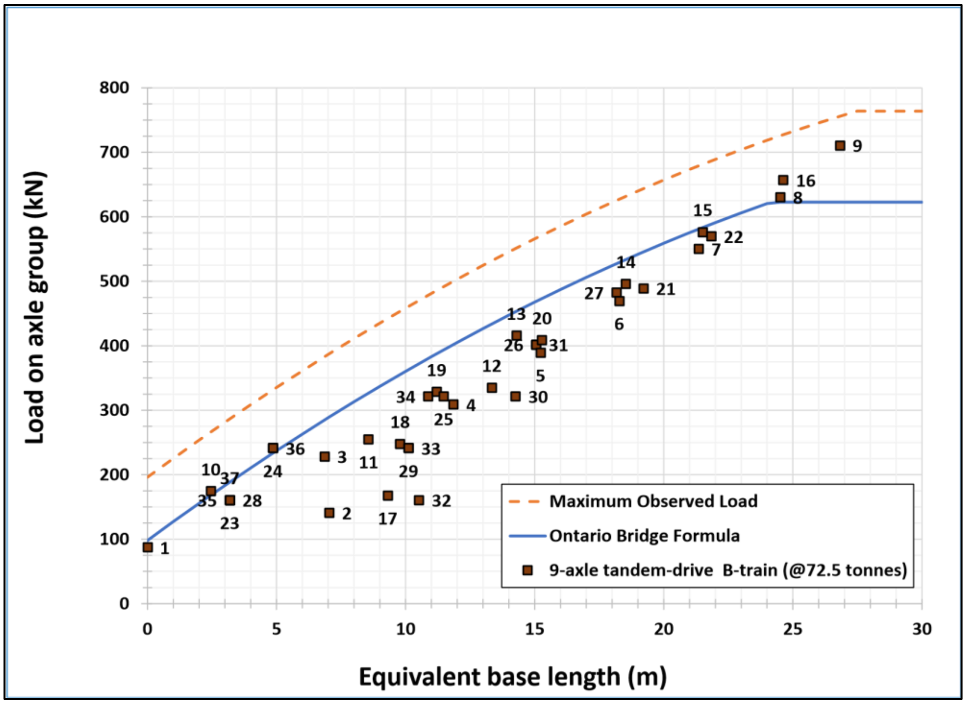

Figure 12. Load - equivalent base-length plot of the 72.5-tonne tandem-drive 9-axle B-train.

The corridor highway segments contain 15 simply supported bridges (14 single span and 1 multi-span) and 37 culverts (19 at-grade and 18 buried). A preliminary screening of each bridge and at-grade culvert in the corridor was completed using Leap CONSYS bridge analysis software. These calculations quantified the maximum end reactions, shear forces, and positive bending moments generated by the 72.5-t 9-axle B-train and by four reference configurations representing current log hauling traffic (the 8-axle B-train and 7-axle tractor/ quad semi-trailer at typical Northern Ontario Log Transportation Association or NOLTA Agreement loadings and at winter weights). For those continuously connected and(or) multi-span bridges the maximum pier reactions and negative bending moments (over the pier) were also calculated. In addition, the impact of the 9-axle B-trains on buried culverts was assessed by contrasting their maximum single, tandem, and tridem axle loadings with those of the reference configurations.

The preliminary screening found that the majority of the simply supported bridge spans and all at-grade culverts will experience a decrease in force effects with the introduction of 72.5-t tandem drive 9-axle B-trains as compared to current log truck loadings. The four longest, simply supported, span bridges will experience 4%-5% increases in shear and 1%-2% increases in bending moment, as compared to current summertime traffic at NOLTA Agreement weights but comparable force effects to the current log truck loadings at winter weights. Finally, due to its lighter axle weights, 9-axle tandem-drive B-trains are predicted to cause a general decrease in forces acting on the buried culvert structures in the corridor.

The corridor highway segments also contain 13 continuously or semi-continuously connected bridges. Bridge analyses when introducing 9-axle B-trains into British Columbia found that negative bending moments over the piers tend to govern with continuous span bridges. A similar result was found with the corridor continuous span bridges and can be explained by the relatively long base-length of the 9-axle B-trains. Table 4 presents the results from the MTO analysis in terms of percent change from the maximum force effects generated by the reference 8-axle B-train at current summer (NOLTA Agreement) loadings.

Table 4. Ratio of Max. Demands from 72.5-t 9-axle Tandem-drive B-trains to the Governing Demands from Two Reference Log Trucks at NOLTA Agreement Loading. Continuously Connected, Multi-span Bridges in the Corridor

Structure	**Span lengths (m)**	**Governing reference truck***	**Maximum demand from 72.5-t tandem-drive 9-axle B-train / maximum demand from governing reference vehicle at NOLTA Agreement loading**		
			Max. Shear	**Max. Positive Bending Moment**	**Max. Negative Bending Moment**
Kaministiquia River Bridge	38-50-38	8-axle	**104.6%**	**101.6%**	**105.3%**
Kakabeka Falls Bridge	18-25-25-25-18	8-axle	98.0%	93.1%	**108.3%**
Seine River Bridge	23-29-29-23	8-axle	99.8%	95.7%	**108.0%**
C.P.R. Overhead at Sheba Kaministiquia	20-26-20	8-axle	100.0%	93.6%	**108.9%**
English River Bridge	27-27	8-axle	99.7%	95.4%	**110.8%**

** Reference vehicles: "7-axle" = 7-axle tractor/ quad semi-trailer (62.055 t); "8-axle" = 8-axle B-train (66.68 t)*

A comparison of force effects in continuous span bridges found that, compared to current log truck loadings, the 72.5-t tandem drive 9-axle B-train would generate small increases in shear (4.6%) and positive bending moment (1.6%) in the longest bridge but decreased shear and positive moment in the other four bridges. However, of more significance was that, compared to current log truck loadings, a 5%-10% increase in negative moment will occur at their bridge piers. At the direction of the MTO, detailed evaluations were undertaken by TBT Engineering, a Thunder Bay-based bridge consultant, on two of the longest, continuously supported, multi-span bridges. These evaluations were taken as representative test cases to determine whether the longest corridor bridges would have sufficient capacity to withstand the additional demands caused by the 72.5-t 9-axle B-train. Both structures were found to have sufficient capacity to withstand the demands of the 72.5-t 9-axle B-trains.

Road fit. Given the gentle terrain and comparable turning requirements of the 9-axle tandem-drive B-train and the 8- and 7-axle trucks currently in use within the hauling corridor it was judged that no formal evaluations of road fit were needed.

Per step 7, and because 9-axle B-trains are similar to existing truck configurations and have an established record of safe use in other Canadian jurisdictions the MTO did not require field testing, a pilot, or special monitoring hardware. Summary reports regarding the technical analyses were prepared by FPInnovations in 2021 and submitted to the MTO for review and approval. At the time of writing aspects of steps 8 and 9 are still being completed. MTO regulators are creating a policy and special permitting program to allow the operation of 72.5-t 9-axle tandem-drive log B-trains on the corridor highways.

Concluding remarks. Canada is a very large country blessed with abundant natural resources; however, these natural resources are located far from markets. Governments and industry in Canada must work together to create safe, reliable, and efficient transportation systems that help ensure industry competitiveness and stability and the economic sustainability of communities reliant on resource extraction. FPInnovations works closely with governments and the forest industry towards this goal. The subject of this paper has been the general process followed by project proponents, industry, and government to introduce new, large, high efficiency, truck configurations. High efficiency trucks that can safely and reliably carry larger payloads are a proven way to reduce transportation costs and create significant economic investment and development. Necessarily, the needs and concerns of affected stakeholders and public infrastructure must be safeguarded. Regulators ensure this by including in their approval processes and terms of reference requirements for robust technical analyses, consultation, and field testing/ monitoring/piloting where appropriate. Further, where high efficiency trucks have been specially permitted for use program participation is treated as a privilege and registrants may be required to demonstrate enhanced levels of safety, maintenance, and compliance.

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