Transport Canada Transports Canada

Transport Canada's Innovation Centre – On-Road RD&D 6x2 Drivetrains Testing & Evaluation

Task Force on Vehicle Weights and Dimensions Meeting

November 27, 2019

Canada

OVERVIEW

- TC Innovation Centre
- Background/Context
- Approach
- Track Testing
- Dynamic Simulation
- Infrastructure Impacts Analysis

Transport Canada's Innovation Centre

In January 2018, Transport Canada launched the Innovation Centre (IC) …

… a transportation innovation Research, Development & Deployment (RD&D) organization tasked with:

- driving an integrated departmental approach to transportation innovation;
- partnering in new ways with government, industry and academia; and
- leveraging emerging technologies for the benefit of all Canadians.

… with a vision: *"To enable bold and innovative transportation solutions that enhance the safety, security, accessibility, and environmental performance of transportation in Canada."*

On-Road RD&D (ecoTECHNOLOGY for Vehicles Program)

- tests, evaluates and provides expert technical information on advanced light-duty vehicle (LDV) and heavy-duty vehicle (HDV) technologies.

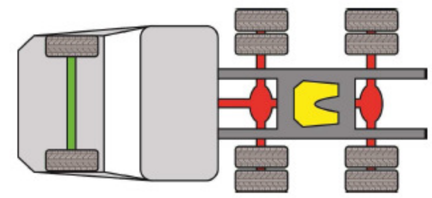
- testing and evaluation results:
  - guide the proactive development of codes, standards, and regulations;
  - support the development of non-regulatory industry codes and standards that anchor industry efforts to integrate new vehicle technologies.

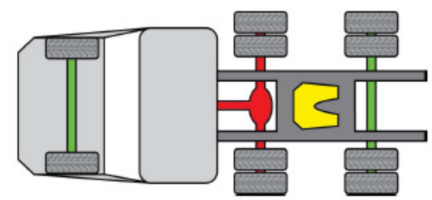
- testing priorities are focused on addressing knowledge gaps, particularly where new innovations have potential environmental or safety implications.

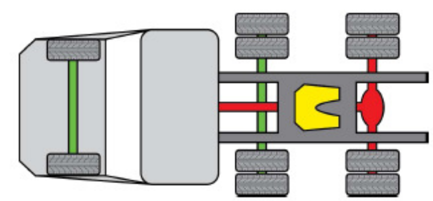
- A few eTV projects related to assessing technologies for improving efficiency include:
  – Cooperative truck platooning systems
  – Vehicle-to-Vehicle Communication Testing (DSRC)
  – **6x2 Axles**

HDV 6x2 Axle Technology – Background Information

- Traditional highway tractors employ a 6x4 drive configuration which uses a non-powered steer axle and two powered rear axles.
- Recent innovations have resulted in increased availability of 6x2 configurations in North America -- which employ only one powered rear axle in one of two configurations:
    - Tag – forward most drive axle is powered (Kenworth, Freightliner); and,
    - Pusher – rear most drive axle is powered (Volvo).
- OEMS can have different load shifting (biasing) strategies, for example:
    - During low speed operation load is transferred to the drive axle to gain traction
    - During high speed operation load is transferred to the dead (LRR) axle for fuel economy
- Increase in individual axle loads could have implications for:
    - Infrastructure (i.e. loading that is higher than the current allowable axle limits); and,
    - Vehicle traction and dynamic stability (i.e. high speed maneuvering after load shifting has occurred).


6x4 arrangement


6x2 tag tandem 6x2 architecture


6x2 pusher tag 6x2 architecture

Potential Benefits	Potential Challenges
• fuel economy • reduced emissions • reduced maintenance • mass reduction	• **loading on infrastructure** • **vehicle dynamics and traction** • tire wear

HDV 6x2 Axle Technology – Project Approach

The eTV Program technical assessment has three planned phases.

✔	**Phase 1 – Technical Literature Review – Completed August 2016** • Review available OEM technical documents, peer-reviewed publications, consult OEMs and suppliers, and other available material to characterize different 6x2 architectures and performance.
✔	**Phase 2A –Test Plan Development – Completed September 2016** • Development of track testing procedure to measure how much load is transferred to the drive axles in various loading configurations.
✔	**Phase 2B – Winter Track Testing (Two vehicle pairs) – Completed February 2017** • Equip the vehicles with wheel force transducers to measure the loads and moments at each wheel Complete track testing at TC's Motor Vehicle Test Center (MVTC) to measure axle loads and moments during accelerations from a dead stop on a low µ (ice) surface.
✔	**Phase 2C – Winter Track Testing (all vehicle pairs) – Completed February 2018** • Similar to Phase 2B, but including a third vehicle pair, transitions to higher speeds, and lighter loads.
✔	**Phase 2D – Dynamic Simulation – Completed September 2019** • Use empirical data from testing to simulate dynamic performance in various scenarios.
✔	**Phase 3A – Infrastructure Analysis – Completed June 2019** • Centre for Pavement and Transportation Technology (University of Waterloo) conducted infrastructure impacts analysis.

Test Vehicles: 6x2/6x4 Vehicle Pairs

Kenworth T680 (provided by ECCC)	VNM62T 200 (provided by Volvo)	Freightliner Cascadia Evolution 125 (provided by TC)
		
PACCAR MX-13 HD, 12.9L 455 hp @1700 rpm, 1650 lb.-ft.@1000 rpm Governed RPM: 2,200 rpm Automated Eaton 10 spd **6x2: tag tandem** G.C.W, 80,000 lbs Fr Axle: 12,000 lbs Rr Axle: 6x4 40,000 lbs, 6x2 34,000 lbs Trailer Load (lbs): 40,000 Emission controls: LRRA, IRTE, ATS, TGR	Volvo D11 425V/1550, 11L 425 hp @ 1600 rpm 1550 lb-ft @1000 rpm Governed RPM: 2,200 rpm I-Shift ATO2612D, **6x2: pusher tandem** G.C.W, 80,000 lbs Volvo VF12 12,500 lbs Meritor RS23-160 23,000 lbs 40K; 20K Volvo Air Suspension, W 20K Liftable Aux Axle 50" Meritor ABS with VEST	Detroit DD15, 14.8L 400 hp @ 1,625 rpm, 1,750 lb-ft @1,075 rpm Governed RPM: 2,200 rpm DT12-OA-1550 automatic **6x2: tag tandem** GCW: 80,000 lbs (36,300 kg) 6x4: 40,000 lbs tandem 6x2: 20,000 lbs single 20,000 lbs tag 2.28 rear axle ratio ABA, ACC and LDW technologies

TRACK TESTING

- Testing at Motor Vehicle Test Centre, Blainville QC
- Open deck trailer with range of ballast amounts and distributions
- Acceleration from a standing start on an ice pad on DELTA, transitioning to clear pavement for a lap around BRAVO (~6.5km), reaching 80km/h
- The magnitude and duration of load shifting events were measured using wheel force transducers.

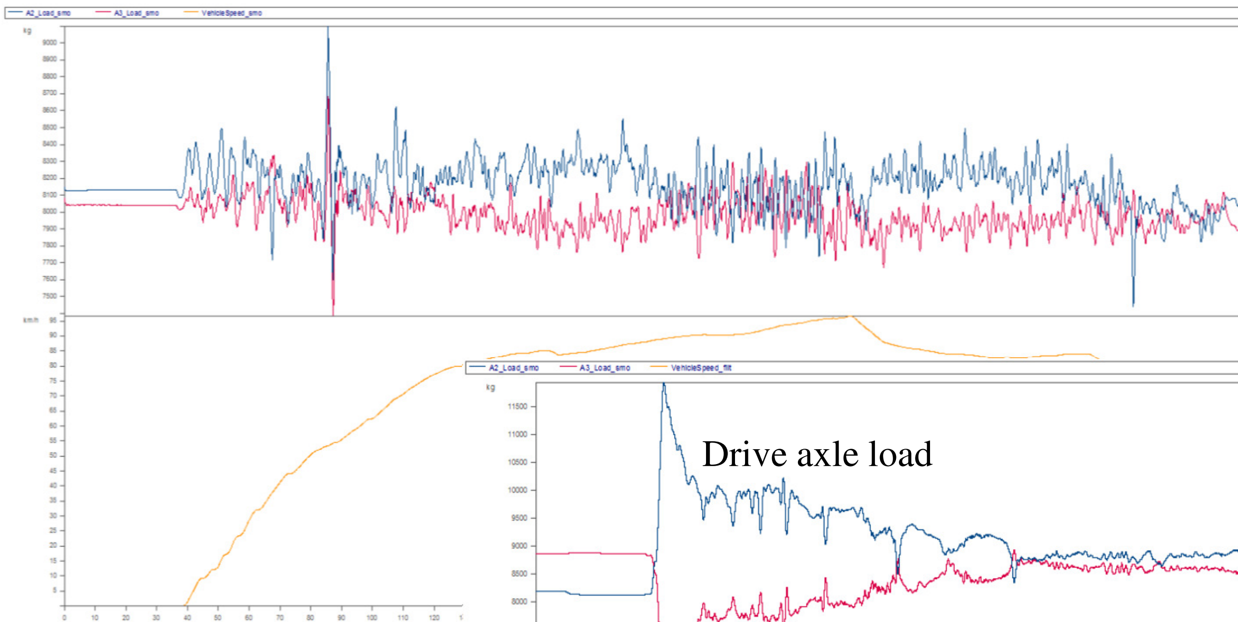
Target Axle Loads

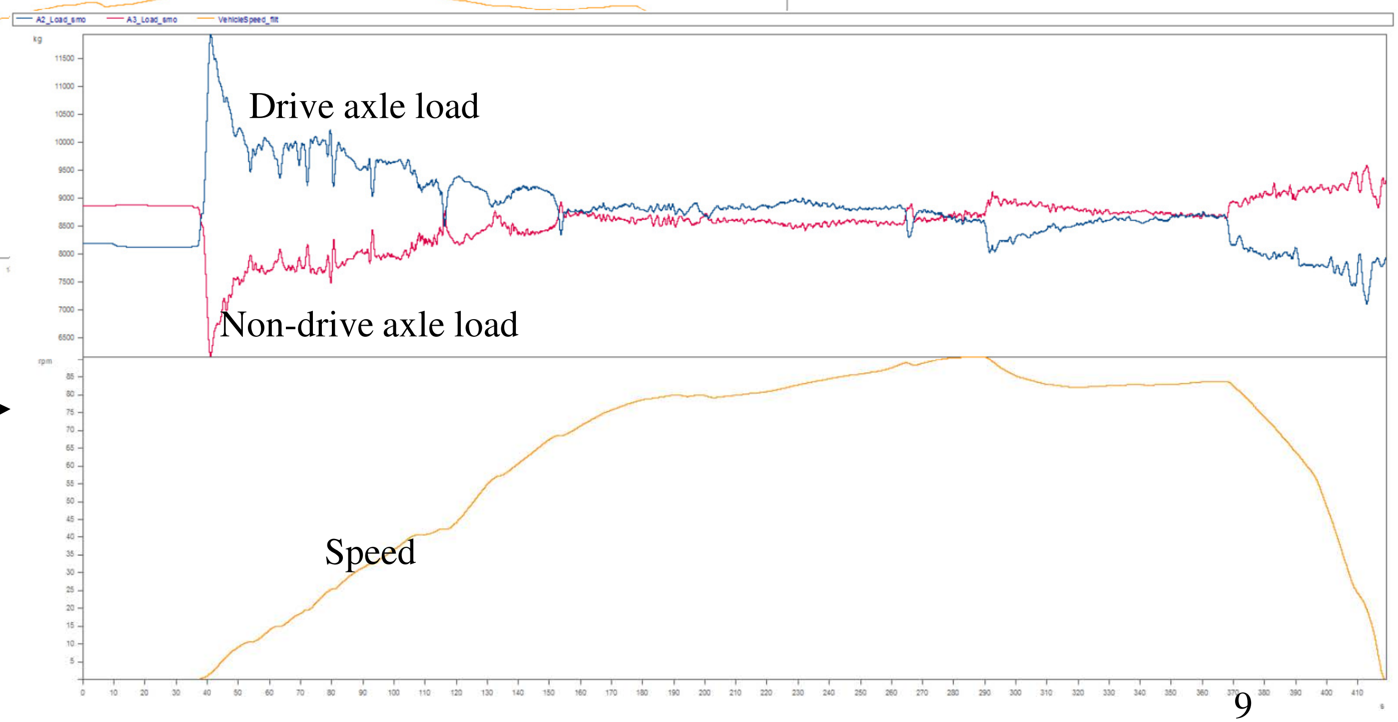
100%	85%	70%	50%	0%
10,000 kg**	8,500 kg*	7,000 kg	5,000 kg	Empty Trailer

*MOU Limit, **Exceeds limits in most jurisdictions (and Kenworth design limit)

TRACK TESTING – EXAMPLE RESULTS

8,500 KG TARGET AXLE LOAD





EXAMPLE RESULTS: 7,000KG STATIC TARGET

Canada
NRC-CNRC

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	7 257	7 504	7 400
	Rear	Driven	7 152	7 231	7 192
KB	Middle	Driven	6 588	8 880	8 795
	Rear	Un-driven	6 593	5 775	5 805
VA	Middle	Driven	6 638	6 821	6 782
	Rear	Driven	6 573	6 750	6 747
VB	Middle	Un-driven	7 051	4 528	4 641
	Rear	Driven	6 915	9 118	9 037
FA	Middle	Driven	7 195	7 327	7 288
	Rear	Driven	7 137	7 167	7 185
FB	Middle	Driven	7 138	8 914	8 906
	Rear	Un-driven	6 862	5 651	5 661

SUMMARY – TRACK TESTING

- Using load biasing, the **6x2 vehicles were able to accelerate from a stop** on a level ice patch with comparable performance to their 6x4 counterparts for all loading conditions.
- **The drive axles had design limits.** As the total weight on the tandem axle set was increased, the magnitude of weight shifted to the drive axle decreased.
- **Load biasing strategies varied between vehicles.**
  - "VB" had the most aggressive load biasing strategy, but limited drive axle weight to ~9,100 kg if possible (ideal for light loads).
  - "KB" employed load biasing for relatively short durations, equalizing axle loads shortly after gaining traction.
  - "FB" employed load biasing during the slip event, and equalized axle load when the vehicle reached a speed of 72 km/h.

PROVINCIAL INPUT

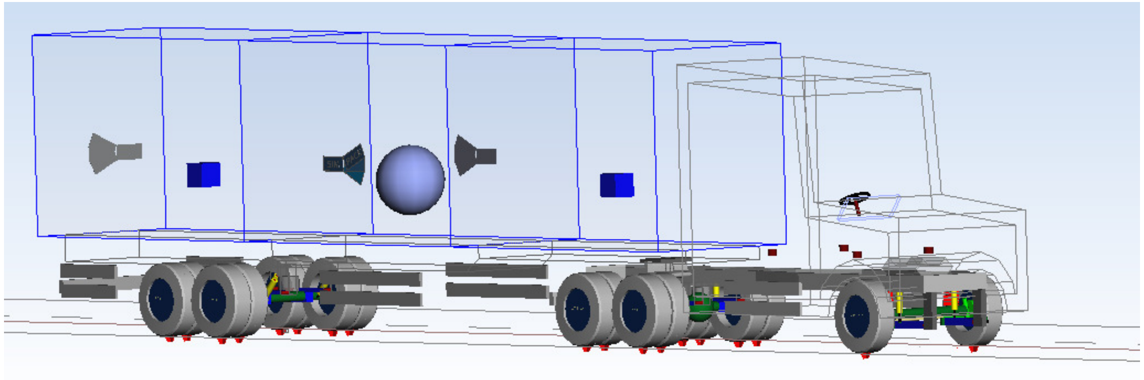
Feedback received from the provinces/territories has included:

- *How do 6x2 axle technology perform in more challenging traction conditions (low friction, grade, with and without tire chains).*
- *How stable are 6x2 technology compared to 6x4 during an emergency lane-change maneuver*
- *What is the 6x2 vehicle response during a load biasing event while at speed, accelerating, and decelerating, cornering along a curved down slope.*
- *How do high traction and low traction tires affect 6x2 performance.*

… challenging to test full range of scenarios on a test track.

DYNAMIC MODELING AND SIMULATION

- **Simpack model developed** for 6x4 and 6x2 tractor-semitrailers that simulates
  - load shifting between axles in tandem set for 6x2,
  - tag and pusher tandem axle configurations for 6x2,
  - various manoeuvers: curves, lane changes, hills, range of speed/acceleration, and
  - various vehicle/road conditions: payloads, tires, coefficients of friction.
- **Limitations:** Model did not include powertrain or engine traction control, ABS braking system not made to match an existing system



SUMMARY – DYNAMIC SIMULATION (1)

- During manoeuvers on **level roads**, including on curves, the 6x2 and 6x4 configurations performed similarly.
- During **hill climbs** up to 15% grade
  - On **packed snow or higher traction** surfaces the 6x2 and 6x4 configurations performed **similarly** at all payloads, and
  - on **low traction surfaces (ice or loose snow)** the 6x4 truck was able to climb steeper grades than the 6x2 truck (load biasing incl.).

6x4 Hill Climb at Constant Speed

Coefficient of Friction	Maximum Grade (%)			
	1300 kg payload	10300 kg payload	20300 kg payload	26300 kg payload
0.1	3.0	3.0	2.9	2.9
0.2	6.2	6.2	6.1	6.1
0.4	12.7	13.2	12.5	12.5
0.6	>15	>15	>15	>15
0.8	>15	>15	>15	>15
1.0	>15	>15	>15	>15
1.2	>15	>15	>15	>15

6x2 (Tag) Hill Climb at Constant Speed

Coefficient of Friction	Maximum Grade (%)			
	1300 kg payload	10300 kg payload	20300 kg payload	26300 kg payload
0.1	3.0	2.8	1.9	1.4
0.2	6.2	5.8	3.8	3.4
0.4	12.8	11.7	7.6	6.5
0.6	>15	>15	11.9	10.1
0.8	>15	>15	>15	13.5
1.0	>15	>15	>15	>15
1.2	>15	>15	>15	>15

Coefficients of Friction

0.1 -> Ice or loose snow
0.3 -> Sanded ice/snow
0.4 -> Packed snow
0.5 -> Wet road
0.6 -> Dry dirt road
0.8+ -> Dry Asphalt
Max. Grade in Canada: 7-12%

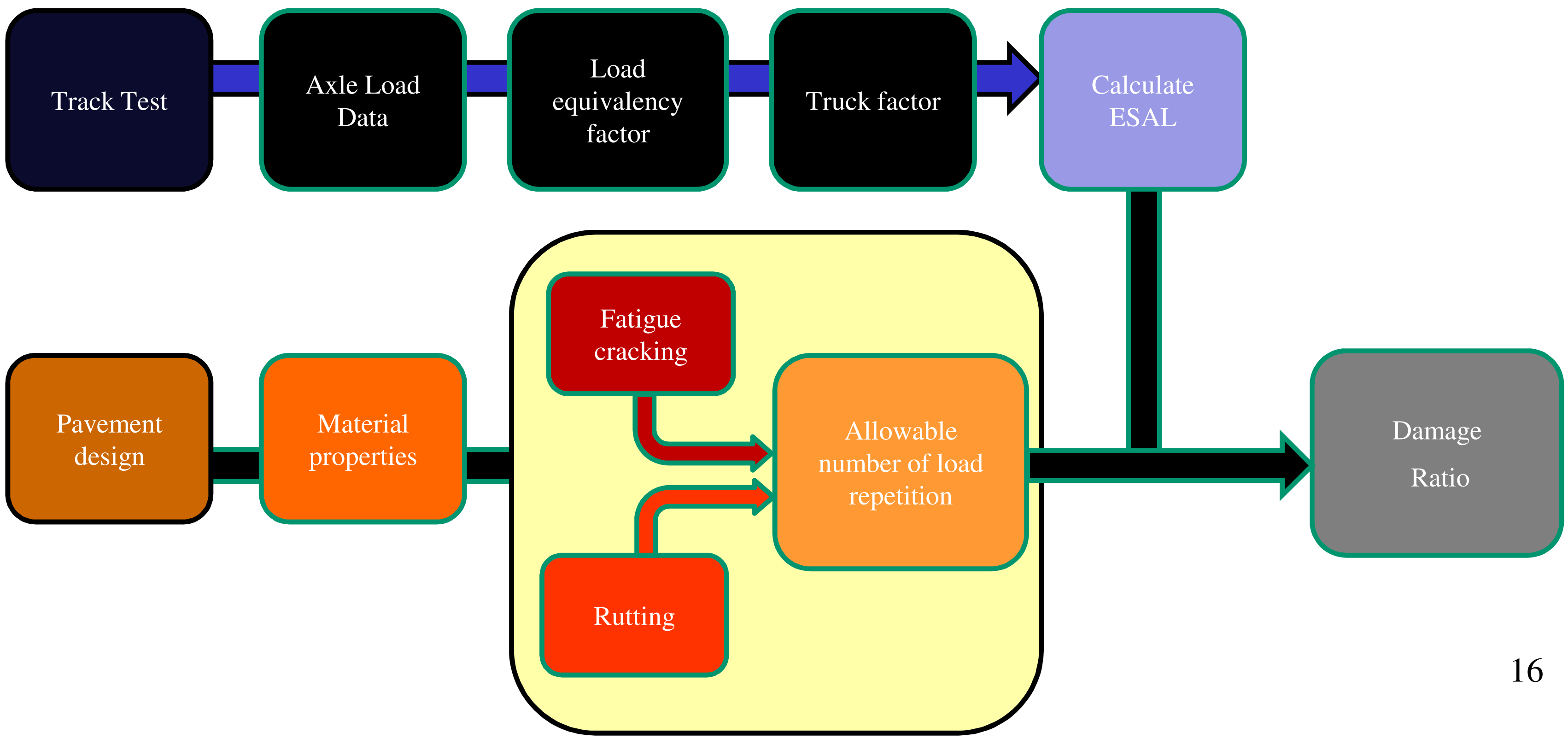
SUMMARY – DYNAMIC SIMULATION (2)

- With **high traction tires**, the maximum ascendable grade increased by at least 25% for all configurations.

- On a **downhill curve** (12% grade and 333m radius)
  - The 6x4 tractor semitrailer could maintain speed on a surface with a lower coefficient of friction (0.17) compared to the 6x2 with load shifted (0.22).
  - Both of these coefficients of friction are representative of un-sanded ice or loose snow.
  - With high traction tires, the 6x2 was able to descend a hill with a coefficient of friction as low as 0.18.

INFRASTRUCTURE IMPACTS ANALYSIS

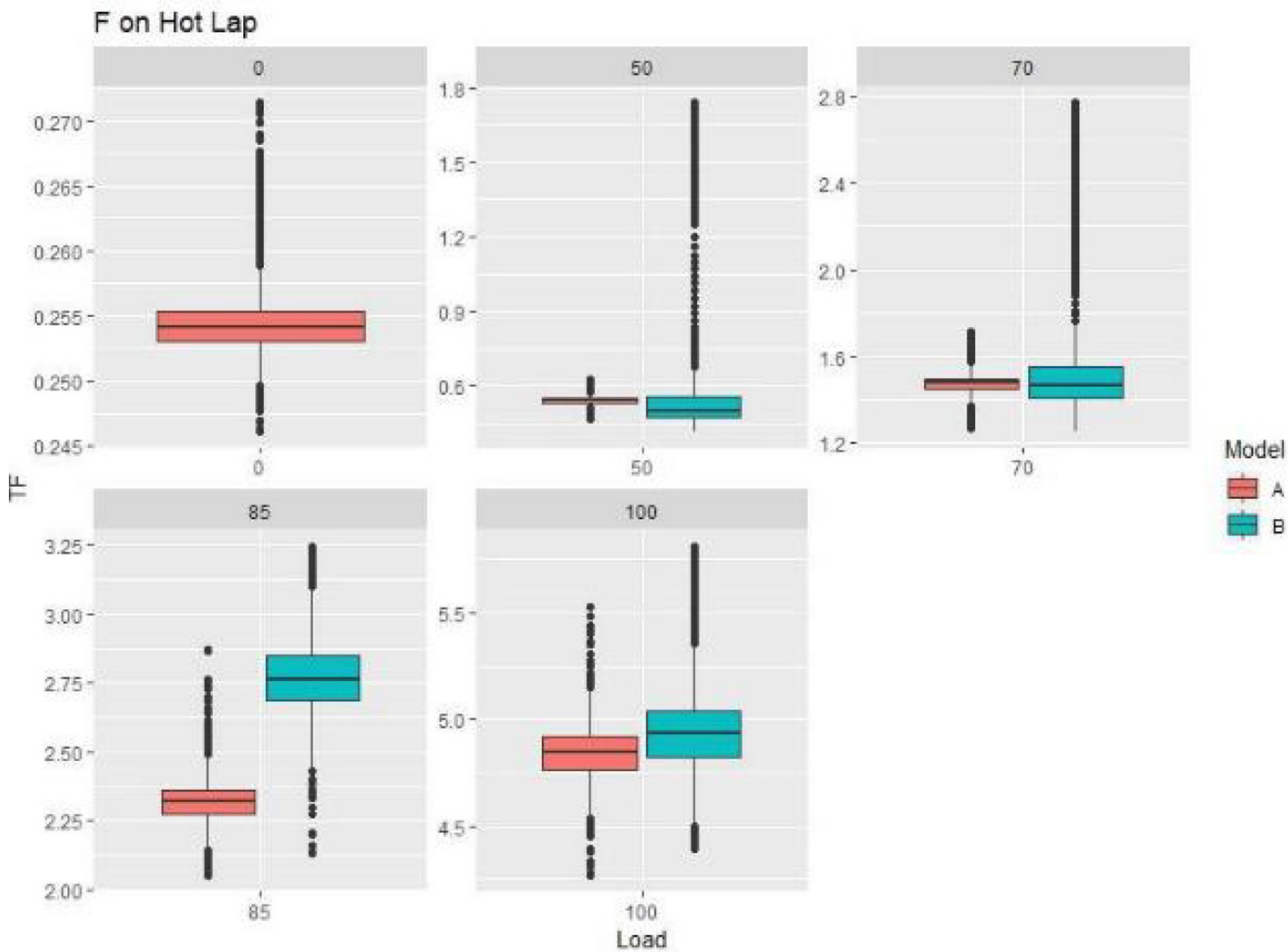
- Online survey conducted to obtain pavement information for Provinces/Territories.
- Track test results used to calculate truck factors and ESAL.



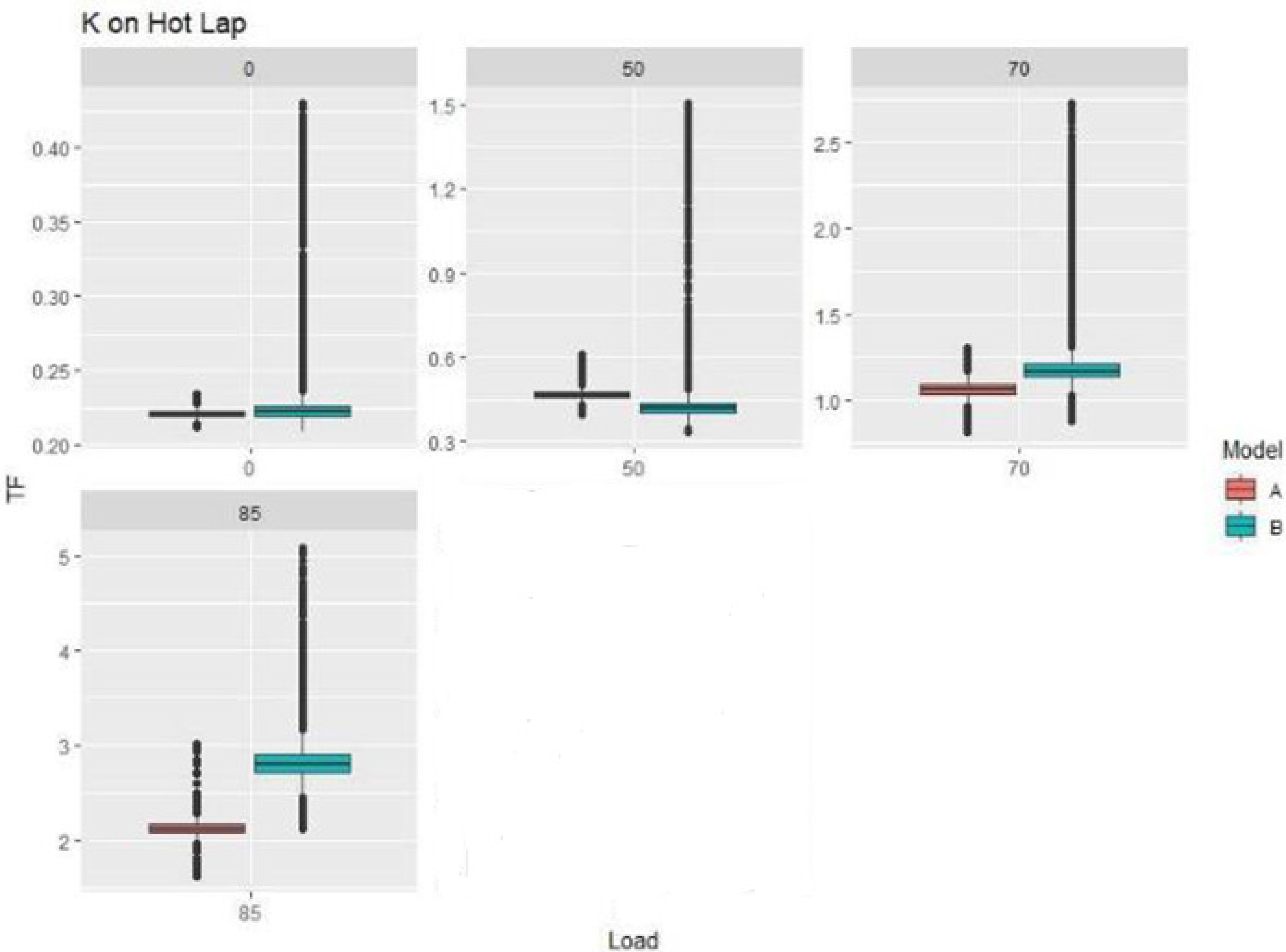
INFRASTRUCTURE IMPACTS ANALYSIS

- When there is **no load biasing event**, infrastructure impacts are **equivalent** for 6x2 and 6x4 configurations.
- Load-biasing events may cause infrastructure impacts.
  - We don't have data on real-world frequency and locations of load-biasing events (e.g. on ice patches).
  - Data from the **NRC Dynamic Axle Load Test** was used for the analysis
    - The test consists of acceleration from a stand-still on ice and transitioning to dry pavement and higher speeds (80 km/h) for a 6.5 km loop.
    - Applied to data from the NRC Dynamic Axle Load Test, the analysis represents a scenario where vehicles repeatedly lose traction in the same location.
    - This is a **particularly challenging scenario** for infrastructure impacts.

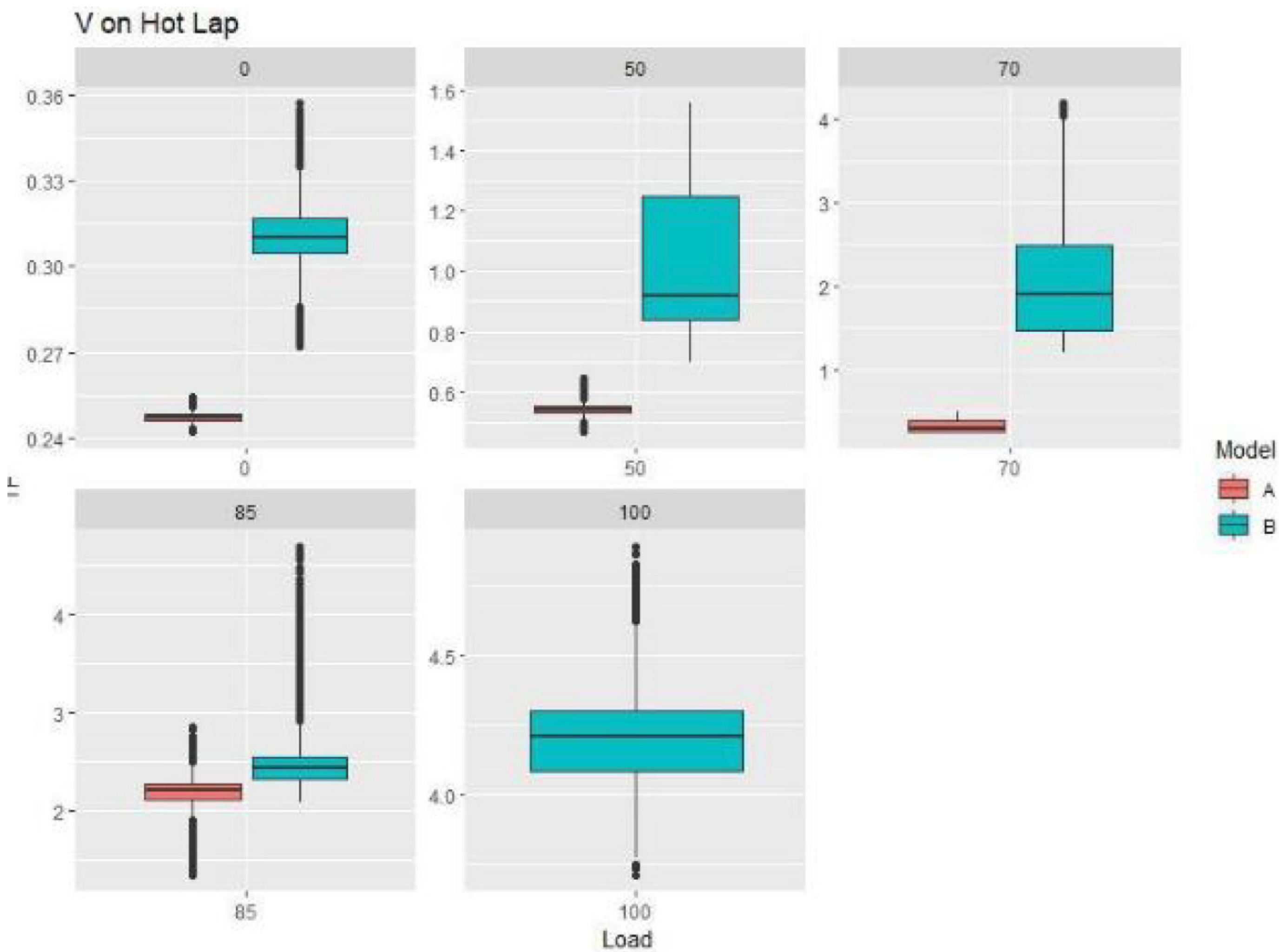
INFRASTRUCTURE IMPACTS – TRUCK FACTOR



INFRASTRUCTURE IMPACTS – TRUCK FACTOR



INFRASTRUCTURE IMPACTS – TRUCK FACTOR



INFRASTRUCTURE IMPACTS - EXAMPLE FLEXIBLE PAVEMENT PRELIMINARY RESULTS

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Fatigue cracking damage ratio (first year) at the average truck factor values *

Road level	Manufacturer	Configuration	Damage ratio (1st year)				
			100% Load	85% Load	70% Load	50% Load	0% Load
Highway	KW	6×2	NA	2.90	1.26	0.46	0.24
		6×4		2.16	1.09	0.48	0.23
	FL	6×2	5.03	2.83	1.65	0.74	-
		6×4	4.94	2.37	1.50	0.55	0.26
	VV	6×2	4.29	2.53	2.03	1.05	0.32
		6×4	-	2.21	0.32	0.55	0.25
Major Arterial	KW	6×2	NA	3.70	1.60	0.59	0.30
		6×4		2.76	1.38	0.61	0.29
	FL	6×2	6.42	3.61	2.11	0.94	-
		6×4	6.30	3.02	1.91	0.71	0.33
	VV	6×2	5.47	3.22	2.59	1.34	0.40
		6×4	-	2.82	0.41	0.70	0.32
Minor Arterial	KW	6×2	NA	1.55	0.67	0.25	0.13
		6×4		1.15	0.58	0.25	0.12
	FL	6×2	2.69	1.51	0.88	0.39	-
		6×4	2.64	1.26	0.80	0.30	0.14
	VV	6×2	2.29	1.35	1.08	0.56	0.17
		6×4	-	1.18	0.17	0.29	0.13
Collector	KW	6×2	NA	0.98	0.43	0.16	0.08
		6×4		0.73	0.37	0.16	0.08
	FL	6×2	1.71	0.96	0.56	0.25	-
		6×4	1.67	0.80	0.51	0.19	0.09
	VV	6×2	1.45	0.86	0.69	0.36	0.11
		6×4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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*6x2 average truck factors are representative of the NRC Dynamix Axle Load Test.

INFRASTRUCTURE IMPACTS - EXAMPLE
FLEXIBLE PAVEMENT PRELIMINARY RESULTS

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Rutting damage ratio (first year) at the average truck factor values*

Road level	Manufacturer	Configuration	Damage ratio (1st year)				
			100% Load	85% Load	70% Load	50% Load	0% Load
Highway	KW	6×2	NA	0.16	0.07	0.03	0.01
		6×4		0.12	0.06	0.03	0.01
	FL	6×2	0.27	0.15	0.09	0.04	-
		6×4	0.27	0.13	0.08	0.03	0.01
	VV	6×2	0.23	0.14	0.11	0.06	0.02
		6×4		0.12	0.02	0.03	0.01
Major Arterial	KW	6×2	NA	0.39	0.17	0.06	0.03
		6×4		0.29	0.15	0.06	0.03
	FL	6×2	0.67	0.38	0.22	0.10	-
		6×4	0.66	0.32	0.20	0.07	0.03
	VV	6×2	0.57	0.34	0.27	0.14	0.04
		6×4	-	0.30	0.04	0.07	0.03
Minor Arterial	KW	6×2	NA	0.52	0.23	0.08	0.04
		6×4		0.39	0.20	0.09	0.04
	FL	6×2	0.91	0.51	0.30	0.13	-
		6×4	0.89	0.43	0.27	0.10	0.05
	VV	6×2	0.77	0.46	0.37	0.19	0.06
		6×4	-	0.40	0.06	0.10	0.05
Collector	KW	6×2	NA	0.32	0.14	0.05	0.03
		6×4		0.23	0.12	0.05	0.02
	FL	6×2	0.55	0.31	0.18	0.08	-
		6×4	0.54	0.26	0.16	0.06	0.03
	VV	6×2	0.47	0.27	0.22	0.11	0.03
		6×4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*6x2 average truck factors are representative of the NRC Dynamix Axle Load Test.

INFRASTRUCTURE IMPACTS
GRAVEL ROADS PRELIMINARY RESULTS

Summary of Gravel Road minimum thickness using avg tf (Serviceability) *

Road level	Manufacturer	Configuration	Minimum Thickness (Damage Ratio)				
			100% Load	85% Load	70% Load	50% Load	0% Load
Gravel Road	KW	6×2	NA	229 (0.93)	178 (0.69)	178 (0.25)	178 (0.13)
		6×4		203 (0.90)	178 (0.60)	178 (0.26)	178 (0.12)
	FL	6×2	279 (0.94)	229 (0.91)	178 (0.91)	178 (0.41)	-
		6×4	279 (0.92)	203 (0.98)	178 (0.83)	178 (0.31)	178 (0.14)
	VV	6×2	254 (0.97)	229 (0.81)	203 (0.85)	178 (0.58)	178 (0.18)
		6×4	-	203 (0.92)	178 (0.18)	178 (0.30)	178 (0.14)

*Summary of Gravel Road minimum thickness using avg tf (Rutting)**

Road level	Manufacturer	Configuration	Minimum Thickness (Damage Ratio)				
			100% Load	85% Load	70% Load	50% Load	0% Load
Gravel Road	KW	6×2	NA	254 (0.90)	178 (0.92)	178 (0.34)	178 (0.17)
		6×4		229 (0.87)	178 (0.80)	178 (0.35)	178 (0.17)
	FL	6×2	330 (0.93)	254 (0.88)	203 (0.99)	178 (0.54)	-
		6×4	330 (0.91)	229 (0.95)	203 (0.91)	178 (0.41)	178 (0.19)
	VV	6×2	305 (0.94)	254 (0.79)	229 (0.82)	178 (0.77)	178 (0.23)
		6×4	-	229 (0.89)	178 (0.24)	178 (0.40)	178 (0.19)

*6x2 average truck factors are representative of the NRC Dynamix Axle Load Test.

SUMMARY – INFRASTRUCTURE IMPACTS

General

– During a load biasing event (e.g. triggered by loss of traction), the 6x2 vehicles have higher truck factors than their 6x4 counterparts.

Flexible Pavement

– Using average truck factors from the NRC Dynamic Load Tests:
  - At 8,500 kg/axle target conditions, the rutting and fatigue cracking damage ratios were 14% to 34% greater for 6x2 compared to 6x4.
  - At lower loads, for most cases damage ratios were 5% to 33% higher for the 6x2 vehicles compared to the 6x4 vehicles.

Gravel Roads

– At 5,000 kg/axle and below, 6x2 and 6x4 had equivalent minimum thickness for both serviceability and rutting.

– At loads above 7,000 kg/axle, if load biasing is triggered, the 6x2 configuration requires a greater gravel road thickness to achieve rutting criteria.

***Results for 6x2 represent a particularly challenging scenario for infrastructure – frequent loss of traction**

QUESTIONS?

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https://www.tc.gc.ca/en/initiatives/innovation-centre.html

EXAMPLE RESULTS: 8,500KG STATIC TARGET

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	8 152	8 445	8 384
	Rear	Driven	8 138	8 237	8 238
KB	Middle	Driven	7 439	9 592	9 322
	Rear	Un-driven	9 220	7 760	7 932
VA	Middle	Driven	8 223	8 301	8 271
	Rear	Driven	8 179	8 286	8 279
VB	Middle	Un-driven	8 381	7 006	7 189
	Rear	Driven	7 954	9 108	8 963
FA	Middle	Driven	8 241	8 354	8 305
	Rear	Driven	8 202	8 211	8 217
FB	Middle	Driven	8 616	9 328	9 741
	Rear	Un-driven	8 385	8 014	7 718