CHALLENGES IN DECREASING GREENHOUSE GAS EMISSIONS BY INCREASING THE AXLE LOAD PERMITTED ON WIDE BASE SINGLE TIRES

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ABSTRACT

In 2006, the Ontario Ministry of Transportation (MTO) initiated a research plan to assess the potential benefits and challenges associated with the mitigation of greenhouse gas emissions by allowing the use of new-generation wide base single (WBS) tires. This would entail increasing the permissible axle weights up to 9000 kg.

An experimental investigation was carried out at the Centre for Pavement and Transportation Technology (CPATT) instrumented test sections at the University of Waterloo. The experiment was designed to assess the additional pavement costs, if any, as a result of increasing the allowable axle load on WBS tires up to 9,000 kg. The second part of the study was to identify potential benefits of raising the allowable axle weights from the economic, environmental and societal perspectives. The third area of study focused on assessing the potential impact on safety in terms of vehicle dynamic performance and collisions. The safety analyses was done by computer simulation.

The results of these studies indicate that the potential benefits, from societal and trucking industry perspectives would be $80 million assuming 50% uptake at a fuel price of $1.00/litre and 1.5% fuel savings per axle. This includes the annual benefits of $5 million associated with reduced greenhouse gas emissions from fuel savings and safety benefits of $5 million associated with the potential collision avoidance. Pavement costs in Ontario could increase up to $34 million annually for the same uptake of WBS tires if the axle load was increased to 9000 kg. In conclusion, the overall benefits outweigh the adverse effects associated with the use of WBS tires carrying an increased axle load of 9000 kg.

INTRODUCTION

Recently, tire manufacturers have been producing a second-generation new technology low-profile WBS tires with a diameter that is identical to dual tires. These manufacturers have approached the Province of Ontario and other provinces requesting that provincial regulations be modified to accommodate the use of the new generation WBS tires as a viable replacement for dual tires. Several advantages of this new technology are cited:

1. Dimensionally compatible with the 11R22.5 dual tires they replace;
2. Improved fuel efficiency through reduced rolling and aerodynamic resistance, which potentially translates into lower operating costs and less environmental impact through lower green house gas emissions;
3. Less overall vehicle tare weight through reduced wheel and tire mass, which potentially translates into increased payload potential, lower raw material and energy inputs, less recycled or disposed mass and less resulting emissions;
4. Better ride quality through increased sidewall flexibility, which translates into reduced potential for cargo damage;
5. Improved handling and vehicle stability, which translates into improved safety performance under normal conditions, and increased potential for collision avoidance/collision severity reduction during emergency manoeuvres.

A key consideration for road and regulatory agencies is to assess the benefits and costs associated with the use of these new-generation WBS tires. In 2006, MTO initiated a research project to assess the potential benefits and the adverse effects of allowing the use of new-generation WBS tires. The research included a comprehensive experimental investigation carried out on the instrumented pavement sections of the Centre for Pavement and Transportation Technology (CPATT) field testing facility at the University of Waterloo. The research was intended to address the concerns among highway agencies on the impact that WBS tires with axle loads of up to 9,000 kg could have on pavements. In addition, MTO retained Knowles Consultancy Services Inc. in 2007 to conduct a comprehensive study, for assessing the benefits and costs from economic, environmental and societal perspectives when the use of new-generation WBS tires is promoted by increasing the allowable axle load to 9,000 kg [1]. The findings of these studies are expected to provide a sound basis for MTO to make an informed decision to allow the use of increased axle load on WBS tires thorough regulatory changes.

SCOPE AND OBJECTIVES

The scope of this study involved an experimental investigation carried out using the CPATT field testing facility at the University of Waterloo, followed by analysis of potential adverse effects on pavements associated with the use of WBS tires. As well, the work completed by Knowles Consultancy Services Inc. was reviewed to assess the potential benefits from economic, environmental and societal perspectives, as well as potential impact on safety in terms of vehicle dynamic performance and collisions.

The specific objectives of this study were: 1) to determine the additional pavement maintenance costs, if any, due to an axle equipped with WBS tires and loaded at 9,000 kg; and 2) to quantify the potential benefits of promoting the use WBS tires from the economic, environmental and societal perspectives.

CPATT EXPERIMENTAL INVESTIGATION

The CPATT test track is located near the University of Waterloo campus. It is a 700 m long and 8 m wide two-lane road with an instrumented test section consisting of 200 mm asphalt layers (100 mm HL-3 surface course and 100 mm HL-4 binder course). The thickness of Granular A base is 300 mm and that of Granular B sub-base is 300 mm.

The field testing included direct measurements of tensile strains at the bottom of the asphalt pavement layer under different axle loads on both dual and WBS tires. The detailed testing procedure and analysis can be found in the published references [2, 3].

With support from the trucking and tire industry, suitable trucks equipped with dual and WBS tires were used to compare the pavement response under different loading but identical environmental conditions. The trucks were equipped with a moveable load on the deck, as shown in Figure 1. The loads on the deck were moved back and forth as needed to achieve the axle load required for each test. The pavement response was assessed in terms of measured tensile strains under the asphalt pavement while the two single axle test trucks, one equipped with WBS tires (Figure 2) and the other with dual tires (Figure 3), travel at a predetermined speed within a minute apart. The main objective of the experiment is to estimate the load on dual tires equivalent to any given axle load on WBS tires that would provide identical pavement response under both tires at similar environmental conditions. This load will be referred to as Equivalent Dual Axle Load (EDAL) in subsequent discussions.

Figure 4 shows the relationship between the axle load and the strain observed on Westbound Lane (WBL) and Eastbound Lane (EBL) sections for both tire types. For the WBL section, the axle load on dual tires producing the same strain as WBS tire at 9000 kg is estimated at 10,700 kg which is identified as EDAL. Similarly, the EDAL value for the EBL section is 12,300 kg corresponding to 9000 kg on the WBS tires. The reason for higher EDAL for EBL section in comparison to WBL is due to the differences in pavement structural strength. The weaker the pavement, the higher is the EDAL value. This finding was supported by the Quebec study [4]. The two EDAL values (10, 7000 kg for strong and 12,300 kg for weak pavements) were used to assess the damage costs associated with different pavement sections of varying structural strengths across Ontario.

In addition, the effects of unequal tire pressures on dual tires, the wander effect on pavements, speed, and dynamic loading were assessed. The results showed that their effects compensate one another and are not considered significant as discussed in the report [2].

PAVEMENT COST ANALYSIS

The pavement maintenance costs associated with WBS tires were estimated using the MTO established procedure based on the comprehensive study carried out in 1996 [5]. In this study, a relationship between the ESAL and the marginal equivalent uniform annual cost associated with pavement maintenance and rehabilitation was established for each functional highway category in Ontario. As such, the impact on pavements associated with WBS tires was assessed in terms of changes in ESALs for trucks as a result of switching to WBS tires. The step-by-step approach used to assess the impact is described below.

Step 1: Ontario highways were divided into different functional categories according to MTO procedure. Table 1 provides the breakdown of the pavement network into functional categories together with the corresponding current Vehicle Kilometres Travelled (VKT) distribution for trucks previously estimated by MTO study [5]. One of the requirements of the cost assessment process was to represent the entire road network by judiciously selecting characteristic sections. Ontario's Road network was classified into 20 *functional categories.* A *functional category* was defined as a portion of the road network with relatively uniform pavement structures, and traffic loads, serving a distinct functional need.

Step 2: The EDAL values for loaded trucks equipped with WBS tires operating on Ontario highways were assigned as shown in Table 2. These values were assigned proportionally to the structural strength of pavement through extrapolation of the EDAL values obtained from the CPATT study. The strength of pavement for each highway category was assessed based on the estimated subgrade deflection under a standard axel load for a given pavement layer thickness as subsequently described. The details were given in the published CPATT report [2].

Step 3: The daily Axle-Vehicle Kilometers Traveled (AVKT) was estimated by axle configurations that might switch to WBS tires if the weight limit was increased to 9,000 kg on WBS tires using the information provided in the report [6]. For example, Table 3 shows the anticipated switch (in terms of AVKT) to WBS tires carrying an axle load excess of 8,000 kg. AVKT was obtained by multiplying VKT by the number of axles per truck.

Step 4: The AVKT (estimated in Step 3) was distributed among each functional category (Table 4) assuming the percent distribution was the same as VKT for trucks as shown in Table 3.

Step 5: Knowing the EDALs (Step 2), the ESAL for trucks carrying a given axle load when dual tires were replaced with WBS tires was calculated. The change in ESALs (the ESAL for trucks with WBS tires minus the ESAL for trucks with dual tires carrying the same axle load - Table 5) associated with each axle load was calculated using the MTO procedure [7].

Step 6: The pavement maintenance and rehabilitation costs corresponding to the change in ESALs were estimated using the relationship between the ESALs and marginal costs (Table 6), established by the study conducted in 1996 by MTO [5] as described before.

Illustrative example for assessing the impact on pavements

A Municipal Southern Local Highway (classified as 11S) was selected as an illustrative example for calculating the annual maintenance and rehabilitation cost of damage for each functional category based on the variable EDALs values as described below.

- Determined the percent distribution of AVKT (same as that of VKT) specifically operating on 11S which is equal to 2.21% as shown in Table 1.

- Selected the appropriate EDALs for different axle loads on with WBS tries operating on Highway 11S. For example, the EDAL for a truck carrying an axle load 9000 kg on WBS tires was equal to 12,731kg (Table 2).

- Determined the uptake of WBS tires in terms of AVKT. For example, daily AVKT carrying an axle load of 9000 kg on all highways was 1,759,657 (Table 3). In this case, it was assumed there was no overload.

- Calculated the total axle AVKTs specifically operating on Hwy 11S based on 2.21% distribution. For example, the total AVKT associated with an axle of 9000 kg on WBS tires was 33,220 (Table 4).

- Calculated the change in ESAL if the dual tires were replaced with WBS at all axle loads. For example, the ESAL change associated with 9000 kg on WBS tires was 4.1 (Table 5).

- Selected the appropriate marginal equivalent uniform annual cost per ESAL per lane kilometre of truck travel ($0.022 for in-service pavement and $0.044 for new pavement) from Table 6.

- Calculated the total marginal cost assuming that 10% of the highway infrastructure is in new condition, and 90% of the infrastructure represents in-service conditions. For example, the marginal cost corresponding to an axle load of 9000 kg on WBS tires was:

  (33220x 365 x 4.1x 0.022) 0.9 + (33220x 365 x 4.1x 0.044) 0.1 = $1,219,000

Similarly, the total maintenance and rehabilitation cost of for all highways was estimated at $10,988,625 (in 1996 dollar value) annually for trucks carrying axle loads between 8000 kg – 9000 kg as shown in Table 7. This was converted to the present worth value as discussed subsequently.

Likewise, analyses were carried out for estimating the costs associated with WBS tires carrying axle loads outside the range of 8000 kg-9000 kg. First case, all axle legal loads from 3,000 kg to 9,000 kg operating on all highways assuming no overloads were considered. In the second case, overloaded trucks based on the survey conducted in 1999/2000were included. According to this survey, about 24% of the trucks considered in this study carry overloads causing an additional maintenance cost estimated at $14 million. Some of them carry as high as 14,000 kg.

It is anticipated that with the introduction of SPIF (Safe, Productive, and Infrastructure-Friendly) vehicles, the number of overloaded vehicles operating on Ontario highways would be minimized.

Table 8 summarizes the pavement costs associated with different axle loads which were converted into the Present Worth Cost (PWC). In this analysis, a discount rate of 6% was considered appropriate to convert the 1996 dollar value to PWC as this rate was originally used in the study by MTO in 1996 [5] to calculate the present worth value of the future maintenance and rehabilitation costs. Based on 6% discount rate, the PWC of the estimated pavement damage assuming 50% uptake may range from $27 to $33 million depending on how well the legal axle load limits were enforced.

BENEFITS

The assessment of benefits for vehicles equipped with new-generation WBS tires was completed by Knowles Consultancy Services Inc. and Synectics Transportation Consultants Inc. in 2007 [1]. The benefits were evaluated from economic, environmental and societal perspectives which fall into following subject areas:

- Reduction in vehicle cost;
- Reduction in vehicle maintenance cost;
- Reduction in fuel consumption;
- Reduction in emissions associated with reduction in fuel consumption;
- Reduction in energy and resource consumption, and emissions, associated with tire manufacturing;
- Reduction in environmental impact associated with tire disposal;
- Increase in payload at weights approaching the permissible maximum gross vehicle weight, associated with reduction in tare weight of vehicle, due to lower wheel and tire mass;
- Improved operational safety due to improved stability and exposure reduction;

The breakdown of the total estimated benefits of 80 million associated with each of the above listed areas is given in Table 9. Because of page limitation, this paper only describes the benefits mainly associated with reduction in fuel consumption, emissions and environmental impact, as well as the potential benefits due to improved operational safety. The detailed calculation of the total benefits is given in the report [1].

Reduction in Fuel Consumption

This benefit is derived from the lower rolling resistance and aerodynamic drag of new-generation wide base single tires, relative to the rolling resistance and aerodynamic drag of conventional dual tires [1]. After a thorough review of associated past studies [10, 11, 12, 13, 14, 15], a representative estimate of 1.5% fuel savings per axle was adopted in the analysis. In consideration of fluctuation of world oil prices, an average diesel fuel cost of $1.0/L was used in the evaluation [16]. In terms of potential uptake on the opportunity to employ WBS tires, MTO expected 50% uptake among Ontario commercial vehicle fleet would benefit from the regulatory change [6]. Accordingly, major tractor and trailer configurations equipped with WBS tires can achieve fuel savings of 50 million litres annually. These fuel savings result in about $50 million as shown Table 9.

Reduction in Emissions and Environmental Impact

This benefit is associated with a reduction in fuel consumption. A study from Ministry of Transportation Quebec [15] suggested that $0.279 per litre be the cost of neutralizing the associated Green House Gas (GHS) emissions. However, considering the introduction of ultra low sulphur diesel fuel, associated emissions will be substantially reduced. Accordingly, the cost of neutralizing was estimated at $0.102/L [1]. The above fuel savings result in an avoidable environmental cost of $5 million annually. The benefit accrues to society as a whole, as the costs to mitigate environmental impacts are borne by society.

Improved Operational Safety

The safety impact of WBS tires is expected to be primarily influenced by their increased stability and reductions in exposure risk [1]. Stability refers to resistance to rollover based on a wider track and lower centre of gravity. Reductions in exposure is because fewer truck trips are required to move the same quantity of bulk commodities due to the increase in permissible gross vehicle weight and the nature of lighter tare weight.

A computer simulation was used to generate the performance of tractor and/or trailer configurations with WBS tires with an increase in axle load from 8,000 to 9,000kg [1]. The results were used to estimate collision avoidance expected from increasing use of WBS tires. Table 11 summarizes the benefits of the said subject areas associated with the proposed regulatory change under consideration [1].

SUMMARY

- The pavement maintenance and rehabilitation cost was assessed for two cases. In the first case, the trucks carrying weights less than 8000 kg and above the current legal load limit of 8000 kg up to the proposed legal axle load limit of 9000 kg were considered. In the second case, trucks carrying weights less than 8000 kg as well as above the proposed legal axle load limit of 9000 kg including overloads were considered. The cost in this case is expected to reflect the overall pavement maintenance and rehabilitation cost in real life as a result of increasing the axle load from 8000 kg to 9000 kg on WBS tires.

- The analysis showed (Table 8) that pavement maintenance and rehabilitation cost was estimated at present worth value of $33 million assuming 50% uptake.

- The total benefits to trucking industry and society in general were estimated at 80 million/year assuming 50% uptake. This includes the benefits associated with reduction of Green House Gas (GHS) emissions of about $5 million and a safety benefit of $5 million associated with potential collision avoidance.

CONCLUSION

The study indicated that the overall benefits will outweigh the pavement maintenance and rehabilitation costs associated with the use of WBS tires carrying an axle load of 9000 kg. The benefits include reduction of GHS emissions estimated at $5 million/year. From an environmental stand point, this will assist the government to reduce GHS emissions as part of creating an environmentally friendly system for transporting goods and services. However, the real challenge for agencies to reduce the GHG emissions using this approach was to convince the critics that the overall societal benefits of $80 million outweighs the cost of up to $33 million to the taxpayers.

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Table 1 Existing VKT (trucks) distribution for each functional category [5]

Code	Functional Category Name	AADT	% Truck	% 5+axles	5+axle AADT	2 Lane km	VKT	%
1N	Provincial Northern Urban Collector	110	4.0%	8.0%	0.4	68	24	0.00
1S	Provincial Southern Urban Collector	7,800	4.0%	8.0%	25.0	519	12,954	0.09
2N	Provincial Northern Urban Minor Arterial	6,500	7.0%	30.0%	136.5	20	2,730	0.02
2S	Provincial Southern Urban Minor Arterial	11,800	7.0%	30.0%	247.8	168	41,630	0.29
3N	Provincial Northern Urban Principal Arterial	4,000	9.0%	60.0%	216.0	42	9,072	0.02
3S	Provincial Southern Urban Principal Arterial	12,200	9.0%	60.0%	658.8	7	4,612	0.01
4S	Provincial Southern Urban Freeway	18,700	12.0%	60.0%	1,346.4	2,402	3,234,053	5.64
5N	Provincial Northern Rural Collector	800	12.0%	8.0%	7.7	7,228	55,511	0.39
5S	Provincial Southern Rural Collector	4,100	8.0%	8.0%	26.2	5,812	152,507	1.06
6N	Provincial Northern Rural Minor Arterial	3,800	16.0%	50.0%	304.0	908	276,032	1.92
6S	Provincial Southern Rural Minor Arterial	6,800	14.0%	50.0%	476.0	2,277	1,083,852	7.55
7N	Provincial Northern Rural Principal Arterial	3,500	22.0%	70.0%	539.0	3,303	1,780,317	12.41
7S	Provincial Southern Rural Principal Arterial	8,100	22.0%	70.0%	1,247.4	234	291,892	2.03
8S	Provincial Southern Rural Freeway	19,900	30.0%	70.0%	4,179.0	2,257	9,432,003	65.74
9N	Municipal Northern Local	300	4.0%	0.0%	0.0	13,273	0	0.01
9S	Municipal Southern Local	500	4.0%	0.0%	0.0	86,888	0	0.12
10N	Municipal Northern Collector	2,500	5.0%	2.0%	2.5	3,035	7,588	0.03
10S	Municipal Southern Collector	3,500	5.0%	2.0%	3.5	22,687	79,405	0.34
11N	Municipal Northern Arterial	3,500	7.0%	4.0%	9.8	1,649	16,160	0.11
11S	Municipal Southern Arterial	4,500	7.0%	4.0%	12.6	25,168	317,117	2.21
	Total				**9,438.5**	**177,945**	**16,797,457**	**100.00**

Table 2 Estimated EDAL values for each functional category

Hwy Type (1)	GBE (2)	Calculated Deflection mm (3)	Estimated % increase in Deflection (4)	EDAL (5)
9S	450	0.64	119	17,346
9N	550	0.53	80	14,946
5S	630	0.46	58	13,592
1S	690	0.42	44	12,731
10S	690	0.42	44	12,731
11N	690	0.42	44	12,731
11S	690	0.42	44	12,731
5N (EBL)	730	0.40	37	12,300
2S	770	0.38	30	11,869
1N	790	0.37	26	11,623
10N	790	0.37	26	11,623
7S	800	0.37	25	11,561
6N	810	0.36	23	11,438
6S	810	0.36	23	11,438
2N	870	0.34	15	10,946
4S	880	0.33	14	10,885
3S	900	0.33	11	10,700
7N (WBL)	900	0.33	11	10,700
8S	980	0.30	2	10,146
3N	1000	0.29	0	10,023

Table 3 Daily Axle-Vehicle Kilometre (AVKT) by axle types using WBS tires carrying axle loads above 8000 kg

Axle Load Kg	Tandem Tractor	Tandem Trailer	Tridem Trailer	Tandem in self-steer Tri-axles	Tridem in self-steer quads	Tandem in B-trains	Axle Load Range kg
8100	381,417	122,377	15,552	0	33,925	35,717	588,989
8200	406,210	86,255	7,039	978	32,432	50,175	583,089
8300	381,411	104,940	16,314	510	10,237	36,340	549,752
8400	412,608	117,357	36,296	0	53,032	50,554	669,846
8500	333,428	114,850	9,557	2,898	14,875	61,972	537,579
8600	256,285	73,729	1,033	952	10,714	54,799	397,512
8700	243,595	39,826	6,997	82	14,765	27,651	332,917
8800	191,769	39,879	3,474	5,029	17,789	32,082	290,021
8900	183,281	53,609	2,661	3,493	3,210	12,736	258,990
9000	1,202,207	237,250	36,549	20,669	147,976	115,006	1,759,657
Total Axle VKT for WBS tires	**3,992,211**	**990,072**	**135,472**	**34,610**	**338,956**	**477,031**	**5,968,353**

Table 4 Distribution of Axle AVKT associated with WBS tires by Functional Categories

Hwy Group	AVKT Distribution	Axle Loads, kg									
		8100	8200	8300	8400	8500	8600	8700	8800	8900	9000+
1N	0.00%	1	1	1	1	1	1	0	0	0	3
1S	0.09%	454	450	424	517	415	307	301	224	200	1,357
2N	0.02%	96	95	89	109	87	65	63	47	42	286
2S	0.29%	1,460	1,445	1,362	1,660	1,332	985	966	719	642	4,361
3N	0.02%	318	315	297	362	290	215	53	157	140	950
3S	0.01%	162	160	151	184	148	109	27	80	71	483
4S	5.64%	113,399	112,263	105,845	128,967	103,501	76,534	18,761	55,838	49,864	338,791
5N	0.39%	1,946	1,927	1,817	2,214	1,777	1,314	1,288	958	856	5,815
5S	1.06%	5,348	5,294	4,991	6,082	4,881	3,609	3,539	2,633	2,351	15,976
6N	1.92%	9,679	9,582	9,034	11,008	8,834	6,532	6,405	4,766	4,256	28,916
6S	7.55%	38,004	37,624	35,473	43,222	34,687	25,649	25,151	18,714	16,711	113,541
7N	12.41%	62,425	61,800	58,267	70,995	56,977	42,131	41,312	30,739	27,450	186,501
7S	2.03%	10,235	10,132	9,553	11,640	9,342	6,908	6,773	5,040	4,501	30,578
8S	65.74%	330,725	327,413	308,694	376,128	301,858	223,209	218,868	162,851	145,427	988,072
9N	0.01%	0	0	0	0	0	0	37	0	0	0
9S	0.12%	0	0	0	0	0	0	403	0	0	0
10N	0.03%	266	263	248	303	243	180	99	131	117	795
10S	0.34%	2,784	2,756	2,599	3,166	2,541	1,879	1,137	1,371	1,224	8,318
11N	0.11%	567	561	529	644	517	382	375	279	249	1,693
11S	2.21%	11,119	11,008	10,379	12,646	10,149	7,505	7,359	5,475	4,889	33,220
Total	**100**	**588,989**	**583,089**	**549,752**	**669,846**	**537,579**	**397,512**	**332,917**	**290,021**	**258,990**	**1,759,657**

Table 5 Increased in ESALs associated with WBS tires carrying axle loads from 8100 to 9000 kg

Axle Load on WBS tires kg	Equivalent load on DT (EDAL)	ESAL Increase
8,100	10,986	2.17
8,200	11,151	2.31
8,300	11,320	2.46
8,400	11,493	2.63
8,500	11,672	2.80
8,600	11,859	3.00
8,700	12,054	3.22
8,800	12,261	3.47
8,900	12,484	3.76
9,000	12,731	4.10

Table 6 Marginal yearly costs of road damage [5]

Functional Category	Marginal Cost	
	In service	New
1N	$0.118	$0.230
1S	$0.021	$0.040
2N	$0.008	$0.016
2S	$0.005	$0.009
3N	$0.007	$0.013
3S	$0.002	$0.005
4S	$0.001	$0.002
5N	$0.056	$0.110
5S	$0.019	$0.036
6N	$0.005	$0.009
6S	$0.003	$0.006
7N	$0.003	$0.006
7S	$0.001	$0.003
8S	$0.000	$0.001
9N	$0.476	$0.925
9S	$0.307	$0.597
10N	$0.056	$0.109
10S	$0.041	$0.081
11N	$0.028	$0.055
11S	$0.022	$0.044

Note: Marginal cost is defined as the cost per ESAL per Kilometre, as established by the MTO study regarding the Impact on the Highway Infrastructure of Existing and Alternative Vehicle Configurations and Weight Limits in 1996 [5].

Table 7 Cost of damage associated with different axle loads on WBS tires using variable EDAL values

Hwy Group	Different axle loads on wide-base tires, kg										Total
	8100	8200	8300	8400	8500	8600	8700	8800	8900	9000	
1N	$49	$52	$53	$68	$59	$47	$42	$40	$39	$291	$740
1S	$8,132	$8,565	$8,600	$11,173	$9,577	$7,579	$6,813	$6,393	$6,183	$45,849	$118,864
2N	$245	$260	$263	$345	$298	$239	$217	$206	$203	$1,530	$3,804
2S	$3,935	$4,154	$4,181	$5,447	$4,683	$3,718	$3,354	$3,161	$3,071	$22,901	$58,605
3N	$245	$266	$275	$370	$328	$270	$252	$247	$251	$1,964	$4,468
3S	$102	$109	$110	$145	$126	$101	$93	$88	$87	$662	$1,625
4S	$43,416	$46,112	$46,719	$61,294	$53,099	$42,516	$38,710	$36,854	$36,226	$273,761	$678,704
5N	$78,052	$82,289	$82,711	$107,583	$92,328	$73,171	$65,871	$61,926	$60,008	$446,036	$1,149,976
5S	$122,920	$129,307	$129,656	$168,199	$143,928	$113,696	$101,983	$95,482	$92,085	$680,633	$1,777,888
6N	$20,332	$21,505	$21,691	$28,321	$24,407	$19,432	$17,582	$16,624	$16,214	$121,436	$307,542
6S	$52,904	$55,956	$56,440	$73,691	$63,506	$50,560	$45,748	$43,254	$42,187	$315,973	$800,219
7N	$45,175	$48,086	$48,833	$64,228	$55,790	$44,800	$40,919	$39,092	$38,574	$292,790	$718,287
7S	$6,415	$6,781	$6,835	$8,917	$7,678	$6,108	$5,521	$5,214	$5,080	$37,991	$96,539
8S	$19,140	$20,640	$21,249	$28,354	$25,006	$20,407	$18,962	$18,452	$18,577	$144,173	$334,961
9N	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9S	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10N	$7,382	$7,800	$7,860	$10,252	$8,824	$7,017	$6,340	$5,985	$5,827	$43,548	$110,834
10S	$100,108	$105,443	$105,873	$137,554	$117,902	$93,310	$83,872	$78,711	$76,119	$564,455	$1,463,347
11N	$13,817	$14,553	$14,612	$18,985	$16,273	$12,879	$11,576	$10,864	$10,506	$77,905	$201,969
11S	$216,195	$227,714	$228,644	$297,062	$254,623	$201,513	$181,130	$169,985	$164,388	$1,219,000	$3,160,253
Total	**$738,563**	**$779,590**	**$784,604**	**$1,021,988**	**$878,435**	**$697,363**	**$628,984**	**$592,579**	**$575,623**	**$4,290,896**	**$10,988,625**

Table 8 Cost summary for axle loads in based on variable EDAL assuming 100% uptake.

Axle Load Category	Axle Load Range, kg	Assumed no overload	Included overload
		Cost, $	Cost, $
Group 2	3,100 - 4,000	407,367	407,367
	4,100 - 5,000	958,871	958,871
	5,100 - 6,000	1,706,751	1,706,751
	6,100 -7,000	3,393,204	3,393,204
	7,100 - 8,000	8,685,064	8,685,064
	8,100 - 8,900	-	6,697,729
	9,000 - 14,000	-	11,346,623
Group 1	8,100 - 9,000	10,988,625	-
	Total in 1996 $ value	26,139,882	33,195,609
	PWC at 6% discount	52,598,579	66,796,088
	For 50% uptake	**26,299,290**	**33,398,044**

Table 9 Potential benefits (50% uptake at a fuel price of $1.00/litre and 1.5% fuel savings per axle for vehicle configurations which would be affected by the regulatory change [1]

Benefit	Annual Value ($ million)
Reduction in new vehicle cost	11.16
Reduction in vehicle maintenance cost	2.96
Reduction in fuel consumption	49.71
Reduction in emissions and environmental impact	5.07
Reduction in energy and resource consumption associated with tire manufacturing	0.05
Reduction in environmental impact associated with tire disposal	0.17
Increase in payload	0.49
Safety operations – Stability	4.99
Safety operations – Exposure reduction or reduced trips associated with reduced tare weight	0.05
Decrease in whole-life cost of ownership of tires	4.95
Total	**79.60**

LIST OF FIGURES

Figure 1 Loading trucks for testing

Figure 2 WBS tire

Figure 3 Weighing axle loads on Dual tires

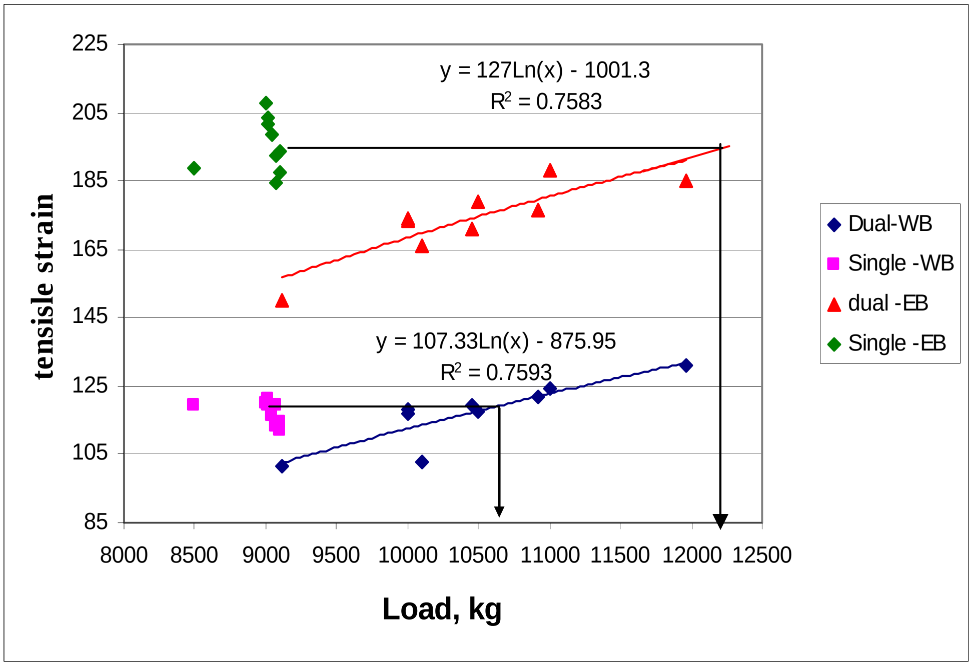

Figure 4 Axle load vs. tensile strain for dual and WBS tires for both lanes