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FLEET EXPERIENCE AND ECONOMIC ANALYSIS OF THE PROTOTYPE CONTROLLED-STEERING B-DOLLY AND LINKED-ARTICULATION DOLLY

A Report to
Saskatchewan Highways and Transportation

C. B. Winkler
Arvind Mathew
Paul Fancher
Patricia Dill

September 1988

UMTRI The University of Michigan Transportation Research Institute

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16. Abstract

The purpose of this report is to provide an assessment of the performance of the CSB- and LA-dollies throughout the field service trial program. Primary objectives of overall assessment considered fleet experiences with respect to dynamic stability, offtracking, ease of operation, coupling, loading, backing, and life-cycle costs. Actual experience with the prototype dollies has been very satisfactory as regards functional and operational considerations. An economic analysis indicates that use of these dollies represents a cost penalty within the "normal" regulatory environment, but that the additional weight allowance under new Saskatchewan regulation provides very strong economic motivation for using these safer dolly designs.

17. Key Words	18. Distribution Statement
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Mr. Wayne Kaldestad, Branch Manager
Mr. Fred Kerns, Maintenance Supervisor
Mr. Ozzie Slobodian, Driver
Mr. Grant Robb, Driver

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1. Introduction and Background

The work reported here was performed by The University of Michigan Transportation Research Institute (UMTRI) for Saskatchewan Highways and Transportation, in cooperation with the Federal Highway Administration (FHWA) of the US Department of Transportation. The work was an extension of a study entitled "Techniques for Improving the Dynamic Ability of Multi-Trailer Combination Vehicles," sponsored by the FHWA under Contract No. DTFH61-84-C-00026.

The original study, pertaining to the dynamic performance of multi-trailer articulated vehicles, led to the development of guidelines for the design of innovative dollies that will improve the roll stability and trailing fidelity of doubles combinations [1]. The major effort of that research investigation involved identification, analysis, and further development of innovative dolly and trailer hitching hardware showing potential for the reduction of rearward amplification and prevention of rollover of the second trailer. Specifically, the project (1) reviewed the current state-of-the-art in innovative coupling mechanisms, (2) performed a parametric sensitivity study, based on computer simulation techniques, of combination vehicles using existing and proposed coupling mechanisms, (3) developed a new type of dolly believed to provide superior safety performance, (4) conducted full-scale tests of combination vehicles using various dollies, including a prototype of the new dolly, and (5) examined the potential safety and economic impacts of the use of innovative dolly hardware.

During this study, two prototype dollies were placed in service with TRIMAC Transportation Services of Regina, Saskatchewan, Canada. The first of these dollies is the "Controlled-Steering B-dolly" or "CSB-dolly." The CSB-dolly is a new concept, developed during the course of the FHWA study. The second dolly type is the "Linked-Articulation Dolly" or "LA-dolly." This dolly was one of the more promising of the existing dollies identified in the study. These dollies were, and are, being used as elements of two dry bulk doubles combination vehicles operated by TRIMAC in Regina.

The purpose of this report is to provide an assessment of the performance of these dollies throughout the field service trial program and to asses the economic potential of these types of dollies.

In order to provide background for the sections that follow (and for those unfamiliar with the prototype dollies), Figures 1, 2 and 3 show the features of the CSB-dolly, and Figures 4 and 5 show features of the LA-dolly.

The CSB-dolly has dual drawbars as shown in Figure 1. Note the additional ball connection that can be seen extending above the fifth wheel plate in Figure 1. This ball connects to the semitrailer that is connected to the fifth wheel of the dolly (see numbers 74 and 112 in Figure 2). As shown in Figure 3, the motion of the ball (part number 74) steers the dolly wheels. Thus the dolly wheels are steered in a controlled manner and in direct ratio to the articulation angle between the two trailers.

Figure 4 is a photograph of an LA-dolly installed on the test trailers of the FHWA study. As shown in this figure, the LA-dolly is actually a standard A-dolly with the addition of a "steering stabilizer arm" attached directly between the two trailers. Figure 5 illustrates the dolly in action. The effect of the additional telescoping arm is to "link" the two articulation angles (lead trailer-to-dolly and dolly-to-pup trailer) so that a specific relationship exists between the two. In effect, the dolly is caused to take on a specific "steer" angle as a direct result of the angle between the two trailers. Although the hardware is very different, the result is very similar in concept to the controlled steering of the CSB-dolly.

For both the CSB-dolly and the LA-dolly, the specific "steering ratio" can be selected to provide both good tracking performance at low-speed and good directional stability at highway speed, as was demonstrated in analyses and proving ground tests in the FHWA study[1].

The dynamic performance capabilities of these two dollies were examined in great detail in the FHWA study. Through extensive vehicle simulations, and full scale proving grounds testing, it was confirmed that both of these dolly types were very effective at reducing rearward amplification, while not degrading low-speed offtracking or introducing other dynamic performance problems.

An important difference between the CSB-dolly and the LA-dolly of Figure 4 regards roll coupling of the two trailers. The double-drawbar configuration of the CSB-dolly serves to tie the two trailers together in roll. This coupling has a powerful stabilizing influence in dynamic maneuvers. The LA-dolly of Figure 4 lacks this important performance benefit. However, further development of the concept, accomplished by

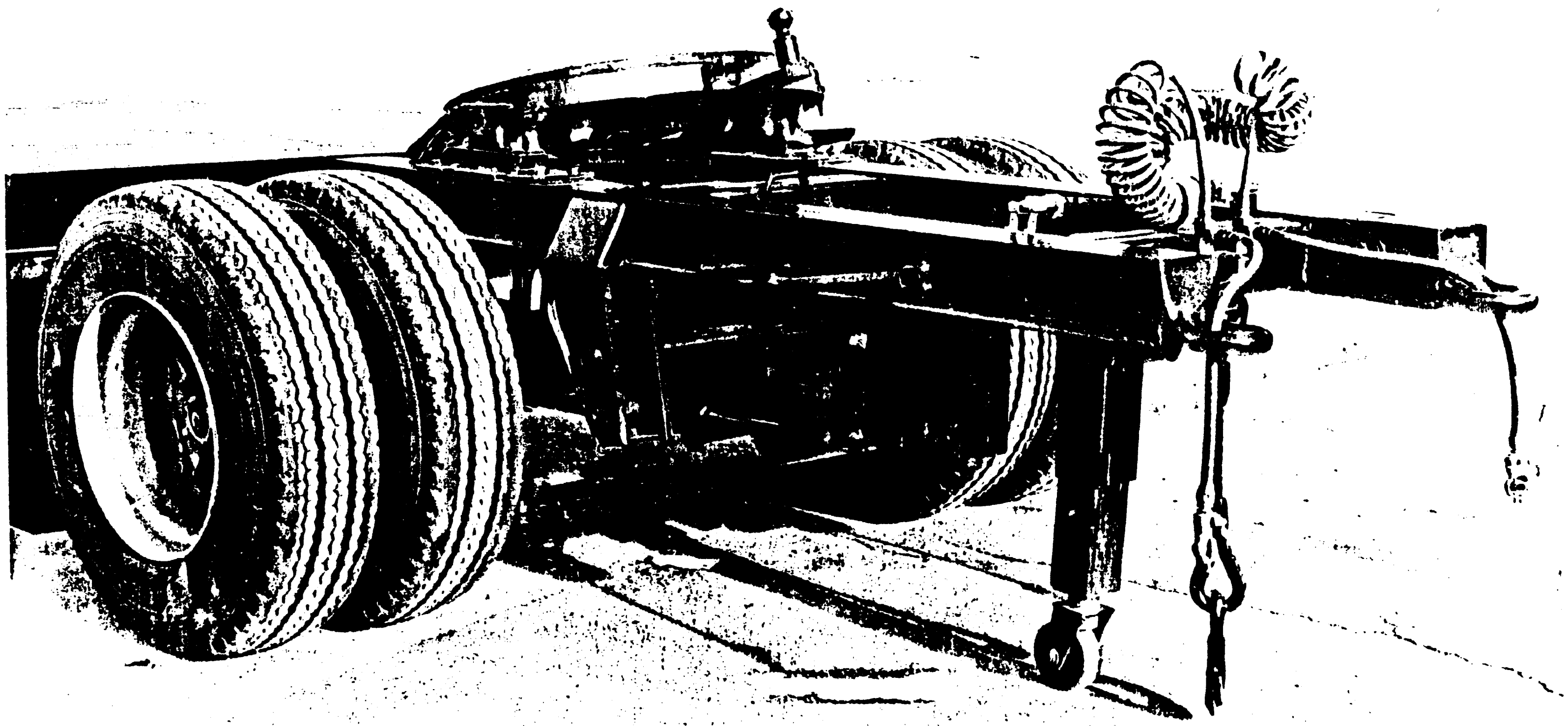


Figure 1. The controlled-steering B-dolly

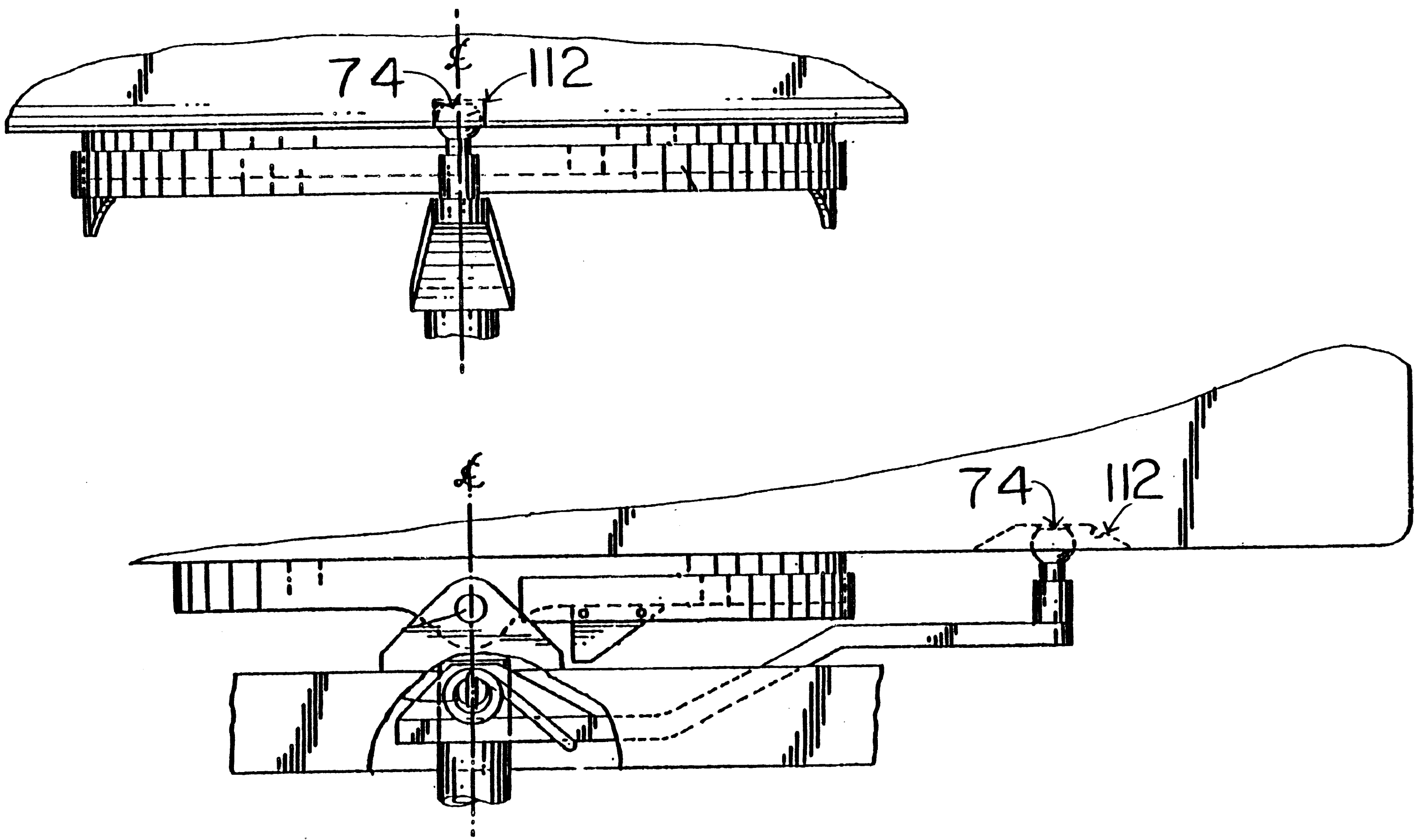


Figure 2. Schematic diagram of the CSB-dolly steering connection with its trailer

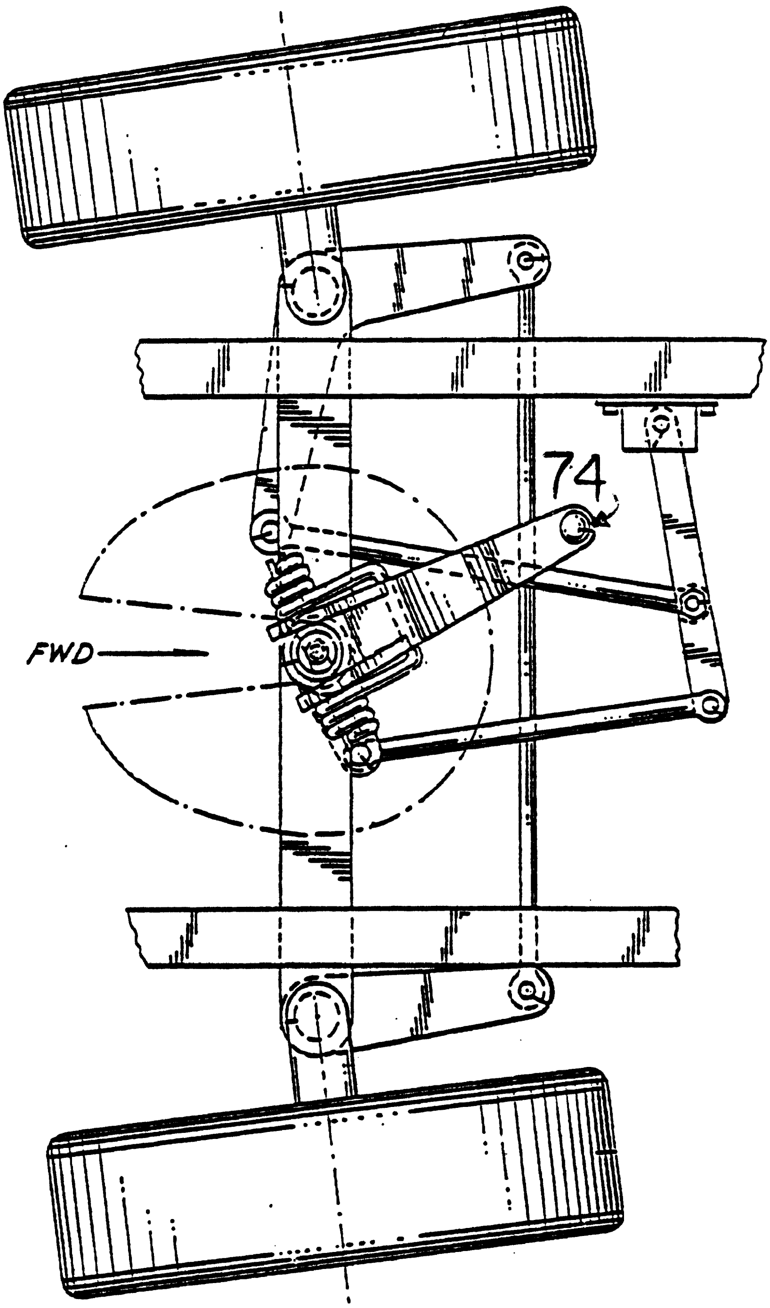


Figure 3. Schematic diagram of the CSB-dolly steering linkage

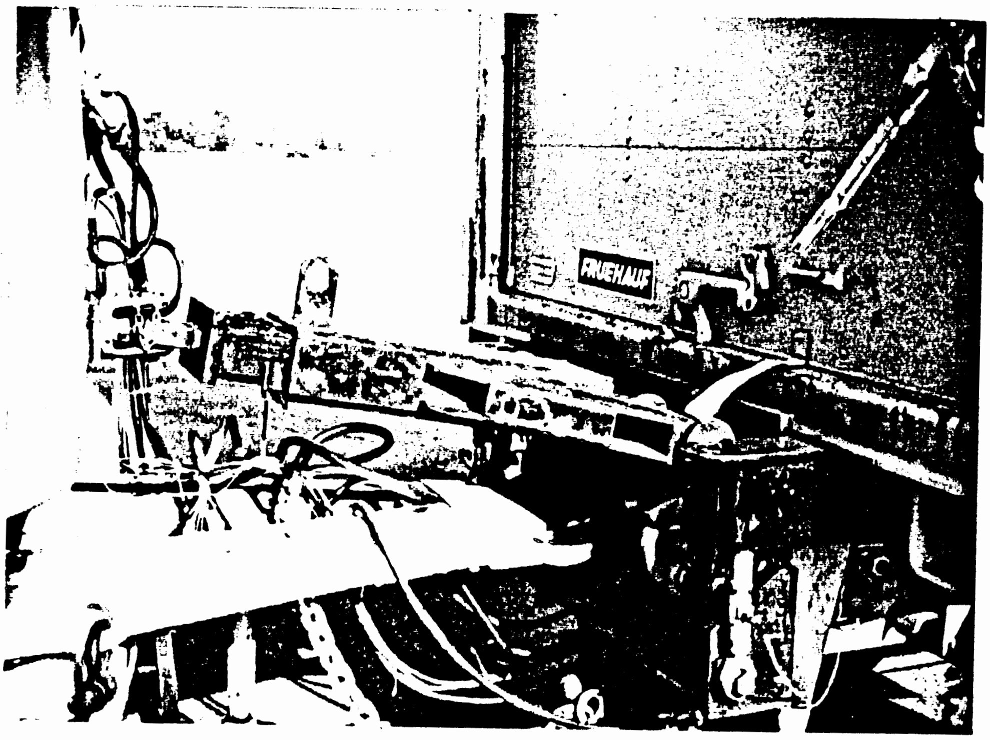


Figure 4. The linked-articulation dolly

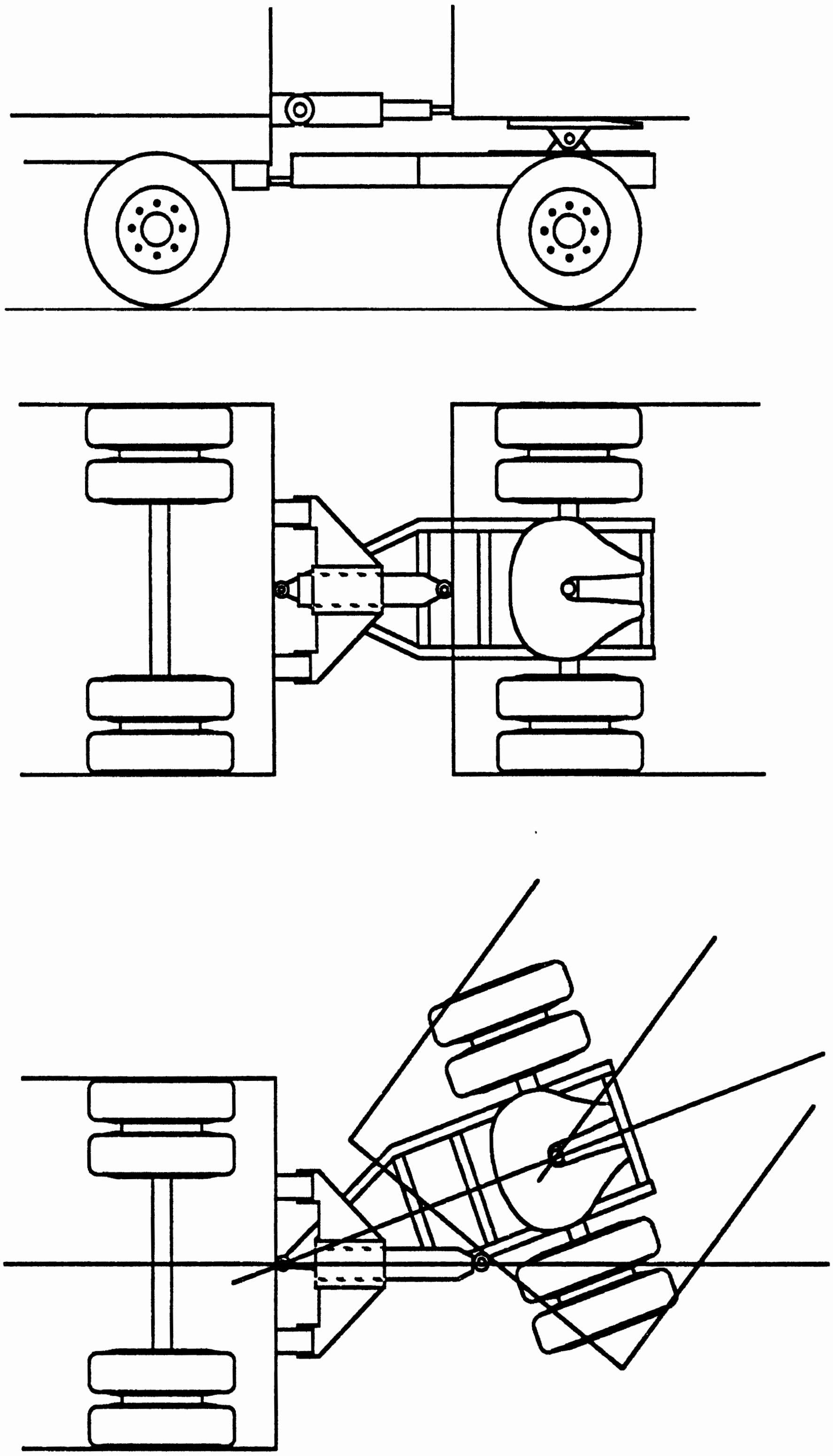


Figure 5. Schematic Diagram of the Linked-Articulation Dolly

ADVANCE Engineered Products Ltd. of Regina Saskatchewan, has resulted in a newer version of the LA-dolly which includes significant roll coupling of the two trailers through the steering stabilizer arm.

Section 2 of this report describes the service environment to which the two prototype dollies were exposed. The subsequent sections present (Section 3) information gathered from the trip reports for the CSB-dolly, (Section 4) quarterly reviews of the CSB-dolly operation, and (Section 5) an economic analysis of the CSB- and LA-dollies, based on field experience and cost data provided by TRIMAC and ADVANCE Engineered Products Ltd. (Section 3 deals only with the prototype CSB-dolly, since trip reports were not available for the prototype LA-dolly.) The final section of this report contains an assessment providing a summary of the performance and economic findings. In essence, the results of the field trial indicate that the prototype dollies performed as well as, or better than, expected with regard to stability, offtracking, backing, and maintenance requirements. Their improved safety performance has allowed regulatory initiatives to increase load allowances, thus improving the productivity and potential profitability of trucking in Saskatchewan

2. Service Environment of the CSB-Dolly

The in-service test of the two prototype dollies was run through TRIMAC Transportation Services of Regina, Saskatchewan, Canada.* The TRIMAC Regina fleet is an attractive environment for testing the prototype dollies since this service environment is generally more severe than that in which most U.S. fleets operate. The results of this more rigorous testing illustrate the true capabilities of the equipment.

TRIMAC Regina is a bulk hauling operation, dealing mainly in the transport of cement and petroleum products. The area in which they operate exposes them to extremes in weather conditions. Ice, snow, rain, and high winds are all common obstacles that driver and truck must face. Many of the destinations of TRIMAC services are off the main road systems, requiring them to travel for many miles on unfinished gravel and dirt roads to pick up and deliver their payload. The bulk hauling operations in the western provinces of Canada operate, to a large extent, under a permit system that allows them a gross combination weight (GCW) of approximately 62,500 kg (138,000 lbs) when double drawbar dollies are used. TRIMAC takes advantage of this permit opportunity, creating a testing environment where the prototype dollies were subjected to GCWs pushing 62,500 kg (138,000 lbs), unfinished roads, and extreme weather conditions.

TRIMAC has chosen to purchase and operate a number of commercially available B-dollies (double drawbar dollies using a number of different styles of "self-steering" axles). The decision to operate B-dollies is largely due to the higher GVW allowed with their use by the permit system. The additional weight of a B-dolly over an A-dolly is of little concern because of the higher GCW allowed. TRIMAC is able to increase the GCW from approximately 53,500 kg (118,000 lbs) to 62,500 kg (138,000 lbs). The increased stability and safety of vehicles equipped with B-dollies is an important factor in deciding to purchase them. Indeed, improved stability is a major element in the rationale of the regulating authorities which has lead to the increased weight allowances for vehicles equipped with B-dollies.

* TRIMAC Transportation Inc. is a nationwide Canadian firm involved in many forms of trucking operations. TRIMAC of Regina is a branch of TRIMAC whose business is composed largely of liquid and dry bulk hauling under contract to various Saskatchewan commercial concerns. These include a dry cement facility, located immediately adjacent to the TRIMAC garages, mining concerns operating uranium mines in northern Saskatchewan, petroleum refining and distributing concerns in Regina, and other industrial and municipal transportation users.

TRIMAC has been operating B-dollies since 1982, with an average of about 200,000 km (125,000 miles) per year per dolly. As of 1986, TRIMAC Canada operated over 50 self-steering B-dollies in double-vehicle combinations nationwide. TRIMAC drivers operating units with B-dollies express satisfaction with the performance of the vehicles, citing that the units are more stable, and that there is a better feel for what the rear of the unit is doing. They have been impressed with the B-dollies' performance in ice and freezing rain, conditions that force most doubles and triples off the road. Much of TRIMAC's operation of double combinations is with vehicles which are not uncoupled for loading and unloading of payload, and which traditionally (i.e., when using A-dollies) require drive–through loading areas (e.g., the bulk hauling fleet of TRIMAC Regina). Self-steering B-dollies are usually equipped with a steering lock which makes it possible to back the doubles vehicle. Given the "married vehicle" nature of the TRIMAC fleet, and the existence of drive-through loading yards geared to A-trains, the ability to back has not had a major influence in TRIMAC' s operation, but is seen as a potential benefit. In general, B-dolly-equipped vehicles draw high marks from the drivers for their performance on the road. (Appendix A includes a questionnaire completed by TRIMAC detailing the operating environment.)

The self-steering B-dollies operated by TRIMAC have experienced failures and wear that have not been observed with combinations using conventional A-dollies. The trailers connected to B-dollies experience greater wear on the kingpin. Tire wear rate on B-dollies is generally high. Some B-dollies have experienced problems with bent and broken axles and with frame failures.

This, then, is the general background of the service environment into which the prototype dollies were introduced.

3. Summary of Information from Trip Reports

Field Trials for the CSB-Dolly

The CSB-dolly was brought into service in March, 1986, and has been undergoing field trials for approximately twenty months. It was operated under the supervision of the Saskatchewan Department of Highways and Transportation and was monitored by personnel from UMTRI. As mentioned earlier, heavy vehicle loads, unpaved road surfaces, and extreme weather conditions presented a fairly rigorous testing environment. As part of the testing agreement, the truck fleet operating the CSB-dolly was required to maintain trip and maintenance records.

The actual vehicle which the CSB-dolly was used with was an eight-axle bulk tanker double composed of a three-axle tractor, two-axle lead semitrailer, the single-axle CSB-dolly and a two-axle pup semitrailer. Axle weight constraints for the test were set by the Province of Saskatchewan, Department of Highways and Transportation. Initially, since the hardware was new, the GCVW was limited to 53,500 kg (118,000 lbs). Later, this was lifted to 60,000 kg (132,000 lb) and finally to 62,500 kg (138,000 lbs). Axle loads were limited to 5,000 kg (11,000 lbs) on the steering axle, 16,000 kg (35,000 lbs) on each of the three tandem pairs, and 9,100 kg (20,000 lbs) on the single, CSB-dolly axle. (These were the individual axle constraints, regardless of the GCVW limit.)

The vehicle was used in hauling bulk cement, flyash, potash, and road salt in southern Saskatchewan, and to haul lime and other bulk material to and from remote mining sites in northern Saskatchewan. In the south, typical hauls were from Regina to Saskatoon (515 km round trip) and Regina to Estevan (400 km round trip). Several trips were made to the northern uranium mines at Key Lake (2000 km round trip). Three hundred and eighty km of this route is on gravel roads which, in some weather conditions, can be considered a severe environment. The dolly continues to be used in this service at this time.

Trip and Maintenance Reports

In addition to periodic shop checks, the CSB-dolly was inspected prior to every road trip. The driver of the vehicle inspected the dolly for signs of wear and fatigue in structural components and in the steering system. A pre-trip inspection check list (see Figure 6) was used to identify critical areas of the dolly's structure and steering linkage. In the event of a problem, the dolly was to be removed from service until the necessary repairs were

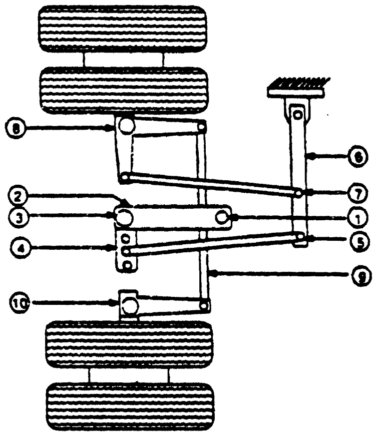
Saskatchewan Highways and Transportation

CSB - DOLLY CONVERTOR REPORT

INSPECTION

In addition to the standard pre-trip inspection, the following checks must be carried out for the CSB - Dolly Convertor.

1. Steering System:



	Normal	Wear
① Steering Ball Hitch	(✓)	( )
② Upper Steering Arm	(✓)	( )
③ Vertical Steering Shaft	(✓)	( )
④ Lower Steering Arm	(✓)	( )
⑤ 1st Steering Link	(✓)	( )
⑥ Idler Arm	(✓)	( )
⑦ 2nd Steering Link	(✓)	( )
⑧ Left Wheel Steering Arm	(✓)	( )
⑨ Tie Rod	(✓)	( )
⑩ Right Wheel Steering Arm	(✓)	( )

2. Structural Components:

	Normal	Abnormal Wear
Main frame rails	(✓)	( )
Cross members	(✓)	( )
Pintle hitches	(✓)	( )
King Pins (Shop check only)	( )	( )
Tire Wear (Shop check only)	( )	( )

If any steering or structural components show signs of wear and/or fatigue which may affect the performance of the vehicle, it is to be taken out of service immediately. The operator is to advise Trimac personnel and personnel of the Transportation Systems Branch, Department of Highways and Transportation of such action. Note defects here:

____

REPAIRS

Please note any repairs required: REPAIR FLAT TIRE
RIGHT OUT SIDE

FOR SHOP USE ONLY

Unit No. __________ Date Inspected Nov 5-6-?

Mechanic's Signature __________

Figure 6. A sample pre-trip checklist

performed. The pre-trip check list was also used in the shop to record maintenance and repairs conducted on the dolly.

In addition to the pre-trip inspection, the driver was required to complete a trip report which recorded, among other things, gross vehicle weight, distance traveled, weather and road conditions, and vehicle performance. A sample trip report is shown in Figure 7. The trip reports provide some insight into the extreme operating conditions of the testing environment.

Summary of Data Gathered During the Testing Period

Over the twenty-month trial period, the CSB-dolly operated on approximately 174 trips and accumulated a total of 99,000 kms. The dolly averaged approximately 570 kms per trip and was subjected to a wide range of weather and road conditions.

Given the testing environment, the dolly performed very well, experiencing only three "shop recalls." The first occurred very early in the trial, and was found to be a "false alarm" concerning the development of lash in the steering linkage. The second recall involved wear of the steering ball (item 74 in Figures 2 and 3). Flat spots developed on the sides of the ball where it rides against the walls of the pocket in the upper fifth wheel. The ball was not replaced, and it was subsequently found that the wear rate virtually stopped once an appreciable contact area developed. There has been no need to replace the ball. These were the only items directly involving the steering mechanism which required attention in the first 99,000 kms. The third item involved the loosening of the u-bolts which attached the axle to the springs. In July of 1986, the original 3/4 inch U-bolts were replaced with 7/8 inch U-bolts and the problem did not reappear.

In early November 1987, the steering system of the CSB-dolly prototype was disassembled and examined for wear and fatigue. The bushings of the upper steering arm hinge were found to have some wear, resulting in a moderate amount of steering lash. Elements of this joint (the hinge pin and the upper end of the vertical steering shaft) were magnifluxed and found to have no evidence of any fatigue damage. Some redesign of this hinge joint may be appropriate if additional CSB-dollies are constructed. However, the wear observed in the prototype was not seen as a major problem.

A summary of the testing mileage is presented in Figure 8 and in Table 1. In the figure, distance accumulated by the dolly is displayed as a function of time. Significant comments made by the driver and shop personnel have also been recorded on the chart.

Saskatchewan Highways and Transportation

TRIP REPORT

GENERAL

Driver D. Subodiak Date Nov 5-6-7 86
Unit No. 11-248 Company Trip Report # 522848

TRIP INFORMATION

FROM	TO	DEPARTURE TIME	ARRIVAL TIME	GVW
Key Lake	Saskatoon	4.30 pm	Nov 6 11.00 pm	
Saskatoon	Regina	9.00 pm	1.30 Am	20740

Total Fuel Used 548 ~~[illegible]~~ litres 35 gals. 1068 kms.

WEATHER

1. Temperature -5°C Clear ( ) Cloudy (✓) Rain ( ) Snow (✓)
2. Wind: Speed W 20 Direction - Head ( ) Cross (✓) Tail (✓)

ROAD CONDITIONS

1. Dry (✓) Wet (✓) Ice (✓) If icy, describe operation of vehicle:

Worked OK.

REPAIRS

Please note any repairs required during the trip:

Flat tire in Pike
House area.
Right outside on converter.

VEHICLE OPERATION

Please describe the general performance of the vehicle during the trip.
Include any unusual vehicle performance or traffic situations that occurred:

OK.

Driver's Signature [illegible]

One of the following is to be notified in the event of any serious problems:

Bernie Churko	Norm Burns	Peter Hurst	Road Systems Unit
787-5533 Bus.	787-5535 Bus.	787-5536 Bus.	Highways & Transportation
545-5628 Res.	586-9802 Res.	545-7750 Res.	7th Floor, 1855 Victoria Ave.
			Regina, Saskatchewan

Figure 7. A sample trip report

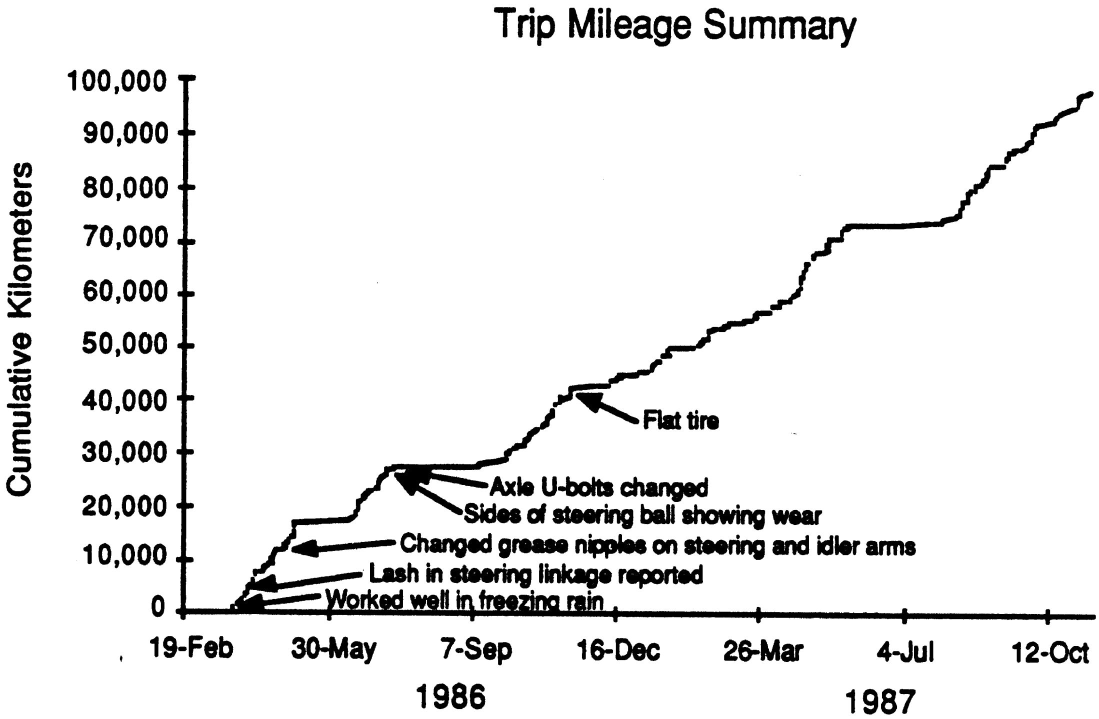


Figure 8. A chronological account of the testing period

Table 1. Prototype CSB-Dolly Trip Summary

Date	Product	Destination	Kilometers	Cumulative Km
24-Mar-86	Cement	Saskatoon	515	515
25-Mar-86	Ash	Regina/B.Dam/Regina	410	925
26-Mar-86	Ash	S.Current	499	1,424
31-Mar-86	Salt	B.Plaine/B.Dam	515	1,939
1-Apr-86	Salt	B.Plaine/B.Dam	515	2,454
2-Apr-86	Cement	Saskatoon	515	2,969
3-Apr-86	Salt/Ash	B.Plaine/B.Dam	515	3,484
4-Apr-86	Cement	Saskatoon	515	3,999
5-Apr-86	Ash	B.Dam	410	4,410
7-Apr-86	Ash	Regina/Battleford	805	5,214
8-Apr-86	Cement	Saskatoon	515	5,729
9-Apr-86	Cement	Saskatoon	515	6,244
10-Apr-86	Cement	Saskatoon	515	6,759
11-Apr-86	Cement	Saskatoon	515	7,274
14-Apr-86	Cement	Saskatoon	515	7,789
16-Apr-86	Salt	B.Dam	515	8,304
17-Apr-86	Ash	B.Dam	410	8,715
18-Apr-86	Cement	Saskatoon	515	9,230
21-Apr-86	Cement	Saskatoon	515	9,745
22-Apr-86	Cement	Saskatoon	515	10,260
23-Apr-86	Cement	Saskatoon	515	10,775
25-Apr-86	Cement	Saskatoon	515	11,290
28-Apr-86	Cement	Saskatoon	515	11,805
29-Apr-86	Ash	B.Dam	515	12,319
30-Apr-86	Cement/Ash	B.Dam/Battleford	1,159	13,478
2-May-86	Cement	Saskatoon	515	13,993
3-May-86	Ash	B.Dam	410	14,404
5-May-86	Ash	Saskatoon	515	14,919
6-May-86	Ash	B.Dam/Saskatoon	925	15,844
7-May-86	Ash	B.Dam	410	16,254
11-Jun-86	Cement/Ash	Wadena/B.Dam	774	17,028
13-Jun-86	Cement/Ash	B.Dam	410	17,439
16-Jun-86	Ash	Battleford	805	18,243
17-Jun-86	Cement	Saskatoon	515	18,758
18-Jun-86	Cement	Saskatoon	515	19,273
19-Jun-86	Cement	B.Dam/Moose Jaw	547	19,821
20-Jun-86	Ash	B.Dam/Saskatoon	925	20,746
21-Jun-86	Ash	B.Dam	410	21,156
24-Jun-86	Ash	Saskatoon	515	21,671
25-Jun-86	Cement	Estevan	402	22,074
26-Jun-86	Cement	Saskatoon	515	22,589
28-Jun-86	Cement	Saskatoon	515	23,104
30-Jun-86	Ash	B.Dam	410	23,514
2-Jul-86	Ash	Saskatoon	515	24,029
3-Jul-86	Cement	Porcupine Plain	612	24,641
5-Jul-86	Cement	Saskatoon	515	25,156
9-Jul-86	Cement	Wadena/B.Dam	772	25,928
10-Jul-86	Ash	Tisdale	724	26,652

Table 1 (continued). Prototype CSB-Dolly Trip Summary

Date	Product	Destination	Kilometers	Cumulative Km
14-Jul-86	Cement	Saskatoon	515	27,167
15-Jul-86	Cement/Ash	B.Dam	410	27,578
10-Sep-86	Ash	B.Dam	410	27,988
22-Sep-86	Ash	B.Dam/Saskatoon	925	28,913
1-Oct-86	Ash	B.Dam/Saskatoon	925	29,839
3-Oct-86	Ash	B.Dam	410	30,249
4-Oct-86	Cement	Saskatoon	515	30,764
6-Oct-86	Cement/Ash	Estevan/B.Dam	410	31,175
7-Oct-86	Cement	Saskatoon	515	31,690
13-Oct-86	Cement/Ash	Weyburn/B.Dam	410	32,100
14-Oct-86	Cement	Estevan	402	32,502
15-Oct-86	Ash	Saskatoon	515	33,017
17-Oct-86	Cement/Ash	Estevan/B.Dam	925	33,943
24-Oct-86	Potash	Richmound	933	34,876
27-Oct-86	Potash	Richmound	933	35,809
28-Oct-86	Potash	Richmound	933	36,743
31-Oct-86	Potash	Richmound	933	37,676
3-Nov-86	Cement	Saskatoon	515	38,191
4-Nov-86	Lime	Saskatoon/Key Lake	644	38,835
5-Nov-86	Lime	Enroute Key Lake	483	39,318
6-Nov-86	Lime	Inbound Key Lake	483	39,801
7-Nov-86	Lime	Inbound Key Lake	644	40,444
13-Nov-86	Salt	Lucky Lake/Emfold	724	41,169
14-Nov-86	Salt	B.Plaine/Hodgeville	483	41,651
15-Nov-86	Salt	B.Plaine/Porcupine Plain	724	42,376
2-Dec-86	Salt	B.Plaine/Rosthern	676	43,051
11-Dec-86	Cement	Estevan	402	43,454
15-Dec-86	Cement	Saskatoon	515	43,969
19-Dec-86	Ash	B.Dam	410	44,379
24-Dec-86	Cement	Saskatoon	515	44,894
30-Dec-86	Ash	B.Dam	410	45,305
6-Jan-87	Cement/Ash	Estevan/B.Dam	410	45,715
8-Jan-87	Cement/Ash	Estevan/B.Dam	410	46,125
9-Jan-87	Ash	Prince Albert	740	46,866
12-Jan-87	Ash/Cement	B.Dam/Saskatoon	925	47,791
15-Jan-87	Ash	B.Dam	410	48,201
21-Jan-87	Cement	S.Current	499	48,700
22-Jan-87	Cement	Saskatoon	515	49,215
23-Jan-87	Cement	Saskatoon	515	49,730
2-Feb-87	Cement	Estevan	402	50,133
9-Feb-87	Cement	Saskatoon	515	50,648
11-Feb-87	Cement/Ash	Estevan/B.Dam	410	51,058
13-Feb-87	Cement	Saskatoon	515	51,573
17-Feb-87	Cement	Estevan	402	51,975
18-Feb-87	Cement	Saskatoon	515	52,490
19-Feb-87	Cementy	Saskatoon	515	53,005
25-Feb-87	Cement	Saskatoon	515	53,520
27-Feb-87	Cement	Saskatoon	515	54,035

Table 1 (continued). Prototype CSB-Dolly Trip Summary

Date	Product	Destination	Kilometers	Cumulative Km
3-Mar-87	Cement/Ash	Estevan/B.Dam	410	54,446
5-Mar-87	Cement/Ash	Estevan/B.Dam	410	54,856
14-Mar-87	Cement/Ash	Estevan/B.Dam	410	55,266
19-Mar-87	Ash	B.Dam	410	55,677
20-Mar-87	Ash	B.Dam	410	56,087
23-Mar-87	Ash	B.Dam	410	56,497
24-Mar-87	Ash	S.Current	499	56,996
2-Apr-87	Empty	Saskatoon	257	57,254
6-Apr-87	Empty	Saskatoon	257	57,511
9-Apr-87	Cement	Saskatoon	515	58,026
10-Apr-87	Cement	Saskatoon	515	58,541
14-Apr-87	Ash	B.Dam	410	58,952
15-Apr-87	Ash	Prince Albert	805	59,756
16-Apr-87	Cement	Saskatoon	515	60,271
20-Apr-87	Cement	Saskatoon	515	60,786
21-Apr-87	Lime	Enroute Key Lake	644	61,430
22-Apr-87	Lime	Enroute Key Lake	483	61,913
23-Apr-87	Lime	Inbound Key Lake	805	62,718
24-Apr-87	Lime	Enroute Key Lake	644	63,361
25-Apr-87	Lime	Enroute Key Lake	483	63,844
26-Apr-87	Lime	Inbound Key Lake	966	64,810
27-Apr-87	Cement	Saskatoon	257	65,067
28-Apr-87	Cement/Lime	Saskatoon/Key Lake	644	65,711
29-Apr-87	Lime	Enroute Key Lake	644	66,355
30-Apr-87	Lime	Enroute Key Lake	483	66,837
1-May-87	Lime	Inbound Key Lake	483	67,320
2-May-87	Lime	Inbound Key Lake	483	67,803
7-May-87	Cement	Saskatoon	515	68,318
12-May-87	Lime	Enroute Key Lake	805	69,123
13-May-87	Lime	Enroute Key Lake	644	69,766
14-May-87	Lime	Inbound Key Lake	483	70,249
15-May-87	Lime	Inbound Key Lake	644	70,893
21-May-87	Cement/Ash	Estevan/B.Dam	410	71,303
22-May-87	Cement	Nipawin	789	72,092
23-May-87	Ash	B.Dam	410	72,502
26-May-87	Cement	Saskatoon	515	73,017
1-Jul-87	Ash	B.Dam	410	73,428
23-Jul-87	Salt	B.Plaine/B.Dam	515	73,943
30-Jul-87	Salt	B.Plaine/B.Dam	515	74,458
7-Aug-87	Salt	B.Plaine/B.Dam	515	74,973
10-Aug-87	Ash	B.Dam/St. Eustache/Winnepeg	644	75,616
11-Aug-87	Cement	Winnepeg	587	76,204
12-Aug-87	Cement	Enroute Edmonton	756	76,960
13-Aug-87	Cement	Inbound Edmonton	756	77,717
17-Aug-87	Salt	B.Plaine/B.Dam	515	78,232
18-Aug-87	Salt	B.Plaine/Saskatoon	547	78,779
19-Aug-87	Salt	B.Plaine/Saskatoon	547	79,326
20-Aug-87	Salt	B.Plaine/Saskatoon	547	79,873

Table 1 (continued). Prototype CSB-Dolly Trip Summary

Date	Product	Destination	Kilometers	Cumulative Km
21-Aug-87	Salt	B.Plaine/Saskatoon	547	80,420
24-Aug-87	Salt	B.Plaine/Melville	402	80,823
26-Aug-87	Salt	B.Plaine/B.Dam	515	81,338
27-Aug-87	Salt	B.Plaine/B.Dam	515	81,853
29-Aug-87	Cement	Saskatoon (twice)	1,030	82,883
1-Sep-87	Salt	B.Plaine/Outlook/B.Plaine	966	83,848
2-Sep-87	Salt	Wadena/B.Plaine/B.Dam	676	84,524
11-Sep-87	Salt	BB.Plaine/B.Dam	515	85,039
12-Sep-87	Cement	Saskatoon	515	85,554
13-Sep-87	Ash	B.Dam	410	85,965
14-Sep-87	Ash	S.Current	499	86,463
15-Sep-87	Cement	Saskatoon	515	86,978
19-Sep-87	Cement	Saskatoon	515	87,493
21-Sep-87	Cement	Saskatoon	515	88,008
26-Sep-87	Cement	Saskatoon	515	88,523
29-Sep-87	Cement	Shavnavon	708	89,231
29-Sep-87	Cement	Saskatoon	515	89,746
30-Sep-87	Cement	Saskatoon	515	90,261
2-Oct-87	Cement	Saskatoon	515	90,776
3-Oct-87	Cement	Saskatoon	515	91,291
5-Oct-87	Cement	Saskatoon	515	91,806
6-Oct-87	Cement	Saskatoon	515	92,321
17-Oct-87	Potash	Richmound	933	93,255
20-Oct-87	Cement	Saskatoon	515	93,770
29-Oct-87	Salt	Esterhazy (twice)	1,030	94,800
30-Oct-87	Salt	Esterhazy	515	95,315
31-Oct-87	Potash	Richmound (twice)	933	96,248
2-Nov-87	Salt	Esterhazy (twice)	1,030	97,278
7-Nov-87	Potash	Richmound	933	98,212
10-Nov-87	Potash	Richmound	933	99,145

Table 1 supplements this information by identifying product, destination, and distance on a trip-by-trip basis.

Economic factors, such as market demands for cement and petroleum products, also affected the operation of the dolly. As can be seen in Figure 8, sluggish demand conditions idled the dolly during May of 1986 and during the summers of both 1986 and 1987. This resulted in a "staircase" effect in the cumulative mileage curve in Figure 8.

4. Quarterly Reviews of Dolly Operations

The following material provides perspectives on dolly performances as observed during the field trial.

August, September, and October of 1986

The CSB-dolly accumulated approximately 40,000 km (25,000 miles) in dry bulk cement hauling service in and about Regina. The dolly is used in an eight-axle (1-2-2-1-2) C-train. Initially, dolly axle loads were constrained to approximately 7,200 kg (16,000 lbs), but were raised to 9,100 kg (20,000 lbs) after the initial, successful experience. The LA-dolly is in similar use in a seven-axle (1-2-2-1-1) C-train.

The operators (TRIMAC Transportation System) express great satisfaction with the operation of the prototype dollies. They note that:

a) The operational stability of the trains is judged by the drivers to be much better than when equipped with an A-dolly, and somewhat better than when equipped with self-steering B-dollies.

b) No frame-stress-related problems have been identified.

c) Tire wear is apparently very good. In particular, the excessive tire wear previously experienced with self-steering B-dollies is absent.

d) With experience, drivers have learned to back the trains. Backing can be accomplished with strategies involving curved paths, not just along straight lines. This is found to be a great advantage in that it allows the use of doubles in services that previously were limited to singles by operational considerations.

e) Although the CSB- and LA-dollies require greasing at various points of their steering systems, TRIMAC indicates that the difference between "regular" maintenance costs of the CSB and other dollies are insignificant. There is not enough accumulated mileage to judge major maintenance (overhaul) costs.

November, December, and January of 1986 and 1987

During the first week of November, the prototype dollies made their first northern trip. The trains, operating at up to 61,000 kg (135,000 lbs) GCW were used to haul lime into (and crystalline ammonia fertilizer out of) the Key Lake uranium mine in northern

Saskatchewan. The haul initiates in Saskatoon, runs north through Prince Albert, and then several hundred miles into the uninhabited north. Paved roads stop about 190 km north of Prince Albert so that most of the trip is on gravel roads. The run is about 12 hours one way. This initial run was made in a four-vehicle convoy consisting of the CSB-dolly vehicle, a similar train using the linked-articulation hardware, a B-train (no dolly) hauling fuel oil, and a passenger van.

UMTRI personnel traveled to Saskatchewan to participate in this initial run. Others who "attended" included officials of Saskatchewan Transportation and of TRIMAC. An UMTRI staff member rode the entire northbound run in the CSB-dolly-equipped train.

The trip was certainly an unqualified success in that all three vehicles performed flawlessly.

The CSB-dolly continued in use in the Regina area through the quarter on a TRIMAC bulk tanker. During the winter quarter, the major use of that fleet is for hauling road salt. Because of the unusually mild winter weather, accumulated mileage was limited. Accumulated mileage by the end of the quarter was between 48,000 and 56,000 km (30,000 and 35,000 miles).

TRIMAC continues to declare that they are very pleased with the service of the dollies. There have been no problems of note. Maintenance costs appear to be very similar to their existing equipment. Tire wear is said to be noticeably improved over A- and self-steering B-dollies in the same service.

February, March, and April of 1987

The CSB-dolly continued in use in the Regina area through the quarter on a TRIMAC bulk tanker. It was used for hauling road salt locally, but was also returned to northern service, delivering lime to the Key Lake uranium mine.

The Saskatchewan Highways and Transportation is now issuing permits for both the CSB-dolly and LA-dolly for weights up to 62,500 kg (138,000 lbs). The essential aim of this scheme would be to allow the use of vehicles in Saskatchewan now, which are anticipated to be allowed nationwide in the future as a result of the Roads and Transportation Association of Canada (RTAC) study findings.

During May, UMTRI staff traveled to Regina and to Calgary, Alberta to interview local and regional officials of TRIMAC in connection with evaluating the CSB-dolly's economic performance. The next section presents the economic analysis.

5. Economic Analysis

INTRODUCTION

Objective. The economic analysis is designed to determine the costs and/or benefits of introducing innovative dollies, such as controlled–steer B–dollies (CSB–dollies) and linked-articulation dollies (LA-dollies), into a fleet that uses conventional A–dollies.

Sources of Related Information. A CSB–dolly and an LA-dolly have been undergoing field trials at TRIMAC Transportation Services, Ltd. in Regina, Saskatchewan, and the Company has maintained trip and maintenance records specific to the two dollies. Moreover, over a ten-month period, ADVANCE Engineered Products, Ltd. has manufactured and sold approximately 40 roll-stiffened LA-dollies to trucking fleets in Saskatchewan. To the extent that reasonable data exist for the two dollies, those data were used in the analysis.

Since the innovative dollies are fairly recent additions to the trucking industry, the related information is limited. With the exception of additional weight and a higher purchasing cost, CSB–dollies are similar in many respects to double-drawbar B–dollies. That is, CSB–dollies are essentially B–dollies incorporating special hardware for steering the dolly wheels. Due to the short observation period for the CSB-dolly, data from B-dolly operators are sometimes used as a surrogate for CSB–dolly data in the following economic analysis. B–dollies have been in use since 1979 and trucking fleets in Alberta and Saskatchewan operate approximately 140 B–dolly doubles with an annual mileage of approximately 32 million kilometers (20 million miles). Data from these fleets were major sources of the information used in this analysis. Similarly, linked-articulation dollies are essentially A-dollies with additional hardware required to "link" the articulation angles between the trailers in a twin-trailer configuration. Consequently, data from A-dolly operators are sometimes used in the absence of LA-dolly specific information. Contacts with U.S. and Canadian fleet operators provided information about the costs involved in using conventional dollies. Canadian fleets have also provided information about the impacts and costs of a change–over from A– to B–dollies. These data were extrapolated to the evaluation of the two new dollies, that is, the CSB-dolly and the LA-dolly.

Scope of Analysis. To focus the analysis on the operational/financial impact of the innovative dollies, a financial model was developed that incorporated the differences in the benefits and costs (advantages and disadvantages) between the conventional (A-dolly) and the two new dollies (the CSB-dolly and the LA-dolly). In other words, the analysis examined issues pertinent to the type of dolly.

Method of Analysis — Sensitivity Analysis. A sensitivity analysis involves changing the values of various parameters, one at a time, to determine their individual impact on a "baseline" or reference situation. Key parameters are identified by their ability to significantly affect the results of the analysis through small variations in their values. A sensitivity analysis helps to identify the important parameters and the key issues associated with the parameters.

In this study, the two innovative dollies were used in bulk-hauling operations and were often subjected to fairly severe loading situations. Much of the information on conventional A–dollies, however, has been obtained from U.S. trucking fleets where more stringent road–use laws create a somewhat different operating environment. Since the two dollies could not be compared directly under similar operating conditions, sensitivity analyses help to clarify the key issues with regard to the use of the CSB–dolly and the LA-dolly.

Further, a specific parameter (parameters are enumerated in "Assumptions Concerning Economic Issues" below) will have varying levels of importance for different types of trucking operations, such as "less-than-load" (LTL) versus bulk cargo, or short-haul versus long-haul. The amount of variation of independent variables used in the analysis below are thought to be "representative", but the sensitivity analysis approach allows the reader to adjust the amount of variation, and thus the eventual influence, of individual variables for the specific situation.

THE FINANCIAL MODEL.

Type of Analysis. The model determines the financial effects of using an innovative dolly, that is, a CSB-dolly or an LA-dolly, as an alternative to the conventional A–dolly. The cash flows (where costs are negative cash flows or an outflow of cash, and benefits are positive cash flows or an inflow of cash) are defined as an increase or decrease in the operating cost due to the use of an innovative dolly instead of an A–dolly. For example, the model projects higher annual preventive maintenance costs (see "Assumptions Concerning Economic Issues") for every innovative dolly added to the fleet. An innovative dolly is, therefore, *more expensive* to maintain than the conventional dolly (all cash flows are in CA dollars ($1.25 CA=$1.00 US). There is also an additional investment due to the extra cost incurred in buying an innovative dolly instead of an A–dolly. In other words, the model analyzes the future *incremental* cash flows resulting from an *additional* investment made today.

The Investment Rule. The Net Present Value (NPV) rule is used as a basis for analyzing the investment decision. The NPV rule reduces all forecasted cash flows to current dollars (based on a given discount rate) and is reliable in ranking projects which offer different patterns of cash flow. Other investment rules such as Payback and Average Return on Book are inadequate when analyzing incremental cash flows.

Life of the Project. The life of the project – that is, the period over which the two dollies would be compared – is determined by the life of an A–dolly. Normal operation of double–trailer combinations results in relatively minor wear on the conventional dolly and some fleet operators believe that A–dollies are virtually indestructible. For this analysis, however, the life of an A–dolly is assumed to be ten years.

Assumptions Concerning Economic Issues. The following parameters, which are assumed to increase or decrease the cost of operation, are used in the financial model:

• Initial cost of the dolly. The CSB–dolly is assumed to cost $7500 more than the conventional A–dolly. This assumption is based on the fact that a Fruehauf single-axle A–dolly (with tires) costs $5625 and an ASTL B–dolly (with tires) costs $10,625. Manufacturing and installing the controlled–steering hardware (on the dolly and the pup trailer) is assumed to cost an additional $2,500. Unlike the CSB-dolly, the linked-articulation dolly is a modified A-dolly with additional hardware to "link" the articulation angles between the two trailers in a twin-trailer configuration. The cost of the "linking" hardware is assumed to be $3,500 (based on information provided by ADVANCE). Consequently, the linked-articulation dolly is assumed to cost $3,500 more than the conventional dolly. Differences in scrap value are taken to be negligible.

• Backing up. Since it is virtually impossible to back up A–dolly-equipped doubles, drivers of such vehicles in common freight service generally need to “break down” the vehicle in an intermediate staging area and maneuver both trailers into their loading docks individually. Depending upon the distance from the loading dock to the staging area, the entire process of assembling and disassembling a set of double trailers can take up to an hour of the driver's time. Use of the CSB– and LA-dollies give the driver the ability to back up a doubles combination which may allow him to deliver both trailers to the loading dock without the time consuming process of assembling and disassembling the combination at the staging area. On the other hand, the linked-articulation dolly, by the nature of its hitching arrangement, is most suited to operations where the two trailers are permanently "married." Transportation of bulk products, such as gasoline and grain, are examples of such operations. Since the loading and unloading of bulk products are performed in a "drive-through" operation, the advantage of being able to back-up twin-trailers in these operations is less significant. Thus, the time saving potential seems to be most applicable to the CSB-dolly only.

One variation in model parameters assumes that the driver of vehicles using CSB-dollies saves twenty minutes by not having to make two trips to and from the staging area. Assuming an internal labor rate of $26.25 (including benefits) the fleet operator saves $8.75 for each double–trailer combination that is assembled and disassembled. This assumes that both the vehicle and the driver are idle for the period.

However, if the time saved were accumulated and put to productive use, such as hauling freight, then the benefits might help recover the increased costs of operating a CSB–dolly. For example, the additional benefits produced from 20 minutes of extra hauling time can be calculated in the following manner. Assuming an average transportation speed of 32 km/hr (20 mi/hr) (including stops, delays, etc.) and a freight hauling charge of $0.0001552 per kg. per km. ($0.0001118 per lb per mi), then a vehicle with a payload of approximately 22,750 kg (50,155 lb) would earn an additional $37.50 per 20–minute period. In other words, the fleet operator would earn $37.50 for each double-trailer combination that is assembled and disassembled.

• Converting existing equipment. At least one semitrailer must be modified for every CSB–dolly purchased. Installing two additional pintle hooks and frame–stiffening the semitrailer's chassis is assumed to cost approximately $3,750.

In the case of the linked-articulation dolly, two trailers must be modified for every LA-dolly purchased. Installing the "linking" hardware to the two permanently "married" trailers is assumed to cost $8,000 (based on information provided by ADVANCE).

• Major overhauls. Canadian operators of both A– and B–dollies believe that B–dollies must undergo a major overhaul twice as often as A–dollies. The industry standard is to overhaul an A–dolly every 800,000 km (500,000 mi) and a B–dolly every 400,000 km (250,000 mi). With respect to the cost and frequency of major overhauls, CSB-dollies are assumed to be similar to B-dollies and LA-dollies are assumed to be similar to A-dollies. In other words, while CSB- and B-dollies undergo a major overhaul every two years, LA- and A-dollies undergo a major overhaul every four years. As an overhaul includes, among other things, fifth wheels, drawbar eyelets, steering systems, brakes, and springs, the cost of a major overhaul is kept as a variable and is defined as a percentage of the initial cost of the dolly. This cost is assumed to include factors related to both (a) time and materials for maintenance and (b) service time lost during maintenance.

• Preventive maintenance. The cost of regular maintenance such as inspection and lubrication depends upon the size of the fleet and the frequency at which maintenance is done. There is, however, a general view in the Canadian trucking industry that maintenance costs of the innovative dollies are twice that of the A-dolly. In the case of the CSB-dolly, the increase in maintenance cost is attributable to the maintenance of the steering system. In the case of the LA-dolly, however, the increase in cost is attributable to maintenance of the additional hitching linkage.

• Tire wear. During normal operation, the tires on conventional dollies last for 160,000–193,000 km (100,000–120,000 mi). Tire scrubbing on B-dollies tends to wear tires 10–15% faster. As far as tire wear is concerned, the CSB- and LA-dollies are better than B–dollies and are assumed to resemble conventional A-dollies.

• Scheduling costs. Scheduling varies across truck fleets, and practices are dependent on the size of the operation. Some large operations have delegated most of the scheduling exercise to computer programs which route tractors, semitrailers, and dollies according to variables such as trip length and freight being hauled. On the other hand, fleets with fewer units are more comfortable maintaining scheduling as part of the day-to-day administration of the trucking operation.

Since the linked-articulation dolly is likely to be used only with "married" trailers, changes in scheduling costs are assumed to be negligible. However, in general freight fleets, partial introduction of CSB-dollies would mean that dollies and trailers were no longer be completely interchangeable. Consequently, there is bound to be an increase in scheduling costs. It is assumed, however, that there is a learning curve associated with the scheduling process, and the increase in cost will disappear over time.

A complete changeover from A- to CSB-dollies would not affect the process of scheduling. If, however, half of the total number of dollies are CSB-dollies, then the increase in scheduling costs is assumed to be at its maximum. To account for this trend, the model assumes a triangular distribution in which scheduling cost varies as a percentage of the CSB-dollies in the fleet. The model assumes a single expense to update computer programs and any scheduling-related data bases.

• Training/loss of productivity. To address the fact that drivers and yard personnel must deal with a new piece of equipment, the model accounts for training and a cost associated with a temporary loss of productivity. The increase in time required to hitch the CSB-dolly is a specific example of a loss of productivity. Operators of B-dollies believe that, with some exceptions (such as hitching on uneven yard surfaces), hitching B- and CSB-dollies could become as routine as hitching an A-dolly. The model uses a learning curve to account for the temporary nature of this cost.

Again, since the LA-dolly involves permanently "married" trailers, the new hitching mechanism would not cause any increases in operating cost.

• Loss of revenue from hauling less weight. Due to the steerable axle and a sturdier frame, the CSB-dolly weighs 455–680 kg (1,000–1,500 lb) more than the conventional dolly. The additional hitching linkage in the LA-dolly also results in a weight increase of 295 kg (650 lb). Under conditions where vehicles are operated at maximum gross weight, the extra weight of the dolly displaces an equivalent amount of freight. The loss of revenue depends upon a number of factors—type of freight (freight class), trip length, etc. For example, the revenue from shipping 4,540 kg (10,000 lb) of *general freight* a distance of 3,800 km (2360 mi) is $2,656. If a vehicle is forced to forego carrying 454 kg (1,000 lb) of such freight, then the loss of revenue for the trip is $265.62. If the vehicle is forced to forego 454 kg (1,000 lb) of *bulk freight*, at the rate of $0.0018 per 100 kg per km ($0.0025 per 100 lb per mi), then the loss of revenue for the trip is $31.05.

• Permit to increase axle loads. In order to promote the use of innovative dollies, and recognizing the economic significance of allowable gross weight, Saskatchewan is now allowing up 9,000 kg (19,800 lb) additional weight when CSB- or LA-dollies are used. The assumption of increased regulatory load allowance (very similar, but of course, opposite to the assumption above) addresses current highway regulation and has been included to describe the Saskatchewan, and other possible situations.

• Savings from fewer accidents. The analysis in the original study [1] predicted that the improved safety characteristics of the CSB–dolly would save the fleet operator

$0.0062/km ($0.010 per mile). Based on engineering judgement regarding the relative effectiveness of the two designs, the LA-dolly is assumed to save the fleet operator $0.0055 per km ($0.00875 per mile) of travel.

• Ability to operate on secondary roads. Some political venues limit the operation of double–trailer combinations to designated highways. Considering a situation where both trailers in a doubles combination are headed for the same destination off the designated highway system, the combination must be disassembled and each trailer must be transported to the final site independently. If such regulation were to be removed because of the improved dynamic performance of doubles with innovative dollies, there would be a cost savings associated with the elimination of two trips to and from the local drop-off site.

APPLICATION OF THE FINANCIAL MODEL.

To study the influence of the economic issues discussed earlier, results for the two dollies are presented here.

Current Operating Environment. Starting with a situation which tries to approximate the current operating and regulatory environment, the financial model is used to analyze the decision by a fleet operator to purchase six innovative dollies. In the case of the CSB-dolly, the Net Present Value (the NPV is defined as the sum of the incremental cash flows over the life of the project reduced to current dollars) of such a decision results in a total negative cash flow (a loss) of $537,492.16. The incremental cash flows projected over ten years are as shown in Table 5 (in Appendix C). The values of the parameters used in this situation are tabulated in Table 4 (in Appendix C). (A brief discussion of the independent parameters, their values and their role in the financial model is also included in Appendix C.)

It is important to emphasize that this loss is an *incremental loss* due to a decision to buy a CSB-dolly instead of an A-dolly. For example, if there were an underlying decision (with an NPV of at least $537,500.00) to use twin–trailer combinations instead of tractor–semitrailers, then the decision to use CSB-dollies would only reduce the profitability of the original decision. The purchase of conventional dollies, however, would not affect the original NPV of at least $537,500.00.

Assuming that the reference fleet were to raise its shipping charges to cover its incremental loss, the freight charges would have to be increased by $0.000311 per 100 kg per km ($0.000224 per 100 lb per mi), as indicated in Table 5 (in Appendix C). The rate increase was determined for six CSB–dollies, observed over a ten year period, travelling 160,934 km (100,000 miles) per year and carrying 18,144 kg (40,000 lb) of cargo per trip. The increase in freight charges translates into an increase of $53.10 for 45,359 kg (100,000 lb) of cargo to be shipped 3,800 km (2360 mi) — an increase of 1.96%.

In the case of the LA-dolly, the Net Present Value of a decision to buy six innovative dollies results in a total negative cash flow of $250,420.79. Since the linked-articulation dolly is lighter than the CSB-dolly, the loss incurred due to displaced cargo is much lower. The incremental cash flows projected over ten years are as shown in Table 7 (in Appendix C). The values of the parameters used in this situation are tabulated in Table 6 (in Appendix C).

It is often helpful to see how a project fares under various scenarios. A sensitivity analysis is helpful in determining the key variables that determine whether a project fails or succeeds. Table 2 contains a list of the reference values and the variations used in the analysis of the CSB-dolly. The influences of some of the variations listed in Table 2 are displayed in Figure 9.

In Figure 9, the reference value of each of the independent variables (i.e., those values from our estimate of the "current operating environment") is shown in brackets (next to the darker shaded bars). According to the financial model, introducing CSB-dollies into this "environment" would result in a change of operating cost of $0.0826/mile (loss), shown as the "baseline value" in the figure (and represented by the darker shaded bars). The lighter shaded bars of the graph represent the change of operating cost which would result if the operating environment was different than our chosen "current operating environment". For example, if the operating environment had a freight charge of $0.0000445/kg/km ($0.0000325/lb/mi similar to bulk rates) rather than $0.000153/kg/km ($0.0001118/lb/mi, a representative general freight rate) then the loss upon the introduction of CSB-dollies into this environment would be less. (The loss is largely due to the loss of cargo resulting from the heavier dolly; lower rates means less dollar loss per pound of lost cargo.)

Figure 9 shows that reasonable increases or decreases in some of the independent variables have little influence on the operating cost while others, namely, (1) freight charges, (2) percentage of trips made at maximum allowed weight, (3) dolly weight, (4) local drops, and (5) double assembly and disassembly, have the strongest influences on the changes in operating cost associated with acquiring CSB-dollies. With regard to accident

Table 2. Variations used in analyzing operating cost sensitivities for the CSB-dolly (see figures 9 and 10)

Variables	Reference Values	Sensitivity Variations	
		Minimum	Maximum
Percentage of trips at max GVW	60%	30 %	90 %
Additional dolly weight	1,500 lbs	750 lb	2250 lb
Miles per year per dolly	100,000 miles	50000 miles	150,000 miles
Charge/lb/mile for freight hauled	$0.0001118	$0.0000325	$0.000207
Overhaul cost (percentage of initial dolly cost)	20 %	10%	30%
Preventive maintenance - per year	$625	$0	$1,250
Double assembly & disassembly (CSB-dolly backup)	0 per day	0.5 per day	2 per day
Accident savings per mile per CSB-dolly	$0.01	$0.000	$0.020
Annual discount rate	10 %	8.00%	12.0%
Local deliveries	0 per year	130 per year	260 per year
Overweight hauling allowance	0 lbs	10,000 lbs	20,000 lbs

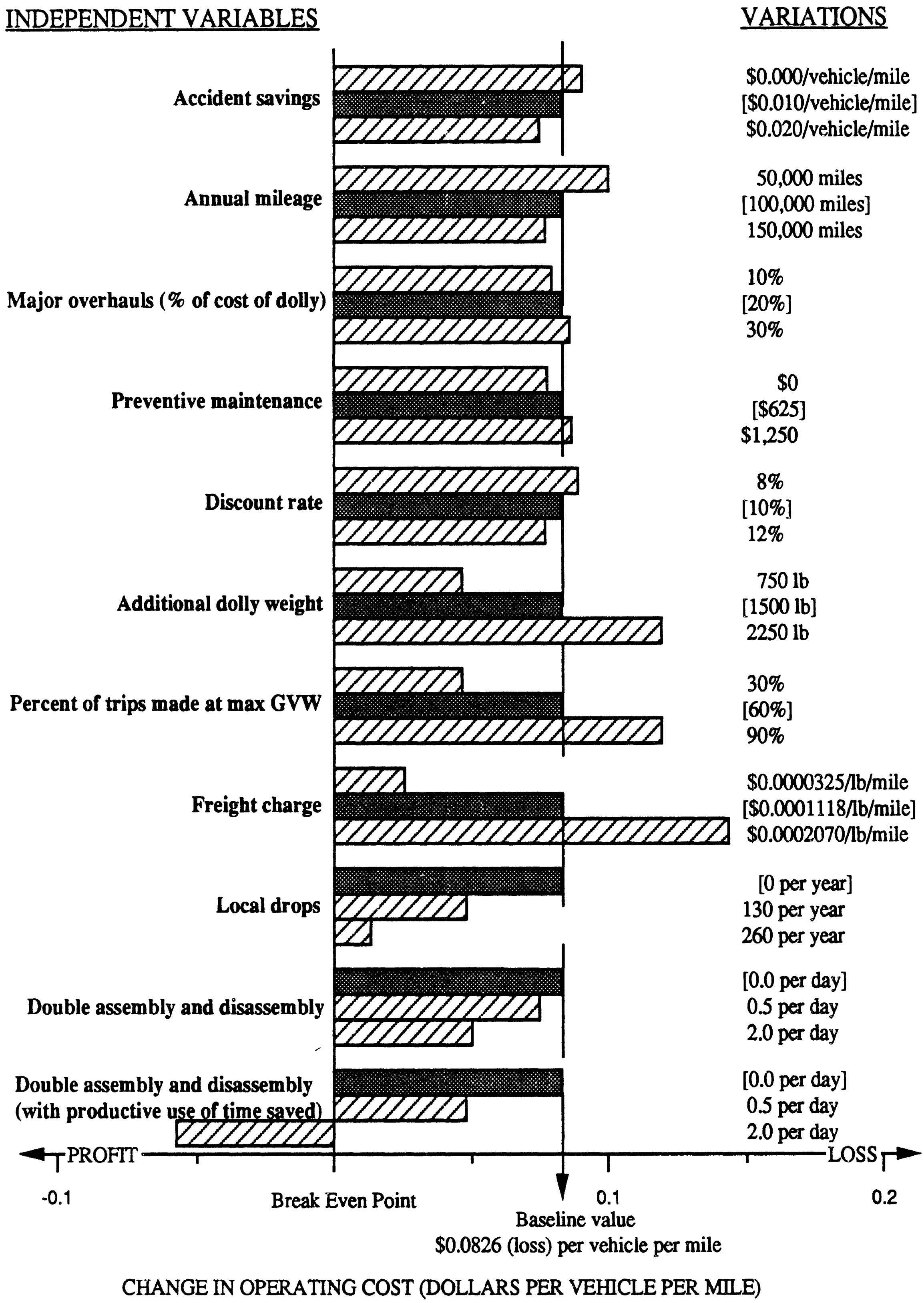


Figure 9. Operating cost sensitivities for a CSB-dolly equipped double

costs, the results presented in Figure 9 show that accident costs have only a moderate influence on the financial picture. The profit side of the bar chart is reached if the owners of CSB-dollies assemble and disassemble their double-trailers twice a day and can use the time saved productively.

If fleet operators are given a weight allowance to compensate for the additional costs of operating a CSB-dolly, it would produce a significant change in the operating environment. Figure 10 displays the effects of a weight allowance relative to the variations of the other independent variables. The benefits of the weight allowance, as shown in Figure 10, completely overshadow the influences of the other key variables. Assuming that fleet operators have the need to carry the extra weight and do not violate some other size or weight law, the weight allowance would make the purchase of CSB-dollies a very attractive financial decision.

It should also be emphasized that, in Figure 10, the benefit of the additional weight allowance is mitigated by the "baseline" assumption that only 60% of trips are made at the full gross loading condition. If a fleet can take advantage of the full allowance for a greater percentage of miles, then the economic benefit would be even greater.

A similar analysis for the linked-articulation dolly is presented in Figures 11 and 12. Table 3 contains a list of the reference values and the variations used in the analysis of the LA-dolly. The same independent variables, that is, (1) freight charges, (2) percentage of trips made at the maximum allowed weight, and (3) local drops tend to play a significant role in changing the operating cost due to the purchase of an LA-dolly. Similar to the case of the CSB-dolly, the weight allowance (shown in Figure 12) would overshadow the influences of the other independent variables.

The economic analysis presented in the preceding discussion has painted a picture which indicates that the introduction of innovative dollies may not be a profitable investment decision unless regulatory changes are made to the current operating environment. Regulatory changes, such as permits to operate on secondary roads and, especially, weight allowances, help increase the profitability of fleet operators using innovative dollies. Also, additional savings might be realized by fleet operators if they were able to take full advantage of inherent productivity advantages of the innovative dollies, such as the potential time savings allowed by the ability to back doubles equipped with innovative dollies.

Table 3. Variations used in analyzing operating cost sensitivities
for the LA-dolly (see figures 11 and 12)

Variables	Reference Values	Sensitivity Variations	
		Minimum	Maximum
Percentage of trips at max GVW	60%	30 %	90 %
Additional dolly weight	650 lbs	500 lb	850 lb
Miles per year per dolly	100,000 miles	50000 miles	150,000 miles
Charge/lb/mile for freight hauled	$0.0001118	$0.0000325	$0.000207
Overhaul cost (percentage of initial dolly cost)	20 %	10%	30%
Preventive maintenance - per year	$625	$0	$1,250
Accident savings per mile per LA-dolly	$0.088	$0.000	$0.018
Annual discount rate	10 %	8.00%	12.0%
Local deliveries	0 per year	130 per year	260 per year
Overweight hauling allowance	0 lbs	10,000 lbs	20,000 lbs

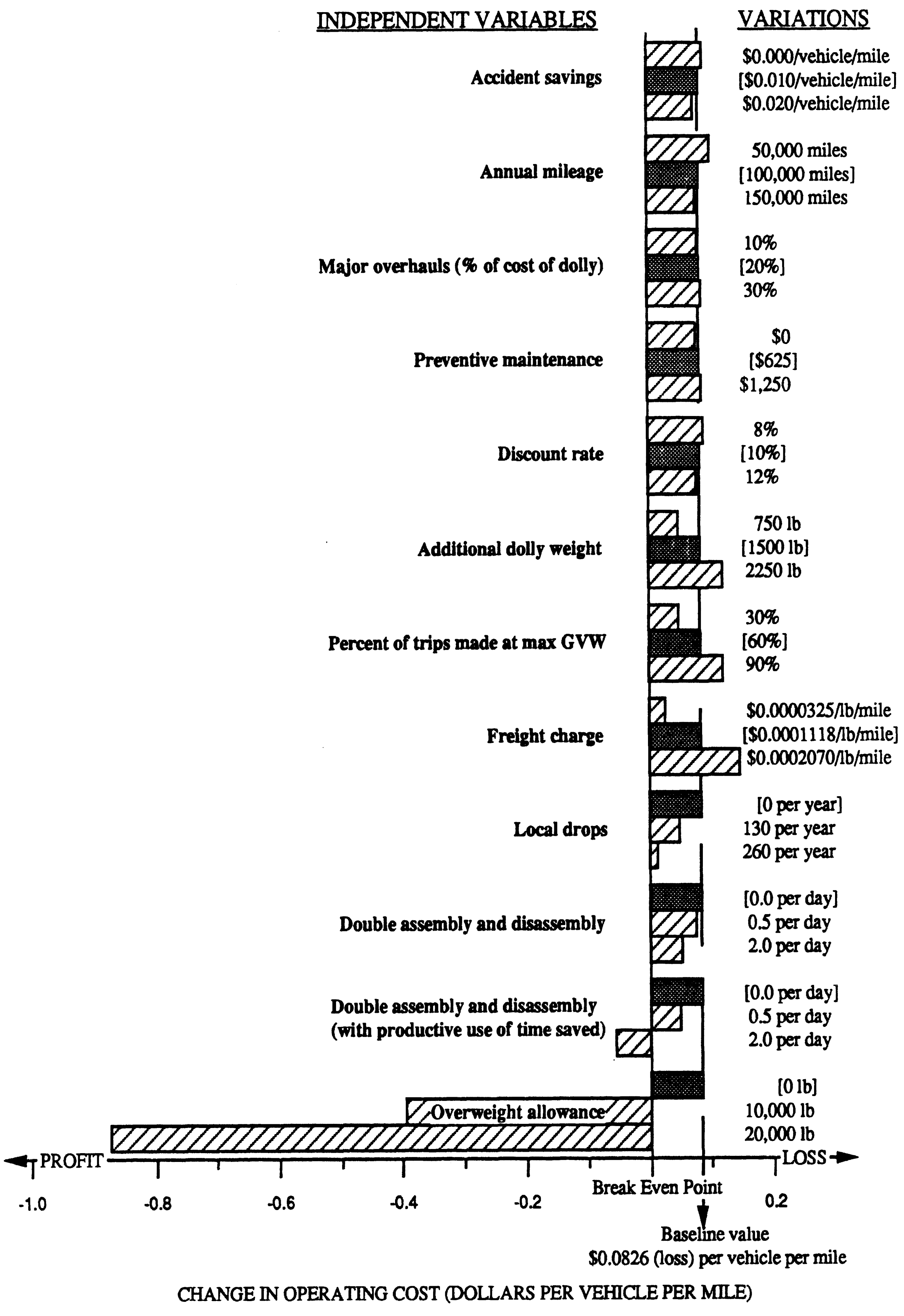


Figure 10. Operating cost sensitivities for a CSB-dolly equipped double

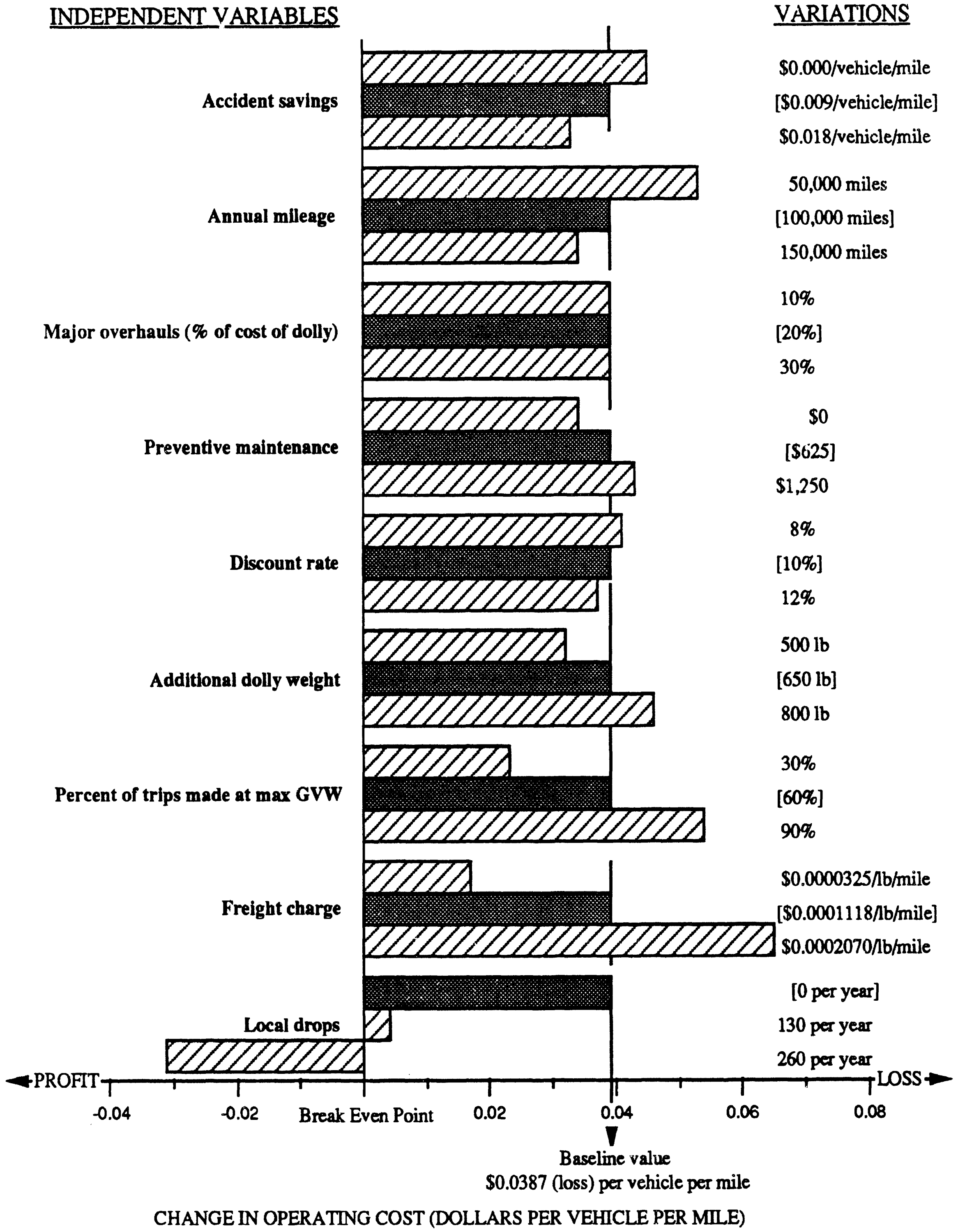


Figure 11. Operating cost sensitivities for a linked-articulation dolly

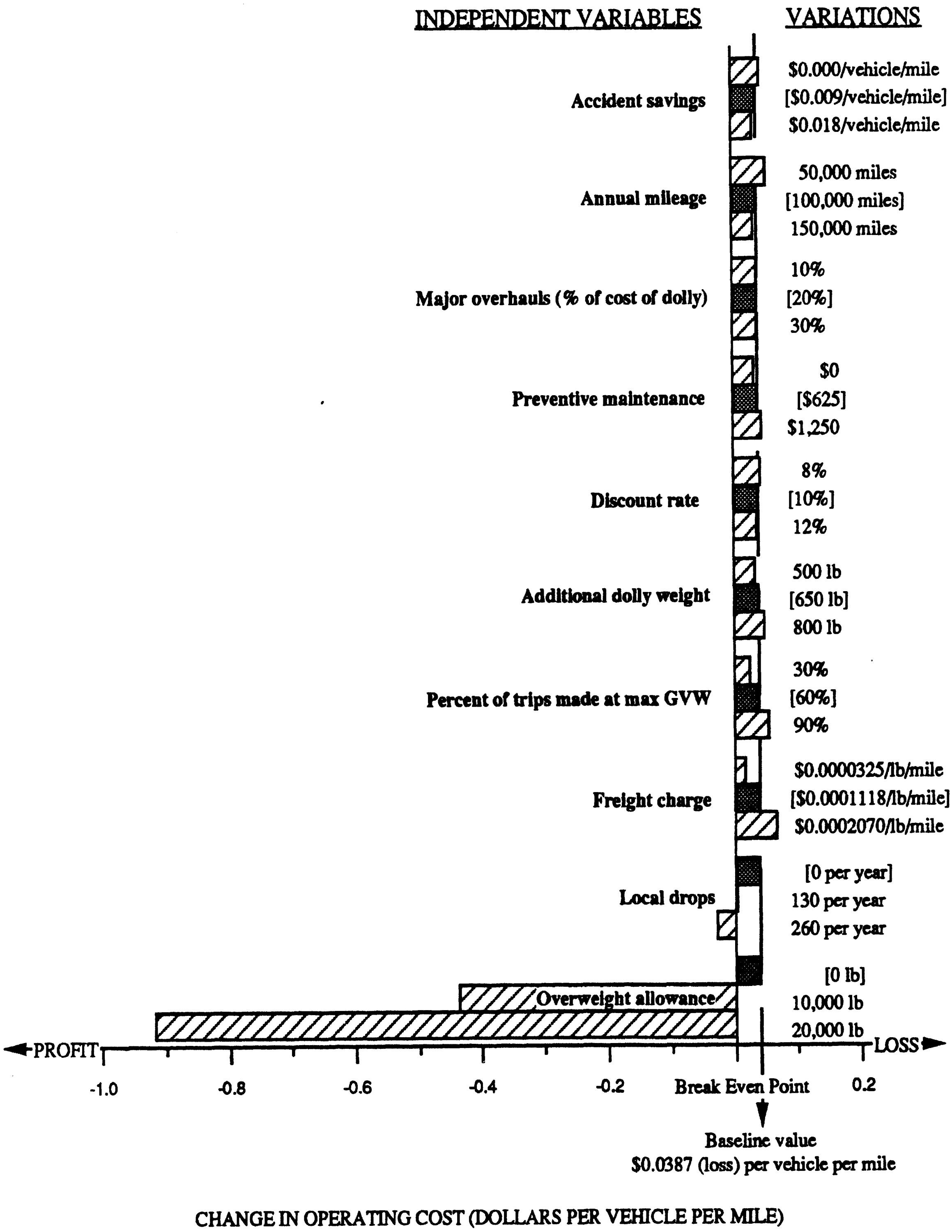


Figure 12. Operating cost sensitivities for a linked-articulation dolly

ESTIMATING THE EFFECT OF THE SASKATCHEWAN REGULATORY ENVIRONMENT.

The reference condition presented earlier was designed to reflect a representative operating environment. If, however, the specific situation of 8,850 kg (19,500 lb) heavier gross vehicle weights, as permitted in Saskatchewan, is assumed, then the results are, of course, quite different. Tables 8 through 13 (in Appendix C) review analyses in which the operating environments include (1) this additional weight allowance, and (2) representative bulk freight rates (Tables 8 through 11), as well as, representative general freight rates (Tables 12 and 13).

The cash flows which could result from the purchase of six CSB-dollies by a hauler using *bulk freight rates* are shown in Table 9. The values of the independent variables used in this case are shown in Table 8. In this case the decision to invest in CSB–dollies could be profitable with an NPV of approximately $1,398,000 over ten years. Similarly, the linked-articulation dolly operating in the same environment would result in an NPV of $1,512,000 over ten years. The cash flows for this situation are shown in Table 11 and the values of the independent variables are presented in Table 10.

Cash flows resulting from using representative *general freight rates* appear in Tables 12 and 13. In these cases, the decision to invest in six CSB–dollies or six linked-articulation dolly could be profitable with an NPV of approximately $5,067,000 or $5,354,000 respectively over ten years.

It is important to emphasize that these impressive figures result from the regulatory weight allowance (not from the use of the innovative dollies, per se). Also, it must be stressed that the financial model assumes that the vehicles have the ability and the need to take advantage of the regulatory changes.

It must also be noted that these results (and, indeed, the financial model used herein) ignore the inevitable influence of increased productivity on freight rates. In the real world, competitive pressures would drive down freight rates as carriers in general gain access to more efficient vehicles. It is very difficult to predict the ebb and flow of pricing in a dynamic market, and this analysis has not attempted to do that. Thus, the predicted NPV profits might not be actually achieved in the long run, but failure to take advantage of the regulatory changes and other benefits associated with the innovative dollies in a market place which generally did so might result in losses of similar magnitude.

CONCLUDING REMARKS

The present use of innovative dollies is limited and, from a financial point of view, may be expected to stay that way unless highway regulations are eased in recognition of the improved dynamic ability of the innovative dollies. With regard to the engineering of the innovative dollies, the economic analysis indicates that the weight of the dolly is a crucial issue. Small changes in productivity have a major influence on operating costs. It appears that reductions in dolly weight might pay for the increases in dolly purchase prices that would accompany the introduction of lighter and stronger materials. (Of course, reduced dolly weight would lead to more productive vehicles whether they employ A–, LA-, or CSB–dollies.)

As shown by the analyses presented here, the difference between profit and loss in the trucking industry depends primarily on productivity. An increase in productivity can offset increases in the costs of operating doubles equipped with innovative dollies. Time savings and the amount of weight hauled are both key factors affecting the productivity of a trucking fleet. Although the innovative dollies cause a decrease in the amount of weight that can be carried, that loss in productivity might be compensated for if fleet operators can find ways to use features of innovative dollies (such as the ability to back up) to increase productivity.

The 8,850 kg (19,500 lb) weight allowance offered by the Saskatchewan regulations provides a massive economic influence toward use of innovative dollies. The increase of productivity which results from this allowance overwhelms all the other economic factors involved.

6. Summary Assessment and Concluding Remarks

The prototype dollies have been a success in these field trials. The dynamic performance measured on the proving grounds has been reflected in the good performance observed in field operations. In fact, the field observations are generally of the "no-problem" type. The trip and maintenance reports are generally uneventful and filled with brief, positive entries such as "OK" and "works well." The drivers have found the stability of the vehicles to be good even in freezing rain on windy days.

The operation at TRIMAC is set up for B-dollies. The TRIMAC operation is easier to perform when a combination is equipped with the CSB- or LA-dolly. Although backing up is not usually required and space is made available to avoid difficulties with offtracking, the increased maneuverability provided by the prototype dollies is seen as a definite advantage. The ability to back up is being used in making deliveries in a few places which that were not previously accessible to doubles.

Maintenance people find the CSB-dolly to be a large improvement over the conventional B-dolly. They have noted less tire wear with the CSB-dolly than with other dollies. Problems with axle bending and kingpin wear, that were experienced with conventional B-dollies, have not occurred with the CSB-dolly.

Initially, the CSB-dolly developed some slack and free play in its steering linkages. After this was corrected early in the field trials, the CSB-dolly performed well without a recurrence of this problem. The only maintenance factor noted lately is that some wear has started to develop on the top of the steering ball. Although the field maintenance personnel do not look on this as a major difficulty (possibly because the CSB-dolly has been much more trouble-free than other B-dollies), the wear of the ball is a matter worth investigating and design improvements are in order for the steering system. Nevertheless, the steering system has functioned very well and it has performed as intended throughout the last year.

The LA-dolly has had similar success regarding these practical issues. Although lack of trailer-to-trailer roll coupling was a safety performance shortcoming of the original prototype, new designs from ADVANCE Engineering are successfully providing significant roll coupling.

In the previous FHWA study [1], the CSB- and LA-dollies demonstrated superior dynamic performance qualities which can provide real safety benefits in use. This, combined with their success in these real-world field trials suggest that their broad use is desirable from a safety point of view and feasible from a practical point of view. However, these innovative dolly designs are not likely to fair well in direct *economic* competition with A-dollies; the additional weight of the innovative dollies is a major disadvantage. The economic analysis shows that this weight penalty would be costly and difficult to recoup in situations where gross combination weight limits are not adjusted to provide an economic advantage to B-dollies. The current CSB-dolly is approximately 680 kg (1,500 lbs) heavier than some A-dollies that could be used in comparable service in Canada. This additional weight is brought about by the second drawbar, an especially heavy steering axle, and the steering linkage incorporated in the CSB-dolly. The LA-dolly suffers a similar weight penalty of of about 295 kg (650 lb). With appropriate redesign and development, lighter CSB- and LA-dollies could evolve. Nevertheless, it would seem that the simpler A-dolly will always have some weight advantage over the CSB- and LA-dollies.

On the other hand, the improved safety quality of the innovative dollies provides the opportunity for improved productivity in trucking through the regulatory mechanism of granting additional weight allowance for vehicle using these dollies. Or conversely, it would appear that increased weight allowance should be an extremely effective means of promoting the use of these safer, innovative dollies. Having made these observations, the regulatory agency in Saskatchewan has opted to provide increase weight allowances up to 8,850 kg (19,500 lb) with the use of these innovative dollies. *Assuming that an operator can make effective use of the allowance being offered*, the economic analysis of this report suggests that the purchase of six LA- and/or CSB-dollies could result in profits over ten years of $1.4 to $1.5 million, net present value, in bulk freight operations, or $5.0 to $5.4 million, net present value, in general freight operations.

REFERENCES

1. Winkler, C.B. Improving the Dynamic Performance of Multi-Trailer Vehicles: A Study of Innovative Dollies. Transportation Research Institute, The University of Michigan, Report No. UMTRI-86-26, July 1986.

Appendix A

TRIMAC Transportation

Questions on the Experience of the Canadian Trucking Industy in the Use of B-Dollies

1) What was the basis for your choosing to purchase and use B-dollies?

HIGHER G.V.W. FROM 108,000 lbs TO 137,000
MORE STABILITY, CRITICAL IN HIGHER GROSS UNITS.
Safety

2) Over what time period (and approximate total vehicle-miles) have you gained experience with B–Dollies?

SINCE 1982
APPROX 125,000 Mi/YEAR.
50 DOLLIES IN USE (AUTOMATIC STEER ONLY)

3) On what types of vehicle combinations do you operate B-Dollies?

DOUBLES ONLY
(WESTERN A TRAIN)

4) In what kinds of hauling operations do you employ these vehicles?

- what kinds of roads are you on? IN SASK. BOTH PAVEMENT & GRAVEL EX SASKATOON PRIMARILY GRAVEL.

- what levels of traffic density are you operating in? LIGHT TO MODERATE.

- what are your typical axle loads? 8 AXLE UNIT.

12	35	35	20	35
STRING	DRIVE	TRL.	DOLLY	REAR TRL.

- what percentage of your loads are
  - a) cube-full 85%
  - b) max GCW 137000 lbs.
  - c) other__________

5) Are your drivers of B-Dolly rigs experienced also in operating A-trains?

YES 3 YEARS MIN EXPERI

6) What do your drivers say about their experience with the B- vs. A-Dolly hardware?

Unit is much more stable.
Driver has a better feel for what rear unit is doing.

7) What has been your accident experience with A- and B-Dolly systems?

- overall accident rates ?

- types of accidents (rollover, sidewsipes, jackknife, etc.)

- weather conditions and loading

8) What unusual experiences have you had in the field operating B-Dollies that never occurred before with A-Trains? (What have been the suprises?)

Broken axle.
greater tire wear.

9) What is the lifespan (between major overhauls) of B- vs. A-Dollies in your experience?

Because of the extreme condition units run in, it would be unfair to judge the -Dolly on Basic pavement operation.

10) What are the major maintenance problems with B-Dollies?

Axle Bending.
King Pin wear.

11) Have you had unusual structural failures in trailers coupled by means of a B-Dolly?

NO

12) What are the differences in maintenance costs incurred with B- vs. A-Dollies?

14) Do you lose revenue because payload is replaced by the heavier B-Dolly?

NO
Due to incentive of Higher gross vehicle wt.

15) What is the overall cost of operating A- vs. B-Dolly vehicles in your business, ($ per ton–mile)? ?

16) In what way is the B-Dolly easier (or harder) to hitch and unhitch than the A-Dolly?
N/A in our operation.

17) Have you used so-called "automatic hitching mechanisms", with B-Dollies, instead of conventional pintle hitches? If so, do they provide any advantages?
NO

18) Is the greater ease of backing up B-Dollies important in your operation?
NO.

19) Do you need less room at your truck terminals for assembling and/or maneuvering B-Dolly-, as opposed to A-Dolly-, equipped vehicles? NO

20) Have you experienced other advantages or disadvantages in the use of B-Dollies which may not have been addressed above? NO.

Appendix B

A few trip and maintenance reports were selected from the sixteen month collection and are included in Appendix B. Information from some of these reports resulted in the "milestones" on the cumulative mileage chart in Figure 8.

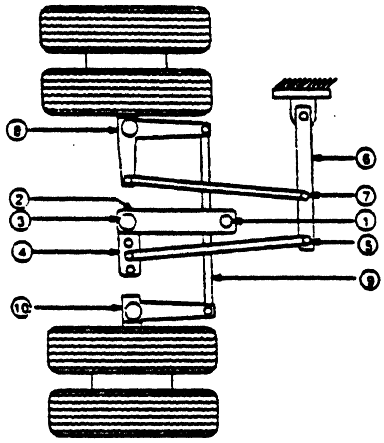
Saskatchewan Highways and Transportation

CSB - DOLLY CONVERTOR REPORT

INSPECTION

In addition to the standard pre-trip inspection, the following checks must be carried out for the CSB - Dolly Convertor.

1. Steering System:



		Normal	Wear
①	Steering Ball Hitch	(✓)	( )
②	Upper Steering Arm	(✓)	( )
③	Vertical Steering Shaft	(✓)	( )
④	Lower Steering Arm	(✓)	( )
⑤	1st Steering Link	(✓)	( )
⑥	Idler Arm	(✓)	( )
⑦	2nd Steering Link	(✓)	( )
⑧	Left Wheel Steering Arm	(✓)	( )
⑨	Tie Rod	(✓)	( )
⑩	Right Wheel Steering Arm	(✓)	( )

2. Structural Components:

	Normal	Abnormal Wear
Main frame rails	(✓)	( )
Cross members	(✓)	( )
Pintle hitches	(✓)	( )
King Pins (Shop check only)	(✓)	( )
Tire Wear (Shop check only)	(✓)	( )

If any steering or structural components show signs of wear and/or fatigue which may affect the performance of the vehicle, it is to be taken out of service immediately. The operator is to advise Trimac personnel and personnel of the Transportation Systems Branch, Department of Highways and Transportation of such action. Note defects here:

top of Steering Ball showing a little wear.

REPAIRS

Please note any repairs required:

FOR SHOP USE ONLY

Unit No. ______ Date Inspected July 26/86

Mechanic's Signature [illegible]

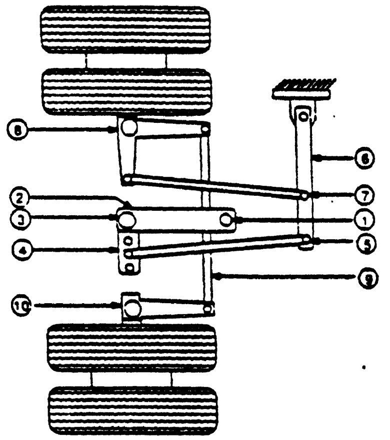
Saskatchewan Highways and Transportation

CSB - DOLLY CONVERTOR REPORT

INSPECTION

In addition to the standard pre-trip inspection, the following checks must be carried out for the CSB - Dolly Convertor.

1. Steering System:



		Normal	Wear
①	Steering Ball Hitch	(✓)	( )
②	Upper Steering Arm	(✓)	( )
③	Vertical Steering Shaft	(✓)	( )
④	Lower Steering Arm	(✓)	( )
⑤	1st Steering Link	(✓)	( )
⑥	Idler Arm	(✓)	( )
⑦	2nd Steering Link	(✓)	( )
⑧	Left Wheel Steering Arm	(✓)	( )
⑨	Tie Rod	(✓)	( )
⑩	Right Wheel Steering Arm	(✓)	( )

2. Structural Components:

	Normal	Abnormal Wear
Main frame rails	(✓)	( )
Cross members	(✓)	( )
Pintle hitches	(✓)	( )
King Pins (Shop check only)	(✓)	( )
Tire Wear (Shop check only)	(✓)	( )

If any steering or structural components show signs of wear and/or fatigue which may affect the performance of the vehicle, it is to be taken out of service immediately. The operator is to advise Trimac personnel and personnel of the Transportation Systems Branch, Department of Highways and Transportation of such action. Note defects here:

____

____

____

____

REPAIRS

Please note any repairs required:

Changed grease nipples on # 6, 7, 10

____

____

____

FOR SHOP USE ONLY

Unit No. ______________ Date Inspected *April 20 86*

Mechanic's Signature ______________

"SCHEDULE A"

TRIP REPORT

Driver O. Slobodian Date March 24/86

Unit No. 11348 Company Trip Report # ____

From	To	Departure Time	Arrival Time	Gross Vehicle Weight Power Unit & Lead Trailer	Gross Vehicle Weight Dolly & Rear Trailer
Regina	Stoon	9:00 AM	1:30 PM	4530 ~~14220~~	
Stoon	Regina	3:40 PM	7:40 PM	16060	53470

Total Fuel Used 78 5750 ~~13240~~

Please note any repairs required during the trip.

Weather Conditons:

Temp -2°C Wind Speed 40 Km Wind Direction East

Sky Clear ____ Cloudy ~~[illegible]~~ ✓ To Stoon Cloudy With Rain ✓ ~~[illegible]~~ To Regina

Road Conditions:

Dry ✓ Wet ____ Ice ____

Vehicle Inspection:

The standard pre-trip inspection is required. If any items show signs of wear and/or fatigue which may affect the performance of the vehicle, it is to be taken out of service immediately. The operator is to advise Trimac personnel and personnel of the Transportation Systems Branch, Department of Highways and Transportation of such action. The Department and Trimac will jointly determine the remedial action necessary to put the vehicle back into service. Note defects here:

Trailer Self Steering Axle Assemblies:

	Loaded	Empty
Pressure on steering system: at start of trip	_____	_____
at completion of trip	_____	_____

Number of times axles on trailer had to be lifted: __________

Reasons the axle had to be lifted for:

____

Describe any occassions when steering axles did not work properly during the trip:

____

Vehicle Operation:

Please describe the general performance of the vehicle during the trip. Include any unusual vehicle performance or traffic situations that occurred during the trip. If difficulties of a serious nature occur please contact one of the people listed below for Trimac and one of the people listed below for the Department of Highways and Transportation.

Unit handled well in freezing [illegible] conditions

Driver's Signature [signature]

Saskatchewan Highways and Transportation

Bernie Churko	Norm Burns	Peter Hurst
787-5533 Bus.	787-5535 Bus.	787-5536 Bus.
545-5628 Res.	586-9802 Res.	545-7750 Res.

Road Systems Unit
7th Floor, 1855 Victoria Avenue
Regina, Saskatchewan

03131/76-77

"SCHEDULE A"

TRIP REPORT

Driver O SLOBODIAN Date 4-4-86

Unit No. 11-348 Company Trip Report # ____

From	To	Departure Time	Arrival Time	Gross Vehicle Weight Power Unit & Lead Trailer	Gross Vehicle Weight Dolly & Rear Trailer
REGINA	ESTEVAN	800 Am	Rolling	34000	19500
ESTEVAN	REGINA	1.00 Pm	5.30 Pm	GROSS	53500

Total Fuel Used 48

Please note any repairs required during the trip.

Weather Conditons:

Temp -1 Wind Speed 22 Wind Direction SOUTH EAST

Sky Clear ____ Cloudy With Snow ✓ Cloudy With Rain ____

Road Conditions:

Dry ✓ Wet ____ Ice ____

Vehicle Inspection:

The standard pre-trip inspection is required. If any items show signs of wear and/or fatigue which may affect the performance of the vehicle, it is to be taken out of service immediately. The operator is to advise Trimac personnel and personnel of the Transportation Systems Branch, Department of Highways and Transportation of such action. The Department and Trimac will jointly determine the remedial action necessary to put the vehicle back into service. Note defects here:

OK.

Trailer Self Steering Axle Assemblies:

	Loaded	Empty
Pressure on steering system: at start of trip	____	____
at completion of trip	____	____

Number of times axles on trailer had to be lifted: __________

Reasons the axle had to be lifted for:

Describe any occassions when steering axles did not work properly during the trip:

Vehicle Operation:

Please describe the general performance of the vehicle during the trip. Include any unusual vehicle performance or traffic situations that occurred during the trip. If difficulties of a serious nature occur please contact one of the people listed below for Trimac and one of the people listed below for the Department of Highways and Transportation.

WORKED REAL WELL

NO PROBLEMS

Driver's Signature ____________

Saskatchewan Highways and Transportation

Bernie Churko	Norm Burns	Peter Hurst
787-5533 Bus.	787-5535 Bus.	787-5536 Bus.
545-5628 Res.	586-9802 Res.	545-7750 Res.

Road Systems Unit
7th Floor, 1855 Victoria Avenue
Regina, Saskatchewan

03131/76-77

Appendix C

A detailed explanation of the independent variables, their values, and their role in the financial model.

APPENDIX C

THE INDEPENDENT VARIABLES AND THEIR VALUES.

1. *Influences of the excess weight of the innovative dolly.*

a. Percent of trips at maximum gross vehicle weight (GVW). Though it is desirable to operate vehicles cube–full and at maximum axle loads, the actual loading situation is determined by the density of the freight being shipped. The reference condition assumes a hypothetical fleet operating its vehicles at maximum GVW 60% of the time. (This value of 60% corresponds to the experience of large LTL ("less than truck load") fleets in the U.S.)

b. Excess weight of the innovative dolly. The CSB–dolly being operated in Canada weighs 680 kg (1,500 lb) more than a conventional dolly. The LA-dolly, also being operated in Canada, weighs 295 kg (650 lb) more than the A-dolly.

c. Miles per year per dolly. In addition to predicting the frequency of preventive maintenance, this variable helps estimate the loss of revenue from having to carry less freight. The industry average for annual dolly–km is 161,000 km (100,000 mi).

d. Freight charges. The freight charge has a direct bearing on the loss of revenue due to displaced cargo. Among other factors, the charge is dependent upon the *distance* and the *type* of freight to be shipped. For the reference condition, it is assumed that the charges are $58.45 per 100 kg ($26.51 per 100 lb) of *general freight* shipped over a long distance of 3,800 km (2360 mi). On a per kilometer basis, the *general freight* rate is $0.0153 per 100 kg per km ($0.01118 per 100 lb per mi). For the same freight class, a charge of $11.00 per 100 kg ($5.00 per 100 lbs) for short runs of 80 km was assumed. This is a rate of $0.137 per 100 kg per km ($0.10 per 100 lb per mi). Correspondingly, typical short haul *bulk freight* rates vary between $0.0018 and $0.0029 per 100 kg per km ($0.0025 and $0.004 per 100 lb per mi).

2. *Size of the fleet.* The size of the operation and the proportion of innovative dollies being added to the fleet determines the scheduling and training costs a company might incur. The pertinent variables are:

a. Number of innovative dollies added to the fleet.

b. Total number of dollies owned by the fleet.

3. *Maintenance.*

a. Cost of a major overhaul. The cost of a major overhaul is defined as a percentage of the original cost of the dolly. The model assumes that a CSB–dolly undergoes a major overhaul every two years while an LA–dolly has a major overhaul once every four years. The cost of a major overhaul for the hypothetical fleet is assumed to be 20% of the cost of the dolly — that is, $2,625 for a CSB–dolly and $1825 for an LA–dolly.

b. Cost of preventive maintenance. From our survey of Canadian and US fleets, we find A–dolly maintenance to cost the fleet operator about $625 per year. Since the innovative dollies would be twice as expensive with respect to preventive maintenance (that is, they are brought in twice as often for routine maintenance of the additional steering and hitching linkages), the difference in the annual cost of preventive maintenance is estimated to be $625.

4. *Number of backups per day.* If a fleet operates over short distances where double-trailer combinations must be assembled and disassembled more than once every day, then the ability to back up two trailers could have an impact on the profitability of the operation. The reference fleet, however, does not consider backing up to be a cost–saving alternative.

5. *Accident savings.* As the CSB–dolly's improved dynamic ability reduces the possibility of accidents, it is assumed to save the fleet operator $0.00625 per dolly per km ($0.010 per dolly per mile). Based on similar vehicle simulations, the LA-dolly is assumed to save the fleet operator $0.0055 per dolly per km ($0.00875 per dolly per mile). These figures are estimates of direct accident costs and do not include losses from down time.

6. *Discount rate.* The discount rate is used to reduce future cash flows to current amounts and is assumed to be 10% (after taxes) for the shipping and transportation industry.

7. *Scheduling and training.*

a. Scheduling programs and data bases. This variable attempts to address the single expense incurred by large fleets when scheduling–related computer programs and data bases are updated. A large fleet is assumed to operate at least 30 dollies.

b. Administrative training. The training of managers and administrative personnel is associated with a learning curve and is defined as the training cost per CSB–dolly during the first year of its introduction.

c. Driver/yard personnel training. The training of drivers and yard personnel is defined in a fashion similar to administrative training. As mentioned earlier, the LA-dolly would not affect the scheduling process and would not require any additional training of administrative and yard personnel.

8. *Local deliveries.* Local deliveries, that is, the ability to operate on secondary roads. Assuming a change in regulation, a double-trailer vehicle saves the fleet operator $37.50 for every local (off the federal highway system) trip it is allowed to make. This $37.50 represents the cost of the extra trip needed for individually towing each trailer to the local delivery site.

9. *Permit to increase gross vehicle weight.* Assuming a change in regulation, an increase in gross vehicle weight is used to offset the additional weight of the innovative dollies.

DISCUSSION OF THE RESULTS

The first column in Table 5 is used to label the economic issues outlined previously in this section. The following columns, titled Year 0 (the current year) through Year 9 (the tenth year), contain the annual cash flows resulting from each of the items mentioned in the first column. Negative cash flows, or expenses, are shown in parentheses.

Net Present Value. In the model, cash flows occurring in Year 0 result from operational costs and one–time expenses such as purchasing, scheduling, and equipment conversions. Cash flows in the following years result from changes in operational costs only. For example, in Table 5, a fleet adding six CSB–dollies versus one adding six A–dollies would have to spend an additional $45,000 to cover the initial cost of the dollies. This cost, plus other initial investments and operational costs, results in a loss of $134,095 in the first year of the project. During the second year, the fleet operator would lose $76,971.98 due to increases in operational costs alone. The Net Present Value (NPV) of the sum of the incremental cash flows over the life of the project results in a total negative cash flow of $537,492.16.

Change in Shipping Charges. Assuming that the reference fleet were to raise its shipping charges to cover its incremental loss, the freight charges would have to be increased by $0.000311 per 100 kg per km ($0.000224 per 100 lb per mi), as indicated in Table 5. The rate increase was determined for six CSB–dollies, observed over the ten-year period, travelling 160,000 km (100,000 mi) per year and carrying 18,000 kg (40,000 lb) of cargo per trip.

Change in Operating Cost. The increased operating cost of a CSB–dolly — that is, the NPV of the investment less the one–time costs of scheduling, purchasing, and converting equipment — is computed (per dolly per km (0.625 mi)) in the last row of the column of Year 0. It is this value (0.05175 CA dollars per dolly per km (0.08275 dollars per dolly per mi)) that is used as the reference value in the sensitivity analyses.

Table 4. The variables used in the financial model in table 5

Variable Names	Values
Percentage of trips at max GVW	60 %
Additional dolly weight	1500 lbs
Miles per year per dolly	100,000 miles
Charge/lb/mile for freight hauled	$0.00011175
CSB-dollies added to the fleet	6 CSB-dollies
Total number of dollies owned	15 Dollies
Percent of tire wear increase over A-dolly	0 %
Overhaul cost (percentage of initial dolly cost)	20 %
Preventive maintenance - per year	$625.00
Double assembly & disassembly (CSB-dolly backup)	0 per day
Accident savings per mile per CSB-dolly	$0.010
Annual discount rate	10 %
Upgrading scheduling programs	$0.00
Administrative Expenses (first year)	$1,250.00
Driver/yard personnel training (first year per dolly)	$1,250.00
Local deliveries	0 per year
Overweight hauling allowance	0 lbs

Table 5. Reference condition for the CSB-dolly

Δ costs/benefits between A and CSB-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($45,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($22,500.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	($15,750.00)	$0.00	($9,000.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($1,000.00)	($367.88)	($135.34)	($49.79)	($18.32)
Training	($7,500.00)	($2,759.10)	($1,015.01)	($373.40)	($137.37)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	($60,345.00)	($60,345.00)	($60,345.00)	($60,345.00)	($60,345.00)
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$0.00	$0.00	$0.00	$0.00	$0.00
Total	($134,095.00)	($76,971.98)	($59,245.35)	($67,518.19)	($58,250.68)
Net Present Value	($537,492.16)				
Cost increase to cover loss /100lb / mile	$2.24E-04				
Change in operating cost / dolly / mile	$0.0826				

Δ costs/benefits between A and CSB-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	($15,750.00)	$0.00	($9,000.00)	$0.00	($15,750.00)
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($6.74)	($2.48)	($0.91)	($0.34)	($0.12)
Training	($50.53)	($18.59)	($6.84)	($2.52)	($0.93)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	($60,345.00)	($60,345.00)	($60,345.00)	($60,345.00)	($60,345.00)
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$0.00	$0.00	$0.00	$0.00	$0.00
Total	($73,902.27)	($58,116.07)	($67,102.75)	($58,097.85)	($73,846.05)

Table 6. The variables used in the financial model in table 7

Variable Names	Values
Percentage of trips at max GVW	60 %
Additional dolly weight	650 lbs
Miles per year per dolly	100,000 miles
Charge/lb/mile for freight hauled	$0.00011175
LA-dollies added to the fleet	6 LA-dollies
Total number of dollies owned	15 Dollies
Percent of tire wear increase over A-dolly	0 %
Overhaul cost (percentage of initial dolly cost)	20 %
Preventive maintenance - per year	$625.00
Double assembly & disassembly (LA-dolly backup)	0 per day
Accident savings per mile per LA-dolly	$0.009
Annual discount rate	10 %
Upgrading scheduling programs	$0.00
Administrative Expenses (first year)	$0.00
Driver/yard personnel training (first year per dolly)	$0.00
Local deliveries	0 per year
Overweight hauling allowance	0 lbs

Table 7. Reference condition for the linked-articulation dolly

Δ costs/benefits between A and LA-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($21,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($48,000.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	$0.00	($4,200.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	($26,149.50)	($26,149.50)	($26,149.50)	($26,149.50)	($26,149.50)
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$0.00	$0.00	$0.00	$0.00	$0.00
Total	($93,649.50)	($24,649.50)	($24,649.50)	($28,849.50)	($24,649.50)
Net Present Value	($250,420.79)				
Cost increase to cover loss /100lb / mile	$1.04E-04				
Change in operating cost / dolly / mile	$0.0387				

Δ costs/benefits between A and LA-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	($4,200.00)	$0.00	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	($26,149.50)	($26,149.50)	($26,149.50)	($26,149.50)	($26,149.50)
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$0.00	$0.00	$0.00	$0.00	$0.00
Total	($24,649.50)	($24,649.50)	($28,849.50)	($24,649.50)	($24,649.50)

Table 8. The variables used in the financial model in table 9

Variable Names	Values
Percentage of trips at max GVW	60 %
Additional dolly weight	1500 lbs
Miles per year per dolly	100,000 miles
Charge/lb/mile for freight hauled	$0.0000325
CSB-dollies added to the fleet	6 CSB-dollies
Total number of dollies owned	15 Dollies
Percent of tire wear increase over A-dolly	0 %
Overhaul cost (percentage of initial dolly cost)	20 %
Preventive maintenance - per year	$625.00
Double assembly & disassembly (CSB-dolly backup)	0 per day
Accident savings per mile per CSB-dolly	$0.010
Annual discount rate	10 %
Upgrading scheduling programs	$0.00
Administrative Expenses (first year)	$1,250.00
Driver/yard personnel training (first year per dolly)	$1,250.00
Local deliveries	0 per year
Overweight hauling allowance	19500 lbs

Table 9. Saskatchewan regulatory environment for the CSB-dolly, bulk freight rates

Δ costs/benefits between A and CSB-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($45,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($22,500.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	($15,750.00)	$0.00	($9,000.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($1,000.00)	($367.88)	($135.34)	($49.79)	($18.32)
Training	($7,500.00)	($2,759.10)	($1,015.01)	($373.40)	($137.37)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$210,600.00	$210,600.00	$210,600.00	$210,600.00	$210,600.00
Total	$136,850.00	$193,973.02	$211,699.65	$203,426.81	$212,694.32
Net Present Value	$1,398,292.58				
Cost increase to cover loss /100lb / mile	$0.00E+00				
Change in operating cost / dolly / mile	($0.2400)				

Δ costs/benefits between A and CSB-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	($15,750.00)	$0.00	($9,000.00)	$0.00	($15,750.00)
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($6.74)	($2.48)	($0.91)	($0.34)	($0.12)
Training	($50.53)	($18.59)	($6.84)	($2.52)	($0.93)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$210,600.00	$210,600.00	$210,600.00	$210,600.00	$210,600.00
Total	$197,042.73	$212,828.93	$203,842.25	$212,847.15	$197,098.95

Table 10. The variables used in the financial model in table 11

Variable Names	Values
Percentage of trips at max GVW	60 %
Additional dolly weight	650 lbs
Miles per year per dolly	100,000 miles
Charge/lb/mile for freight hauled	$0.0000325
LA-dollies added to the fleet	6 LA-dollies
Total number of dollies owned	15 Dollies
Percent of tire wear increase over A-dolly	0 %
Overhaul cost (percentage of initial dolly cost)	20 %
Preventive maintenance - per year	$625.00
Double assembly & disassembly (LA-dolly backup)	0 per day
Accident savings per mile per LA-dolly	$0.009
Annual discount rate	10 %
Upgrading scheduling programs	$0.00
Administrative Expenses (first year)	$0.00
Driver/yard personnel training (first year per dolly)	$0.00
Local deliveries	0 per year
Overweight hauling allowance	19500 lbs

Table 11. Saskatchewan regulatory environment for the linked-articulation dolly, bulk freight rates

Δ costs/benefits between A and LA-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($21,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($48,000.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	$0.00	($4,200.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$220,545.00	$220,545.00	$220,545.00	$220,545.00	$220,545.00
Total	$153,045.00	$222,045.00	$222,045.00	$217,845.00	$222,045.00
Net Present Value	$1,512,104.62				
Cost increase to cover loss /100lb / mile	$0.00E+00				
Change in operating cost / dolly / mile	($0.2550)				

Δ costs/benefits between A and LA-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	($4,200.00)	$0.00	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$220,545.00	$220,545.00	$220,545.00	$220,545.00	$220,545.00
Total	$222,045.00	$222,045.00	$217,845.00	$222,045.00	$222,045.00

Table 12. Saskatchewan regulatory environment for the CSB-dolly, general freight rates

Δ costs/benefits between A and CSB-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($45,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($22,500.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	($15,750.00)	$0.00	($9,000.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($1,000.00)	($367.88)	($135.34)	($49.79)	($18.32)
Training	($7,500.00)	($2,759.10)	($1,015.01)	($373.40)	($137.37)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$724,140.00	$724,140.00	$724,140.00	$724,140.00	$724,140.00
Total	$650,390.00	$707,513.02	$725,239.65	$716,966.81	$726,234.32
Net Present Value	$5,067,313.57				
Cost increase to cover loss /100lb / mile	$0.00E+00				
Change in operating cost / dolly / mile	($0.8516)				

Δ costs/benefits between A and CSB-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	($15,750.00)	$0.00	($9,000.00)	$0.00	($15,750.00)
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	($6.74)	($2.48)	($0.91)	($0.34)	($0.12)
Training	($50.53)	($18.59)	($6.84)	($2.52)	($0.93)
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$724,140.00	$724,140.00	$724,140.00	$724,140.00	$724,140.00
Total	$710,582.73	$726,368.93	$717,382.25	$726,387.15	$710,638.95

Table 13. Saskatchewan regulatory environment for the linked-articulation dolly, general freight rates

Δ costs/benefits between A and LA-dollies	Year 0	Year 1	Year 2	Year 3	Year 4
Initial cost of dollies	($21,000.00)	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	($48,000.00)	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	$0.00	($4,200.00)	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$758,335.50	$758,335.50	$758,335.50	$758,335.50	$758,335.50
Total	$690,835.50	$759,835.50	$759,835.50	$755,635.50	$759,835.50
Net Present Value	$5,354,384.93				
Cost increase to cover loss /100lb / mile	$0.00E+00				
Change in operating cost / dolly / mile	($0.8954)				

Δ costs/benefits between A and LA-dollies	Year 5	Year 6	Year 7	Year 8	Year 9
Initial cost of dollies	$0.00	$0.00	$0.00	$0.00	$0.00
Converting existing equipment	$0.00	$0.00	$0.00	$0.00	$0.00
Major overhauls	$0.00	$0.00	($4,200.00)	$0.00	$0.00
Tire wear	$0.00	$0.00	$0.00	$0.00	$0.00
Preventive maintenance	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)	($3,750.00)
Scheduling	$0.00	$0.00	$0.00	$0.00	$0.00
Training	$0.00	$0.00	$0.00	$0.00	$0.00
Ability to back up	$0.00	$0.00	$0.00	$0.00	$0.00
Less weight hauled	$0.00	$0.00	$0.00	$0.00	$0.00
Fewer accidents	$5,250.00	$5,250.00	$5,250.00	$5,250.00	$5,250.00
Ability to operate on secondary roads	$0.00	$0.00	$0.00	$0.00	$0.00
Allow higher GVW	$758,335.50	$758,335.50	$758,335.50	$758,335.50	$758,335.50
Total	$759,835.50	$759,835.50	$755,635.50	$759,835.50	$759,835.50