The 2CM Freight Wagon Bogie - an Appraisal

Report

The operations of a railway system can often be enhanced by the introduction of improved technology. Clearly the benefits of the new technology should more than compensate for its costs. The introduction of the 2CM freight bogie would enhance the operations of the Australian railways, however the question of the value of the benefits in relation to the additional costs has been a vexed one. This report has been prepared with the object of clarifying the economic merits of the 2CM bogie.

BUREAU OF TRANSPORT ECONOMICS

THE 2CM FREIGHT WAGON BOGIE - AN APPRAISAL

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FOREWORD

The operations of a railway system can often be enhanced by the introduction of improved technology. Clearly the benefits of the new technology should more than compensate for its costs. The introduction of the 2CM freight bogie would enhance the operations of the Australian railways, however the question of the value of the benefits in relation to the additional costs has been a vexed one. This report has been prepared with the object of clarifying the economic merits of the 2CM bogie.

The study was undertaken by Mr N.F. Gentle under the direction of Mr R.H. Heacock of the Transport Engineering Branch. Assistance was also given by the Operations Research and the Materials Handling Branches.

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Bureau of Transport Economics,

Canberra,

March 1976.

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SUMMARY

The 2CM freight wagon bogie was evaluated for NSW conditions and for conditions applying to other systems. Only two benefits could be quantified. They are bogie maintenance costs and reduced rolling resistance.

Of these, only the first was significant and sufficient to justify the use of 2CM bogies for NSW conditions. However, maintenance costs alone were not large enough to justify the use of 2CM bogies for conditions applicable to the other systems. The main cause of this result is the lower wheel life experienced by the NSWPTC compared to the other systems.

Other possible benefits which were discussed but which were not quantified are;

- reduction in track maintenance costs
- reduction in freight damage
- reduced derailment risk.

Of these, the reduction in track maintenance costs is potentially the most important benefit. The relationships which would allow these benefits to be quantified are the same relationships needed to provide a rational set of design criteria for an optimal bogie. A number of recommendations are made for additional studies to allow the relationships which are necessary to support a decision to introduce a new bogie to be determined.

ACKNOWLEDGEMENTS

Several organisations and individuals assisted the BTE in the preparation of this report. Without the data provided by these organisations, this report would not have been possible. In particular, specific acknowledgements are due to the following for their assistance.

- New South Wales Public Transport Commission
- Victorian Railways
- Australian National Railways Commission
- South Australian Railways
- Westrail
- Mr S.A. Rose, Commonwealth Steel Company Limited.

CHAPTER 1 BACKGROUND TO THE EVALUATION

1.1 DEVELOPMENT OF THE 2CM BOGIE

The conventional 3-Piece bogie has given reliable service for many years. However, it suffers from a number of shortcomings when the demands of current and possible future operations are considered. The recognition of these shortcomings led ANZR to ask the New South Wales Government Railways to produce a new bogie design in March 1969. The features to be included in this new design were:

- Increased bogie centre diameter and increased bogie centre engagement depth,
- Reduced clearances of bogie centres and parallel engagement,
- Improved springing to give softer ride and positive springing at tare loading,
- Improved damping,
- Elimination of racking.

The initial approach by NSW was to investigate the existing 3-Piece bogies. The objective was to see if the limitations of the 3-Piece bogie could be overcome by reasonably simple design modifications. In September 1972, NSW reported to ANZR the results of a series of tests of standard commercially available 3-Piece bogies and NSW modified bogies. It was concluded that none of these bogies provided satisfactory solutions to the ANZR bogie design criteria.

European railway systems have long recognised the shortcomings of the 3-Piece bogie, and are seeking solutions to these shortcomings.[1] These systems have concluded that the design of bogies required to run in excess of about 95 km/h must be based on the use of a rigid frame and the use of a primary suspension between the bogie frame and the axle boxes.[2] The railway operators in the USA have also become aware of the problems of the 3-Piece bogies. A number of papers at recent American conferences have been concerned with the problems presented by the 3-Piece bogie in the modern railway environment. Papers by Smith[3] and McLean[4] are typical. The Federal Railroad Administration, in response to the concern about the performance of 3-Piece bogies, has engaged the Southern Pacific Transportation Company to conduct a search for a more suitable bogie design. This project is known as the Truck Design Optimisation Project.

Within this environment, the New South Wales Public Transport Commission considered that further modifications to the Ride Control 3-Piece bogie would not be useful. A number of overseas designs were considered, the major ones being the

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(1) J.L. Koffman, Limitations of the Three-Piece Bogie, Railway Gazette, May 15, 1970, pp. 379-384.
(2) Ibid, p. 384.
(3) L.W. Smith, The Freight Car Truck "Capability Gap", Railroad Engineering Conference 1974, Technical Proceedings, pp. 26-32.
(4) L.A. McLean, A Re-Evaluation of Freight Car Truck Performance Requirements, 1973 Dresser Engineering Conference, Technical Proceedings, pp. 20-47.

Rockwell, Aligned, National Swing Motion and the French Y25 bogies. The Y25 had an acceptable ride performance, however its design was based on the use of a hemispherical centre casting. This casting had a number of potential wear problems which made it unsuitable for Australian conditions. The other overseas bogies were found to have performances which were not significantly better than a modified Ride Control bogie and were not considered further. A new bogie design was therefore developed. This bogie, designated 2CM, incorporated a rigid frame and a primary suspension between the frame and axle boxes.

The 2CM bogie, while it is superior to 3-Piece bogies at speeds in excess of 95 km/h, is considerably more expensive and its introduction has met with considerable opposition. In an attempt to resolve the issue the Advisory Committee on Railway Policy (ACRP) requested the BTE to examine the economic merits of the 2CM bogie.

1.2 AIM AND SCOPE OF THE STUDY

The study is concerned with the economic evaluation of the 2CM bogie. The costs and benefits of the 2CM bogie are compared with those of the Ride Control[(1)] 3-Piece bogie, which is considered to be the most suitable alternative.

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(1) Proprietary Product of American Steel Foundries and their Australian licensee, Bradken Consolidated.

The evaluation is done in two parts. In the first part, the economic merits of the 2CM bogie for NSW conditions are assessed. In the second part, the economic merits of the 2CM bogie for use in systems other than NSW are assessed. It is assumed, in both parts of the evaluation, that trains operate at maximum speeds in the range of 80 to 95 km/h. This range of maximum speeds applies to most systems and currently there are no demands for higher speeds except in NSW.

CHAPTER 2 EXPECTED BENEFITS OF THE 2CM BOGIE

2.1 BOGIE MAINTENANCE BENEFITS

The NSW railway is the only system where the 2CM is operated and maintained under the same conditions as Ride Control bogies. Data collected there indicate that reduced bogie maintenance cost is the major quantifiable benefit resulting from the use of the 2CM.

The wheels fitted to 2CM bogies have been found to have a considerably longer life than those fitted to Ride Control bogies. In NSW wheels on Ride Control bogies need turning at 80,000 km intervals whereas 2CM bogies have travelled in excess of 400,000 and have not yet required wheel turning.

Theoretical considerations suggest that this level of improvement could be expected since the amount of lateral wheel sliding for rigid frame bogies is about one third that for 3-Piece bogies.(1) If this were the only source of wheel wear, then the 2CM bogie could be expected to have three times the wheel life of 3-Piece bogies.

Annex A summarises some NSW accelerometer tests of a number of bogies including the 2CM. Generally, it can be

(1) Koffman, op. cit. p. 381.

said that these tests show that the vertical and lateral accelerations of 2CM bogies are lower than the accelerations of other bogies. In addition, the wheels on 2CM bogies are subjected to lower dynamic loads which would increase wheel life. Therefore the theoretical studies and the accelerometer tests are both consistent with the longer wheel life experienced by the 2CM bogie.

The design of the 2CM bogie paid particular attention to the wearing parts. Spring steel liners have been welded to the bolster and side frame to minimise wear of these components. Wear liners have also been welded to the side frame horns to minimise wear in these areas. These wear liners are expected to last the life of the bogie. Equivalent wear points on the Ride Control bogie (i.e. between the bolster and side frame) need regular maintenance to ensure that there is sufficient metal at these points.

In NSW, the 2CM bogie is expected to require scheduled maintenance at five year intervals compared to three year intervals for Ride Control Bogies. This maintenance is expected to comprise the replacement of pins and bushes in the brake gear at five year intervals and the replacement of the bolster friction liners at ten year intervals. Also some welding of the centre plate liner will be required at five year intervals.

A summary of the NSW situation is that the 2CM bogie has a considerably longer wheel life and reduced frame maintenance costs. In addition, the NSW PTC officers consider that they will need to maintain a spare parts inventory equivalent to only five per cent of the number of 2CM bogies in use compared to an inventory of ten per cent for Ride Control bogies. The difference in maintenance costs between 2CM bogies and Ride Control bogies can be expected to increase as train speeds increase. This is because 3-Piece bogies become increasingly prone to hunting as speed increases, and this, in turn, leads to increased wear.

Comparison of 2CM bogie maintenance in NSW and 3-Piece bogie maintenance in other states is not a simple matter. Other systems have different maintenance procedures, lower operational speeds, harder wheels, and generally flatter terrain with fewer curves. These differences would result in lower maintenance costs for both types of bogie but the reduction would be less for 2CM frame maintenance than for Ride Control frames. The ratio of 2CM wheel life to Ride Control wheel life is, however, expected to be the same for all systems.

Basic maintenance benefits are analysed for NSW in Section 4.3.1 and for other systems in Section 4.3.2.

2.2 TRACK BENEFITS

The lower acclerations recorded at the floor of wagons equipped with 2CM bogies, compared to wagons equipped with 3-Piece bogies, suggest that the forces imposed on the track are correspondingly lower. The 2CM bogie, with its primary suspension between the axle box and the frame, has a lower unsprung mass than a 3-Piece bogie which has no primary suspension. The lower accelerations, coupled with a lower unsprung mass, imply that the track forces are considerably lower for 2CM bogies compared to 3-Piece bogies. The increased wheel life of 2CM bogies is further evidence that the track forces are lower.

Unfortunately the tests performed so far are not sufficient to estimate the track forces with any accuracy. Furthermore, while it is correct to say that lower track forces will lead to lower track maintenance costs, there is no available method of determining the relationship between dynamic loads imposed by rail vehicles and resultant track maintenance.

2.3 REDUCTION IN FREIGHT DAMAGE

It has been claimed that the level of damage to cargo is likely to be much lower for 2CM bogies compared to 3-Piece bogies. However, no data exist to support this claim. Officers of the Materials Handling Branch of the BTE are of the opinion that the major damage to lading occurs during shunting impacts and impacts due to slack run-outs and run-ins. This view is supported by the results of tests performed in the United States, which showed that impact forces are much higher than forces encountered in transit. These results are summarised in Figure 2.1.[(1)]

The curves show that for transit at 80 km/h, accelerations do not exceed 1g at any frequency. The coupling shock accelerations exceeded 1g for all frequencies in excess of about 2Hz. The slack run-out and run-in curve is intermediate between the other two curves. Accelerations in the lateral and longitudinal directions are not shown but have similar characteristics. Although these curves should be fairly typical, the text of the report did not state the type of wagon used in the shock spectra measurements.

The vibrations encountered in transit can lead to product deteriorations, particularly in relation to surface finish. Typical examples of this type of damage would be the scratching of the outer surfaces of glassware, and the scuffing of coiled steel strip. However no techniques are available which would enable monetary values to be put on any improvement of ride due to 2CM bogies. Further comments about freight damage are to be found in Annex A.2.

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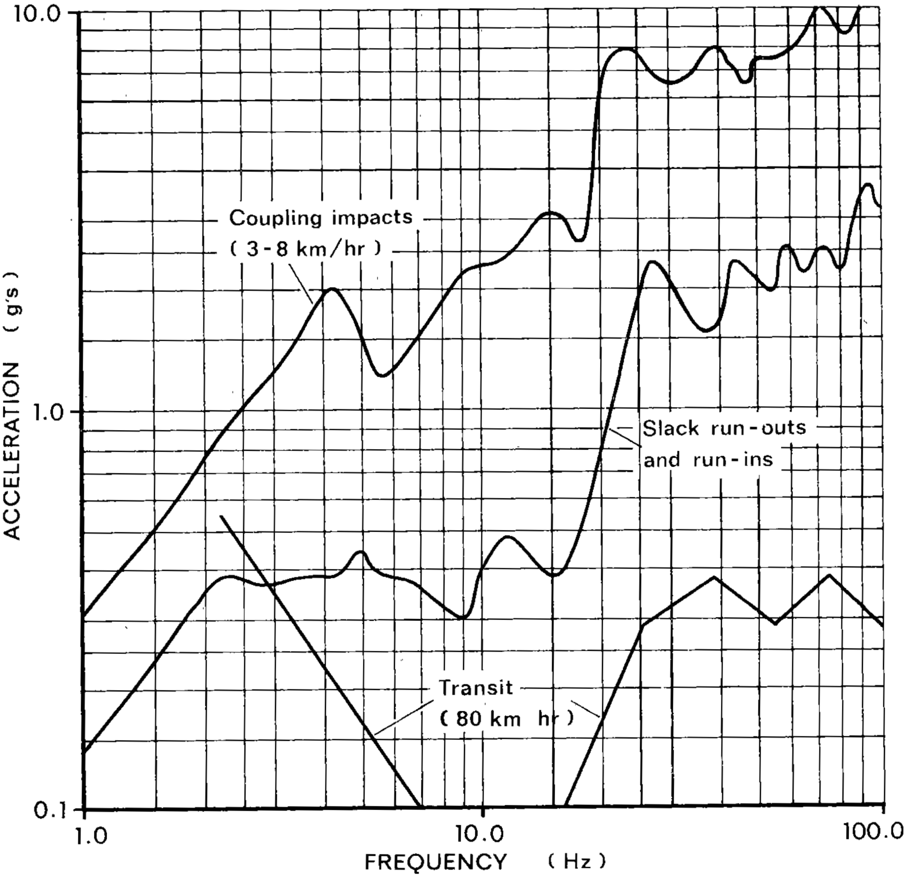
(1) F.E. Ostrem, et. al., A Survey of Environmental Conditions Incident to the Transportation of Materials, General American Transportation Corporation, Niles, Illinois, October 1971, NTIS PB-204 442.



SOURCE : F.E OSTREM, et al, A Survey of Environmental Conditions Incident to the Transportation of Materials, General American Transportation Corporation, Niles, Illinois, October 1971, NTIS PB-204 442

FIGURE 2.1

VERTICAL ACCELERATIONS FOR VARIOUS RIDE CONDITIONS

2.4 REDUCTION IN ROLLING RESISTANCE

The NSWPTC performed tests in April and May 1975 to determine the difference in rolling resistance between 3-Piece bogies and 2CM bogies. These tests are discussed in Annex A.1. The reduction in rolling resistance provides a small potential saving in locomotive fuel. However the reduction in rolling resistance is counteracted by the greater weight of the 2CM bogie when compared to a 3-Piece bogie. The net fuel savings due to reduced rolling resistance are quite small, being about 0.016 cents/wagon km. These savings are estimated in greater detail in Annex B.

2.5 OPERATIONAL ADVANTAGES AT HIGHER SPEEDS

The ride characteristics of the 2CM bogie is clearly superior to those of 3-Piece bogies at speeds in excess of 95 km/h. In New South Wales many freight trains operate at these speeds but other systems do not have any current requirement for speeds greater than 95 km/h. The normal maximum speed of freight trains outside NSW is in the range 80 km/h to 95 km/h. Therefore, higher speeds for freight trains are not seen as an option that will be adopted in the near future for most Australian railway systems. Nevertheless, it would be short sighted to assume that Australian railway systems will continue to maintain the current operational speeds indefinitely. The Commonwealth Railways recognised this in their reply to an Industries Assistance Commission questionnaire on rolling stock. They stated that the major changes in the Australian railway systems would be:

> "in the area of improvement to track standards, particularly on interstate routes to provide for locomotives and rolling stock with higher axle loads moving at higher speeds..... Increased speed of freight trains will result in a great improvement in transit time with resultant increased utilisation of valuable locomotives and rolling stock."(1)

Speeds in excess of 95 km/h will almost certainly demand a better bogie than the three piece bogies now in use. Data is not available, however, to do more than speculate on the economic merits of the 2CM at these speeds.

2.6 REDUCED DERAILMENT RISK

The risk of derailment is usually described by the ratio of lateral to vertical forces acting on the wheel. Any reduction in vertical wheel load will increase the risk unless there is a corresponding reduction in lateral forces. For this reason, the maximum reduction in wheel load when running over twisted track is an important variable in bogie design. According to Koffman, bogies with flat centre plates and stiff springs will not allow a bogie to follow a twist of 1 in 150 without "excessive" reduction in wheel load.(2) 3-Piece bogies normally have these characteristics. The 2CM bogie, on the other hand, has relatively soft primary springs

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(1) This questionnaire was part of the Industries Assistance Commission's "Public Inquiry: Railway and Tramway Locomotives, Rolling Stock, etc." A public hearing at which Commonwealth Railways appeared was held on 21 August 1975.

(2) J.L. Koffman, The Torsionally Stiff Bogie Wagon, The Railway Gazette, August 18, 1967, pp. 629-632.

and should therefore be able to follow twisted track with much less risk of derailment.

The potential benefits of a reduced derailment probability are large. The estimated costs of derailments in NSW are of the order of five to ten million dollars per annum. The relative probabilities of derailment for 3-Piece bogies and for 2CM bogies are not known, but it is thought that the improved compliance of the 2CM bogie would definitely reduce the derailment risk. The following example illustrates the extent to which reduced derailment risk could affect the economic merit of the 2CM bogie. NSW has approximately 8000 bogie wagons. If it is assumed that derailment costs would be reduced by 30 per cent if all these wagons were equipped with 2CM bogies, an investment of from 15 to 30 million dollars would be justified. The additional cost of 2CM bogies would be about 40 million dollars for a fleet of this size. That is, in this example, the reduced derailment risk represents 37 to 75 per cent of the additional cost required for 2CM bogies.

To put accurate monetary values on this benefit requires a knowledge of the distribution of derailment costs and the probability of derailment under various conditions. In the absence of data this benefit has been ignored in this evaluation.

CHAPTER 3 OBJECTIONS TO THE 2CM BOGIE

3.1 TECHNICAL OBJECTIONS

A number of technical reservations have been made by some rail authorities. The more important of these are discussed below.

The Victorian Railways has pointed out that the bottom of the side frames infringes the ANZR loading gauge. This is certainly correct for the earlier versions of the 2CM bogies. The most recent version (NSW drawing 104 821) has a modified side frame which overcomes this problem. This latest side frame modification was made possible by replacing the previous dual-rate bolster spring by a single rate bolster spring.

The Victorian Railways also pointed out that the height of the side frame was greater than that permitted by the ANZR standards. The ANZR freight bogie standards specify the characteristics of 3-Piece bogies only. The specifications do not cope with the different deflection characteristics of bogies with both primary and secondary suspensions and are therefore applied to the 2CM with difficulty. Even so, there does not appear to be any functional infringement of ANZR standards.

It has been claimed that the vertical movement of couplers on wagons equipped with 2CM bogies can be excessive. An examination of the drawings confirms that coupler movements can exceed 4 inches (the Victorian Railways tolerance). However, the coupler movements of wagons using 2CM bogies in practice have been consistently less than those equipped with 3 Piece bogies.

The Victorian Railways are of the opinion that the frame of the 2CM bogies is overstressed. The only test data provided for study by the BTE (see Annex A.3) does not lend support to this opinion. The BTE cannot accept this claim in view of the tests discussed in Annex A.3.

The opinion has been expressed that the 2CM bogie suffers greater damage in derailments than 3-Piece bogies. This claim is difficult to assess by merely observing derailed bogies since it is impossible to determine from visual inspection the forces that have been imposed on the bogies. No concrete evidence to support this claim has been brought forward by the critics of the 2CM bogie. The structural tests of the frame discussed in Annex A.3 suggest that the damage to 2CM bogies in derailments should not be excessive.

3.2 ADDITIONAL MASS OF THE 2CM BOGIE

The 2CM bogie weighs 5.1 tonnes, 1.05 tonnes more than Ride Control bogies. The additional mass is a definite disadvantage; a pair of 2CM bogies reduces the capacity of a wagon by 2.1 tonnes and increases fuel consumption.

However, the reduced rolling resistance more than counteracts the effect of increased mass on fuel consumption. (See Annex B)

The effect on wagon payload would be quite serious if wagons normally run at capacity loads. The BTE has investigated the distribution of wagon loads utilising data collected for a study of wagon utilisation. Only NSW data was used and load distributions for all X and Y wagons were determined.(1) To ensure reasonable sample sizes, classes of wagons were not included when less than 100 records were available. Load distributions for some of the wagons studied are shown in Figures 3.1 and 3.2.

These curves show the cumulative probability distributions of the loads carried by the wagons. Figure 3.1 shows the distributions of the loads of flat wagons and Figure 3.2 shows the distribution of loads of louvre vans and flexi vans. Typical distributions only are shown; inclusion of all distributions would have made the figures extremely difficult to read.

The probabilities shown are the proportion of time a wagon carries a load less than that shown on the abscissa.

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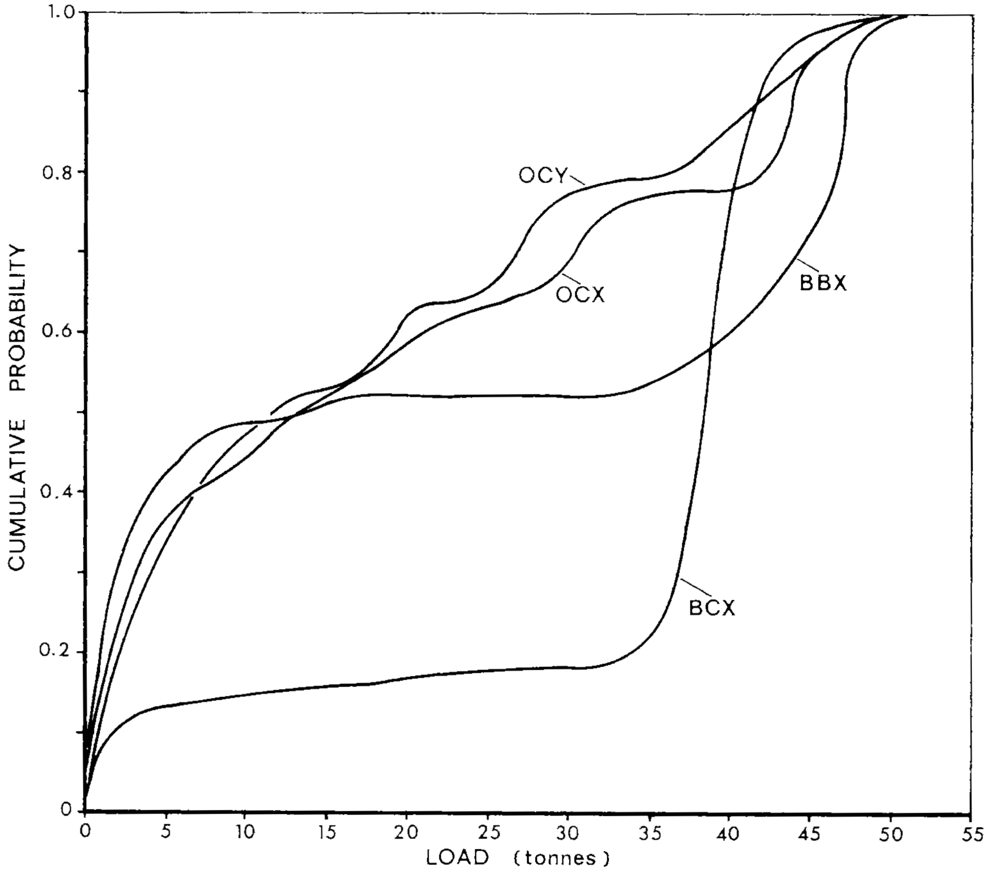
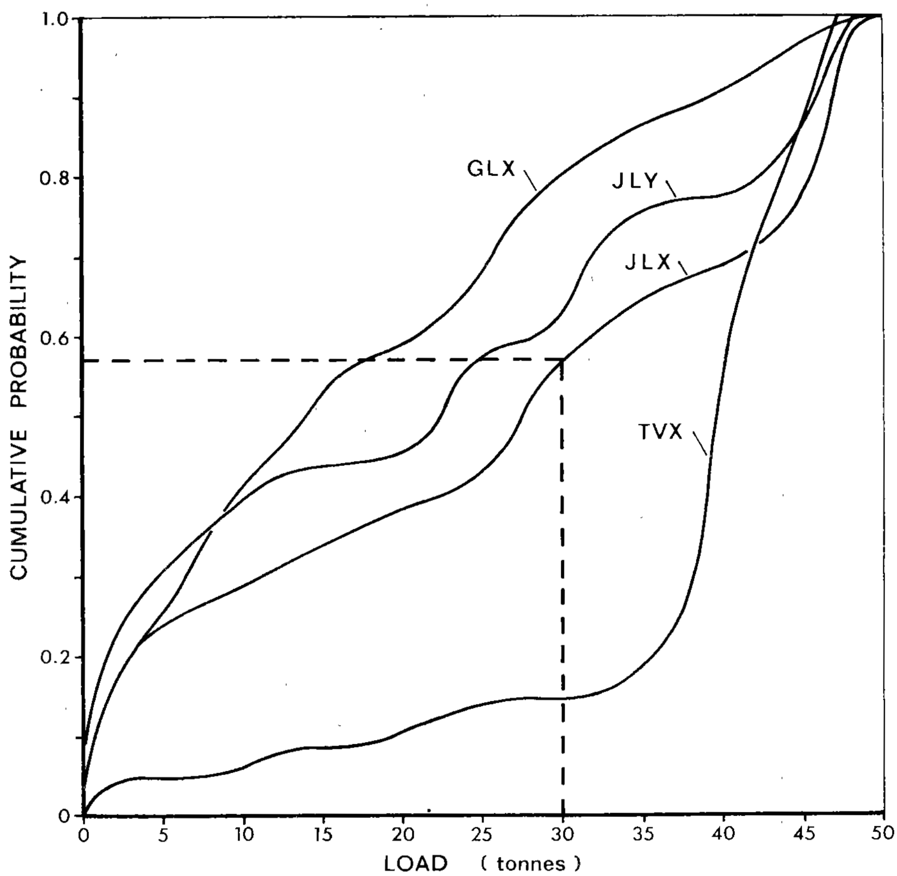
(1) X type wagons are designed to be fitted with bogies with a 12 inch centre plate. Y type wagons are designed to be fitted with bogies with a 14 inch centre plate of which the 2CM is the only example.



Probability is based on proportion of time wagon load is less than load shown

Maximum capacities: BBX = 47t
BCX = 49t
OCX = 55t
OCY = 52t

FIGURE 3.1
CUMULATIVE PROBABILITY DISTRIBUTIONS
OF THE LOADS CARRIED BY FLAT WAGONS



Probability is based on proportion of time wagon load is less than load shown

Maximum capacities : GLX = 48t
JLX = 49t
JLY = 48t
TVX = 47t

FIGURE 3.2

CUMULATIVE PROBABILITY DISTRIBUTIONS OF THE LOADS CARRIED BY LOUVRE VANS AND FLEXI VANS

For example, from Figure 3.2, a JLX wagon carries a load of less than 30 tonnes for 57 per cent of the time.

From these curves it can be seen that wagons spend only a small proportion of time with loads within two or three tonnes of the maximum load. The X wagons, for which distributions were estimated, carried loads within three tonnes of their maximum capacity for 5.7 per cent of the time.(1)

The average gross mass for the wagons considered was 45.6 tonnes and this value was used in the fuel savings calculations in Annex B. The extra mass of the 2CM bogie is included in the economic evaluation in the form of the capital cost of additional wagons to provide for the reduction in load capacity of 2CM equipped wagons.

3.3 BOGIE EXCHANGEABILITY

Bogies used for bogie exchange purposes have a 12 inch centre plate. The 2CM bogie, as currently manufactured, has a 14 inch centre plate and cannot be exchanged with 12 inch centre plate bogies. The 2CM bogie therefore could only be used where a change of gauge was not required if present operating procedures are continued.

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(1) The wagon study recorded loads in integral numbers of tonnes only; in order to ensure that all loads which would be affected by the use of 2CM bogies were covered, it was necessary to adopt a cut-off point of three tonnes less than the maximum capacity.

The 12 inch centre plate does have its limitations. The original ANZR specification given to NSW in 1969 included the requirement for an improved centre plate with the view to overcoming these limitations. The 14 inch centre plate on the 2CM bogie appears to have been successful in this respect but more work is required to determine if this centre plate is the best available solution, and how to introduce an improved centre plate design into the bogie exchange system.

If it were decided to use the 2CM bogie for inter-system traffic it could be fitted with a 12 inch centre plate to make it bogie exchangeable under present conditons. With a 12 inch centre plate the 2CM bogie would need sprung side bearers to retain its high speed performance.

CHAPTER 4 EVALUATION

4.1 METHODOLOGY

The evaluation methodology adopted was to compare the discounted life costs of two container wagons. One wagon was assumed to be equipped with 2CM bogies and the other was assumed to be equipped with Ride Control 3-Piece bogies. Apart from the capital costs of the wagons and bogies, the only costs considered were maintenance costs and reduction of fuel costs due to lower rolling resistance of 2CM bogies.

It would be desirable to include other costs that are known to result from the use of freight wagons (e.g. track maintenance costs). However, relationships which would allow such costs to be determined from the physical characteristics of the wagon and bogies are not available. Therefore, these costs, which may be significant, had to be excluded.

The present value of the costs of owning and operating a wagon equipped with Ride Control bogies was subtracted from the present value of the costs of a wagon using 2CM bogies. This difference, the net present value, was calculated for a range of annual travel distances. This enabled the break-even distance to be estimated, above which the 2CM bogie was an economic proposition (positive net present value) and below which it could not be economically justified (negative net present value).

Discount rates of 7 and 10 per cent were used, together with an evaluation period of 20 years. Wagons and bogies are normally expected to have a life in excess of 20 years and for the purposes of this evaluation, it has been assumed that the bogies and wagons have a life of 25 years. The wagons and bogies will therefore have a residual value at the end of the evaluation period. The method used for calculating residuals is shown in Annex C.

The internal rate of return was also calculated for each annual travel distance considered. The internal rate of return is the discount rate which would give a zero net present value. The purchase of 2CM bogies would not be justified if the cost of capital was greater than the internal rate of return.

All costs and benefits are in constant November 1975 dollars.

4.2 COSTS

4.2.1 Capital Costs

The capital costs used in the study, including a capital allowance for inventory requirements, were provided by the Technical Services Section of the Rail Branch, Department of Transport, Canberra. These costs were $22,100 for a flat wagon equipped with Ride Control bogies and $26,930 for the same wagon equipped with 2CM bogies. The difference is due entirely to bogie costs, and the spares inventory allowance.

The effect of the increased weight of the 2CM bogie needs to be taken into account. Earlier it was shown that 5.7 per cent of wagon hours for X type wagons would be affected by the increased weight if they were fitted with 2CM bogies. The load not able to be carried by the 2CM equipped wagon would have to be carried by other wagons. Additional wagons would therefore need to be purchased to compensate for the reduced capacity. The capital cost of the wagon equipped with 2CM bogies was increased by 5.7 per cent to represent the need for additional wagons; 5.7 per cent being the percentage of wagon hours that a wagon would have a load in excess of capacity if it were equipped with 2CM bogies rather than Ride Control bogies. The capital costs used for a wagon with 2CM bogies was therefore $28,440.

4.2.2 Maintenance Costs

A large variation was found in the maintenance costs and wheel life reported by the different systems. A comparison of the respective costs is given in Table 4.1. A feature of these costs is the large variation in 3-Piece bogie costs experienced by the different systems. The ratio of highest to lowest costs for some items is 2:1. This

TABLE 4.1 - COMPARISON OF BOGIE MAINTENANCE

(1975 Prices)

Item	NSW PTC		VR	ANR	WAGR
	2CM	3-Piece	3-Piece		
Scheduled maintenance interval[(f)]	5 years	3 years	5 years	400 000 km	1 200 000 km
Wheel material[(a)]	BS468 Class C	BS468 Class C	AAR-M208/73 Class U	BS468[(b)] Class D	AAR-M107/71 Class C
Type of Wheel	Solid	Solid	Solid	Tyre[(c)]	Solid
Distance between wheel turnings (km)	480 000	80 000	600 000[(d)]	225 000	224 000
No. of turnings	2	2	1	3	4
Wheel life (km)	1 440 000	240 000	900 000[(d)]	900 000	1 120 000
Cost of wheels ($)	185	185	225	75[(e)]	165
Cost of wheel replacement per wagon ($)	1860	2070	Not stated	770	2000
Cost of wheel turning per wagon ($)	180	180	Not stated	26	55
Cost of scheduled maintenance per wagon excluding wheels ($)(f)	265 or 320[(g)]	560	320	290	600
Cost of scheduled maintenance per wagon with wheel turning ($)[(f)]	448 or 500[(g)]	660	640	312	655
Cost of scheduled maintenance per wagon with wheel replacement ($)[(f)]	2040 or 2100[(g)]	2340	Not stated	1085	2600

(a) BS468 Class C, 0.47 to 0.56% C; AAR Class U, 0.66 to 0.80% C; BS468 Class D, 0.61 to 0.64% C; AAR Class C, 0.67 to 0.77% C.

(b) ANR uses several specifications of which this is typical.

(c) Purchases in recent years have been solid wheels.

(d) The wheel normally used by VR is nominally a one wear wheel. It is normally given one turning to have its life extended by 50%

(e) This is the price for tyre replacement.

(f) Bogies are scheduled for overhaul at the intervals shown. The costs are the costs per wagon for bogie maintenance for each scheduled overhaul.

(g) The higher cost applies to scheduled maintenance at 10 year intervals.

variation might be explained by the use of different accounting procedures as well as different operational conditions.

The difference in wheel life for 3 Piece bogies is particularly marked. The distance between turnings varies from 80,000 km for the NSW PTC to between 550,000 km and 600,000 km for Victorian Railways, a range of about 7 to 1. The NSW PTC uses softer steel for its wheels than VR and operates over more difficult terrain. Both these factors would tend to shorten the life of wheels but it is difficult to account for a 7 to 1 difference.

NSW is the only area where 2CM bogies and 3-Piece bogies are operated under equivalent operating conditions and maintenance policies. For this reason, the evaluation has been performed in two parts. The first part considers the NSW situation alone using NSW data. The second part of the evaluation considers the situation applying in other systems using data which is a composite of the data obtained from systems other than NSW. The data used for the two parts of the evaluation is summarised in Table 4.2.

For systems other than NSW, 225,000 km between turnings for Ride Control bogies seems a reasonable choice since both ANR and WAGR both experience wheel life of this magnitude. The distance between turnings for 2CM bogies was given a value of three times that for the Ride Control bogie

TABLE 4.2 - SUMMARY OF DATA USED FOR ECONOMIC EVALUATION

25 Year Life Cost of One Wagon, 1975 Prices

	NSW		Other Systems	
	2CM	Ride Control	2CM	Ride Control
Capital costs($)	28 440	22 100	28 440	22 100
Scheduled maintenance interval(years)(d)	5	3	5	5
Distance between wheel turnings(km)	480 000	80 000 100 000 120 000(b)	675 000	225 000
No. of turnings	2	2	2,3(c)	2,3(c)
Cost of wheel replacement per wagon ($)	1860	2070	2000	2000
Cost of wheel turning per wagon ($)	180	180	55	55
Cost of scheduled maintenance per wagon excluding wheel ($)(d)	265 or 320(a)	560	265 or 320(a)	400
Cost of scheduled maintenance per wagon with wheel turning ($)(d)	445 or 500(a)	660	320 or 375(a)	455
Cost of scheduled maintenance per wagon with wheel replacement ($)(d)	2040 or 2100(a)	2340	2265 or 2320(a)	2400

(a) The higher cost applies to scheduled maintenance at 10 year intervals.
(b) Evaluation performed repeatedly assuming these distances.
(c) Evaluation performed assuming 2 and 3 turnings.
(d) Bogies are scheduled for overhaul at the intervals shown. The costs shown are the costs per wagon for bogie maintenance for each scheduled overhaul.

and not six times as has been experienced in NSW. The wheel life assumed for inter-system use is based on the use of the harder steels. It is not known how much the use of harder steels would extend the expected life of 2CM wheels. The factor of three is consistent with the work of Koffman described earlier and in this case would be a reasonable estimate especially since the economic viability of the 2CM for systems other than NSW is not sensitive to this assumption. (1)

The approximate average of the VR, ANR, and WAGR estimates for scheduled maintenance, excluding wheels of Ride Control bogies is $400. The cost of scheduled maintenance of 2CM bogies excluding wheels for the other system case has been assumed to be the same as for the NSW case. The costs of wheel turning and wheel replacement have been assumed to be those experienced by WAGR. In addition, the wheel costs of both types of bogies have been assumed to be equal.

The evaluation uses the data shown in Table 4.2, and one result of this is that, in a number of cases, wheels may become due for turning or replacement at times not coincident with scheduled maintenance. No cognizance has been taken of the fact that in actual practice wheels may be turned or replaced during scheduled maintenance before either operation is really necessary. This might be done to avoid

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(1) J.L. Koffman, op. cit., p. 381.

withdrawing a wagon from service a relatively short time after the scheduled maintenance.

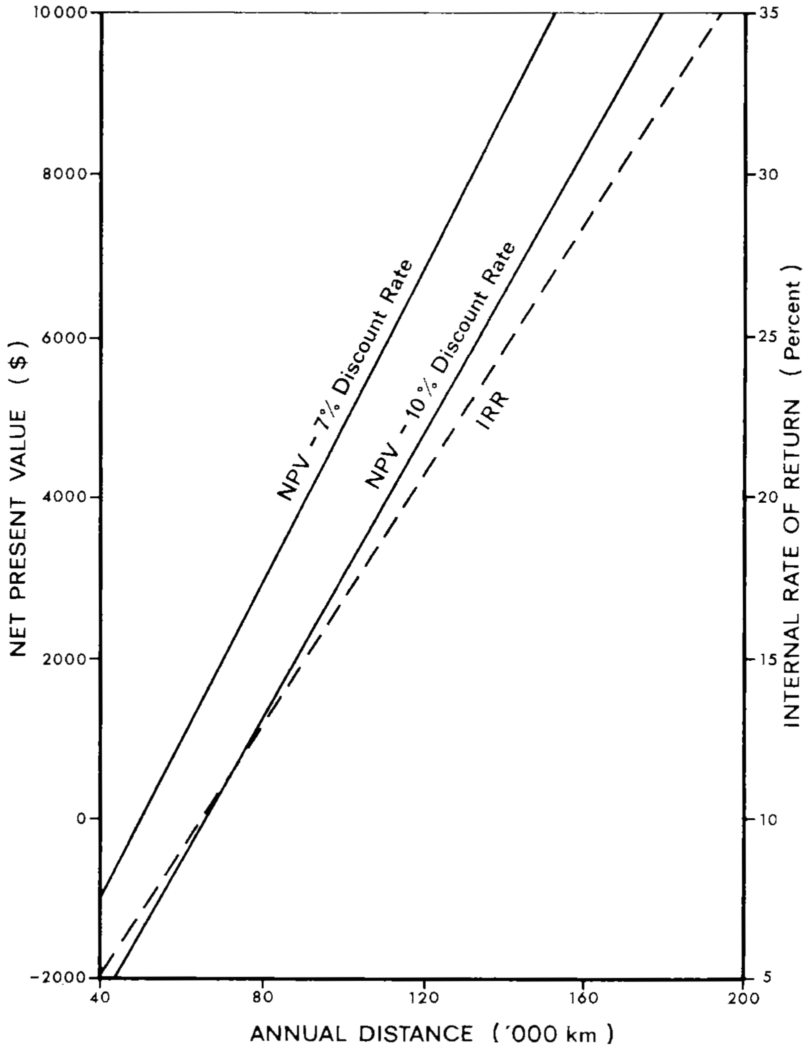
A value of 0.016 cents per wagon km was used for the fuel cost savings resulting from the use of the 2CM bogie. This is a representative value from Table B.2. The fuel savings benefit was small, therefore any one of the values given in Annex B would be sufficiently accurate for the purposes of the evaluation.

4.3 RESULTS

4.3.1 NSW Evaluation

The distance between wheel turnings is an important variable and could have considerable variation depending on the operational environment. For this reason the evaluation was performed using three distances between wheel turnings for Ride Control bogies.

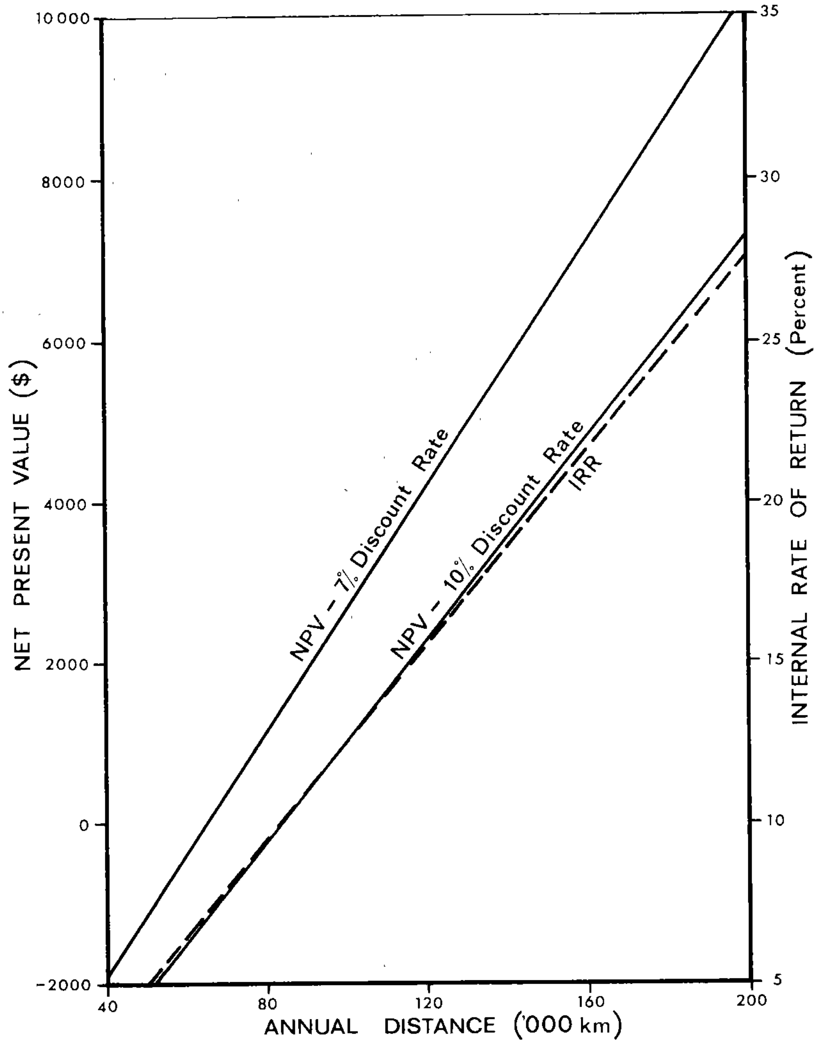
The results of the evaluation are shown in Figures 4.1 to 4.3, and summarised in Table 4.3. The effect of distance between wheel turnings is seen to be very important. If wheel life can be increased 50 per cent, then a wagon must travel 60 per cent further in order to justify the 2CM bogie (7 per cent discount rate). Using a 10 per cent discount rate a wagon must travel 70 per cent further.



80,000 km between wheel turnings for
Ride Control Bogies

FIGURE 4.1

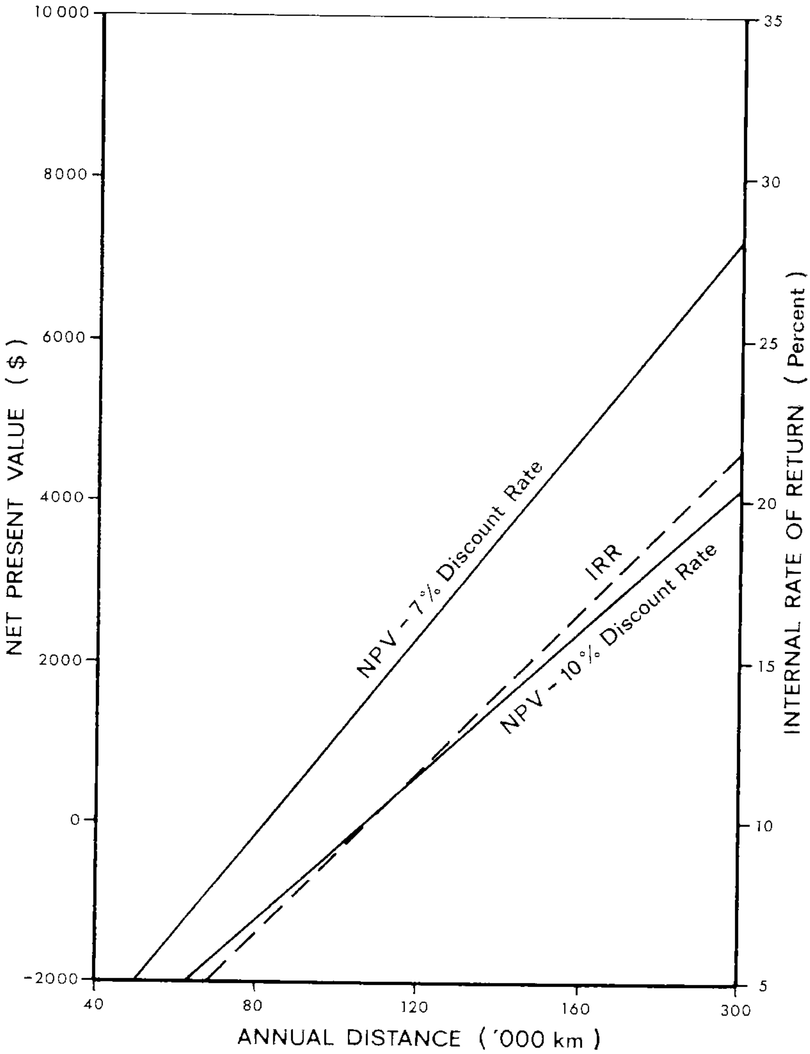
RESULTS FOR NSWPTC DATA



100,000 km between wheel turnings for Ride Control Bogies

FIGURE 4.2

RESULTS FOR NSWPTC DATA



120,000 km between wheel turnings for Ride Control Bogies

FIGURE 4.3

RESULTS FOR NSWPTC DATA

TABLE 4.3 - ANNUAL DISTANCE TO JUSTIFY THE 2CM BOGIE AND INTERNAL RATE OF RETURN FOR NSW CONDITIONS

Distance between wheel turnings	Annual distance to justify 2CM		IRR at 160,000 km/annum(a)
	7%	10%	
'000 km	'000 km	'000 km	per cent
80	50	65	28.5
100	65	80	21.5
120	80	110	16.5

(a) 160,000 km/annum is representative of the utilisation of 2CM bogies in NSW.

Nevertheless, under NSW conditions, and considering only those benefits that can be quantified, the 2CM bogie can be justified for annual distances in excess of 110,000 km. This is the most stringent set of condition shown in Table 4.3 with a distance between wheel turnings of 120,000 km and a 10 per cent discount rate. Since 2CM bogies currently in use normally travel in excess of 110,000 km, the decision to use 2CM bogies in NSW is economically justified. The effect of the other, as yet unquantifiable, benefits would be to enhance the economic value of the 2CM and to reduce the break-even distance.

4.3.2 Evaluation for Systems Other than NSW

This evaluation was performed for two and three turnings per wheel. These numbers of allowable turnings were considered to be reasonably representative of the data shown in Table 4.1. The distance between wheel turnings was held constant at 225,000 kilometres for the two cases. The results are summarised in Figures 4.4 and 4.5. Table 4.4 summarises the result of different distances between turnings.

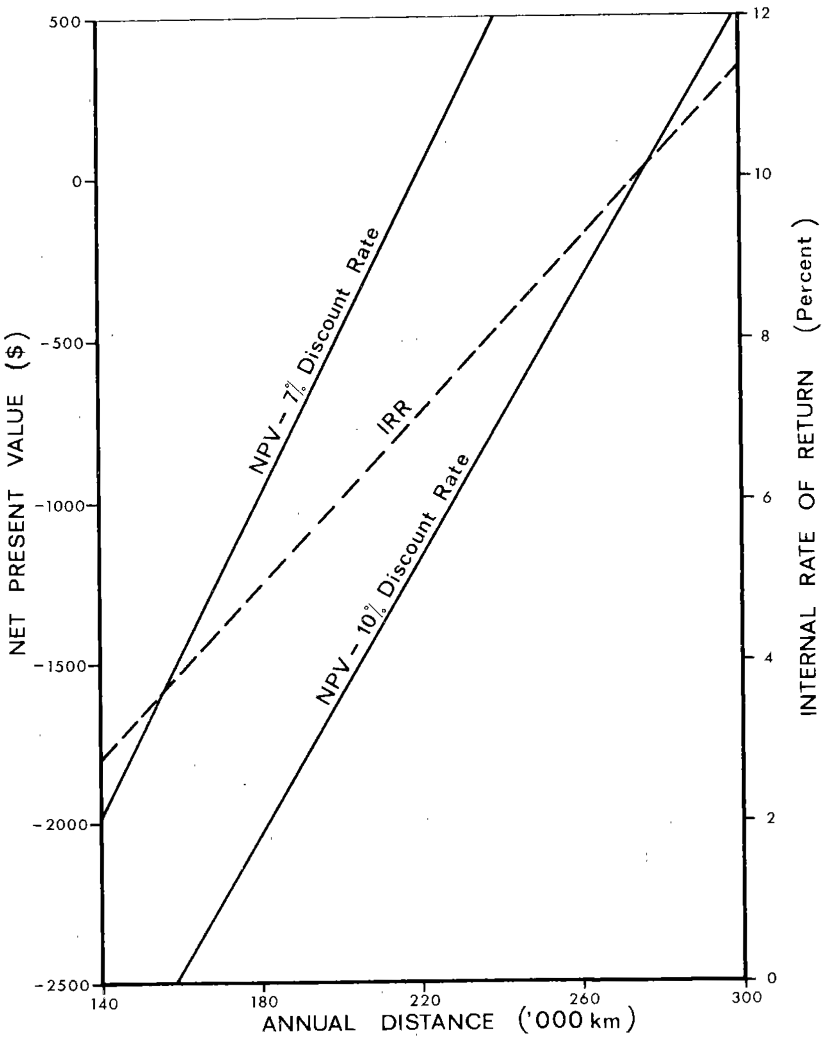
TABLE 4.4 - ANNUAL DISTANCE TO JUSTIFY THE 2CM BOGIE AND INTERNAL RATE OF RETURN FOR SYSTEMS OTHER THAN NSW

Number of wheel turnings (a)	Annual distance to justify 2CM		IRR at 160,000 km/annum (b)
	7%	10%	
	'000 km	'000 km	per cent
2	220	275	3.8
3	280	350	1.6

(a) 225,000 km between turnings
(b) 160,000 km/annum is chosen to all comparison with Table 4.3.

Considering only those benefits that can be quantified, the use of the 2CM bogie cannot be justified for use in systems other than NSW unless extremely high annual distances are achieved for 2CM equipped wagons. Distances of these magnitudes seem unlikely under current conditions.

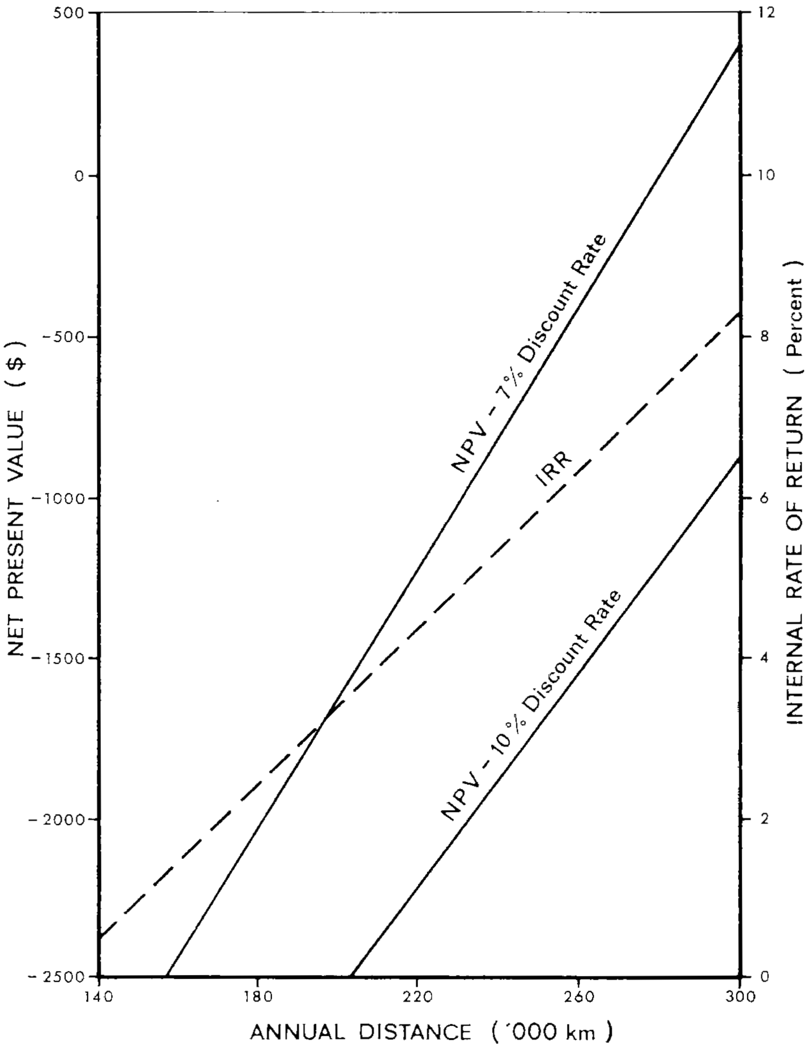
Wheel replacements are a key factor in the comparison of the 2CM bogie with the Ride Control bogie. The results were tested for their sensitivity to the cost of wheel replacements. The effect of a 10 per cent change on the break even distance is shown in Table 4.5.



2 turnings per wheel and 225,000 km between wheel turnings for Ride Control Bogies

FIGURE 4.4

RESULTS FOR COMPOSITE DATA



3 turnings per wheel and 225,000 km between wheel turnings for Ride Control Bogies

FIGURE 4.5

RESULTS FOR COMPOSITE DATA

TABLE 4.5 - EFFECT ON BREAK-EVEN DISTANCE OF A 10 PER CENT CHANGE IN WHEEL REPLACEMENT COSTS

Change in wheel replacement costs	Number of turnings per wheel (a)	Change in break-even distance
%		%
	7% discount rate	
+10	2	-7.8
-10	2	+7.8
+10	3	-7.1
-10	3	+7.1
	10% discount rate	
+10	2	-7.3
-10	2	+9.1
+10	3	-7.1
-10	3	+8.6

(a) 225,000km between turnings.

The changes in break-even distances have an average value of about 7.3 per cent for a 10 per cent increase in wheel replacement costs. For a 10 per cent decrease in wheel replacement costs the break-even distance increases by about 7.5 per cent for a 7 per cent discount rate and increases by about 8.8 per cent for a 10 per cent discount rate. These relationships do not alter the conclusion that the 2CM is not justified for use in non-NSW systems when only readily quantifiable benefits are considered.

The cost of wheel maintenance is the most significant of the quantifiable factors affecting the economic viability of the 2CM bogie. For this reason the 2CM bogie would be justified in other systems if they also used the same wheels and brake blocks as the NSWPTC. On the other hand if the wheel life of 3-Piece bogies can be increased in some way, it becomes more difficult to justify the use of 2CM bogies.

Of the presently unquantifiable benefits, track maintenance savings are the most likely to be of sufficient magnitude to justify use of the 2CM outside NSW. The extent of the track maintenance benefits required to justify the use of the 2CM bogie are shown in Figure 4.6. They are shown in terms of cents per kilometre of distance travelled by one wagon.

On the basis of a sample of track maintenance costs obtained by the BTE for another study, the costs of track maintenance per kilometre of distance travelled by a bogie wagon were estimated.(1) The costs per kilometre showed considerable variation as may be expected, however an average value of 3 cents per kilometre per bogie wagon in 1975 prices is a reasonable estimate of typical maintenance costs. On

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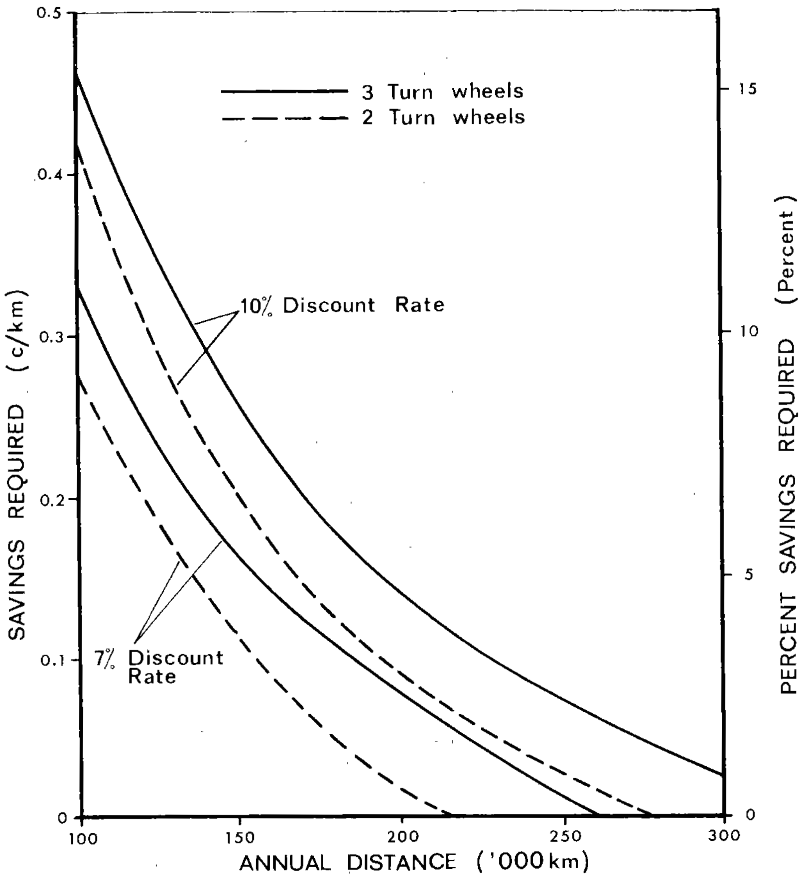
(1) These costs were the avoidable maintenance costs. They included labour and material costs associated with routine maintenance gangs, flying or extra gangs and resurfacing gangs - overheads and renewal costs were not included.



Use : 225,000km between wheel turnings for Ride Control Bogies

FIGURE 4.6

SAVINGS IN TRACK MAINTENANCE COSTS NEEDED TO JUSTIFY 2CM BOGIE FOR SYSTEMS OTHER THAN N.S.W.

this basis, Figure 4.6 also shows the per cent reduction in track maintenance costs required to justify the use of 2CM bogies.

At 160,000 wagon kilometres per annum and a discount rate of 10 per cent, the required saving in track maintenance is 0.17 cents per wagon kilometre (5.7 per cent) and 0.23 cents per wagon kilometre (7.7 per cent) for two turn wheels and three turn wheels respectively. A cost reduction of this order does not seem unreasonable in the light of the improved compliance of the 2CM bogie, but current knowledge does not allow any definite statement to be made on the matter.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main conclusions to be drawn from the economic evaluation are that:

- the 2CM bogie is economically justified in NSW, under NSW operating conditions;
- when only benefits currently quantifiable are considered, the 2CM bogie is not justified for use in other systems;
- wheel maintenance costs are the most significant of the quantifiable benefits included in the evaluation. This becomes of importance when interstate routes are considered. The optimal combination of wheels and brake blocks for intrasystem operation may be quite different from the optimal combination for intersystem operation. This is relevant to interstate routes such as the Sydney-Melbourne route where the superior braking performance of composition brake shoes is of value on the more difficult terrain in NSW;
- of the unquantifiable benefits, reduction in track maintenance costs is the one most likely to be of sufficient magnitude to justify the use of the 2CM bogie in other systems. Only a modest saving in track

maintenance costs is required to justify the additional cost of the 2CM bogie for reasonable annual wagon distances;

fuel savings in favour of the 2CM bogie are not significant in the speed range of interest. At 160,000 km/annum the fuel savings represent less than 2 per cent of the quantifiable benefits at a 10 per cent discount rate.

As well as these economic conclusions, some engineering conclusions can be reached. These are that;

the 2CM bogie meets the AAR/ANZR stress specifications with a considerable margin. If these specifications are a satisfactory standard then it must be concluded that the 2CM bogie is heavier than it needs to be;

the advantages that the 2CM may have in relation to the freight carried are not clear. The accelerations measured on the floor of a wagon equipped with 2CM bogies are such that impact damage to freight during line haul is unlikely. Other bogies do have accelerations which may cause impact damage. The magnitude of accelerations likely to cause abrasion damage is not known. If it is assumed that abrasion damage is proportional to the product of the acceleration magnitude and number of occurrences of that magnitude then the 2CM bogie would cause less damage than the 3-Piece bogie. However, no monetary values can be placed on this advantage; at present the lack of necessary data prevents the design of an optimal bogie for Australian conditions. In particular, the following relationships need to be developed:

- relationship between wheel design and wheel maintenance costs;
- relationship between bogie performance and the cargo environment. This requires the development of a suitable standard for the ride of freight wagons and the analysis of the trade off between reduced packaging costs and better bogies;
- relationship between bogie performance and track forces;
- relationship between track forces, track deterioration and induced maintenance costs;
- relationship between bogie performance, track characteristics and derailment risks.

The BTE is of the opinion that the 2CM bogie is technically superior to 3-Piece bogies. Despite this superiority, the quantifiable benefits are not sufficient to justify the introduction of the 2CM bogie outside NSW. Before a decision can be reached on the desirability of the introduction of the 2CM bogie, or any other bogie, into these other systems, a number of studies should be undertaken. These studies would develop the relationships required to estimate the value of the currently unquantifiable benefits and are described in the following section.

5.2 RECOMMENDATIONS

In collecting information for this study it became clear that there were a number of deficiencies in the knowledge required to adequately evaluate the bogie designs. These deficiencies relate to the establishment of suitable criteria against which a bogie design should be judged. The relationships discussed in the conclusions which are necessary to allow these design objectives to be determined are not available. In other words, it is not known what performance a well designed bogie should have.

The following recommendations are designed to fill in these gaps:

(i) Wheel life was the most important variable in the evaluation, yet the type of wheels in use varied markedly between systems. The types varied from soft wheels in combination with composition brake blocks in NSW, to hard wheels and composition brake blocks in Western Australia and to replaceable tyres and cast iron brake blocks used by ANRC. Not all, if any, of the choices of wheels, tyres and brake blocks are necessarily optimal when all considerations are taken into account. It is recommended that the optimal combinations of wheels and brake blocks be determined through tests and economic evaluation of rail systems requirements.

(ii) The risk of derailment is thought to be lower for a 2CM bogie than for a 3-Piece bogie. This is a result of the improved performance of the 2CM bogie under track twist conditions. The amount of wheel load reduction is lower for a 2CM bogie than for a 3-Piece bogie under these conditions. The 2CM bogie would therefore provide a higher degree of protection against derailment. Unfortunately the relative probabilities of derailment for each type of bogie is not known. In addition, the distribution of derailment costs is not known. It is recommended that studies be initiated to determine the separate probabilities of derailment for 3-Piece bogies and for 2CM bogies. This, in combination with the distribution of derailment costs, which should also be estimated, would allow this benefit of the 2CM bogie, if any, to be calculated. It is further recommended that a derailment test program be supported through the introduction of a number of 2CM bogies over the whole of the Australian standard gauge system.

(iii) The current method of determining bogie performance by means of the ride index is not appropriate for freight bogies. The effect of ride on freight is certainly different from the effect on passengers. Impact damage is relatively simple to analyse. As discussed in Annex A, accelerations in excess of 1 g. will almost certainly cause impact damage, and accelerations between 0.75 g. and 1 g. will cause impact damage under certain conditions. Abrasive damage is more difficult to analyse. To the knowledge of the BTE, no results have been published which relate abrasive damage to acceleration magnitudes. The usual situation is for a package designer to design a package to withstand a known hazard whereas, from the bogie designers point of view, a desirable hazard level should be the design aim. No such standard exists against which a bogie can be assessed in terms of its likely damage to freight. It is therefore recommended that studies be undertaken to determine a suitable ride standard or bogie performance standard.

(iv) The 2CM bogie is thought to have a less damaging effect on the track than a 3-Piece bogie. This is because of its lower unsprung mass and acceleration magnitudes. However, the relative magnitudes of the dynamic track forces are not known. It is recommended that tests be performed to determine the magnitude of the forces imposed on the track by a 2CM bogie compared to a 3-Piece bogie. These tests would give useful qualitative information on the likely effect that the 2CM bogie, or other rigid frame bogie, would have on track maintenance costs.

(v) Perhaps the most important area requiring study is the relationship between track forces and track maintenance. Such a study would be much more complex and difficult than studies arising out of the previous recommendations. It would be imperative that the study be structured to insure close collaboration between theoretical and experimental approaches and that it be complementary to other similar studies being carried out by overseas administrations. It is recommended therefore that a nationally coordinated program of track deterioration studies be initiated.

(vi) The ANZR standards for freight bogies should be examined and extended so that innovative bogies can be designed, tested and compared within a generally agreed framework.

To implement these recommendations efficiently requires national coordination; each study should contribute to the overall objectives of the development of an optimal bogie for Australian conditions and the optimal design of track structures.

ANNEX A

TESTING OF THE 2CM BOGIE

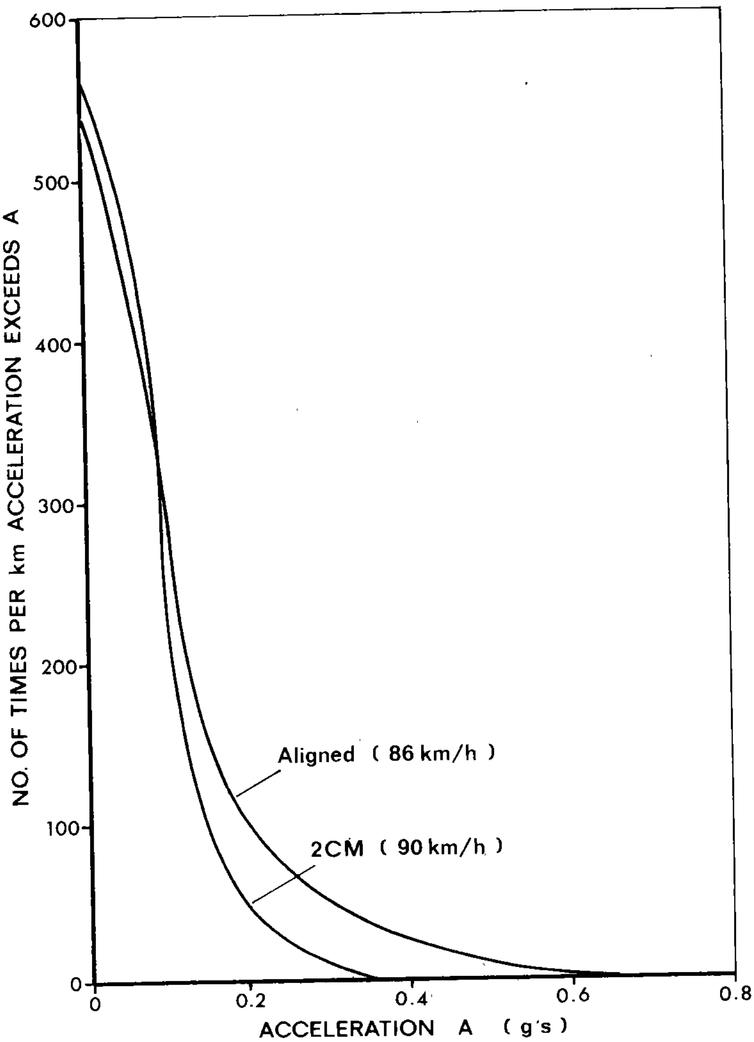
A.1 RIDE CHARACTERISTICS

The riding properties of the 2CM bogie have been characterised through tests conducted by the NSWPTC in 1973. During these tests the vertical and lateral accelerations of JLX and JLY louvre vans were measured by accelerometers mounted on the van floor directly over the forward bogie.[1] The tests were conducted at tare weight and at various speeds on a section of line between Liverpool and Campbelltown.

The data collected during the tests consisted of accelerometer traces. These were used by the NSWPTC to estimate ride index. The BTE has used a sample of these traces to determine the distributions of peak acceleration amplitudes, as shown in Figures A.1 to A.6.

Figures A.1 and A.2 give the distributions for 2CM and Aligned bogies for vertical and lateral accelerations recorded at 86 km/h for the Aligned bogie and 90 km/h for the 2CM bogie. These speeds are of particular interest because they are typical of current operating speeds. In Figure A.1 the 2CM bogie shows a marked reduction in the

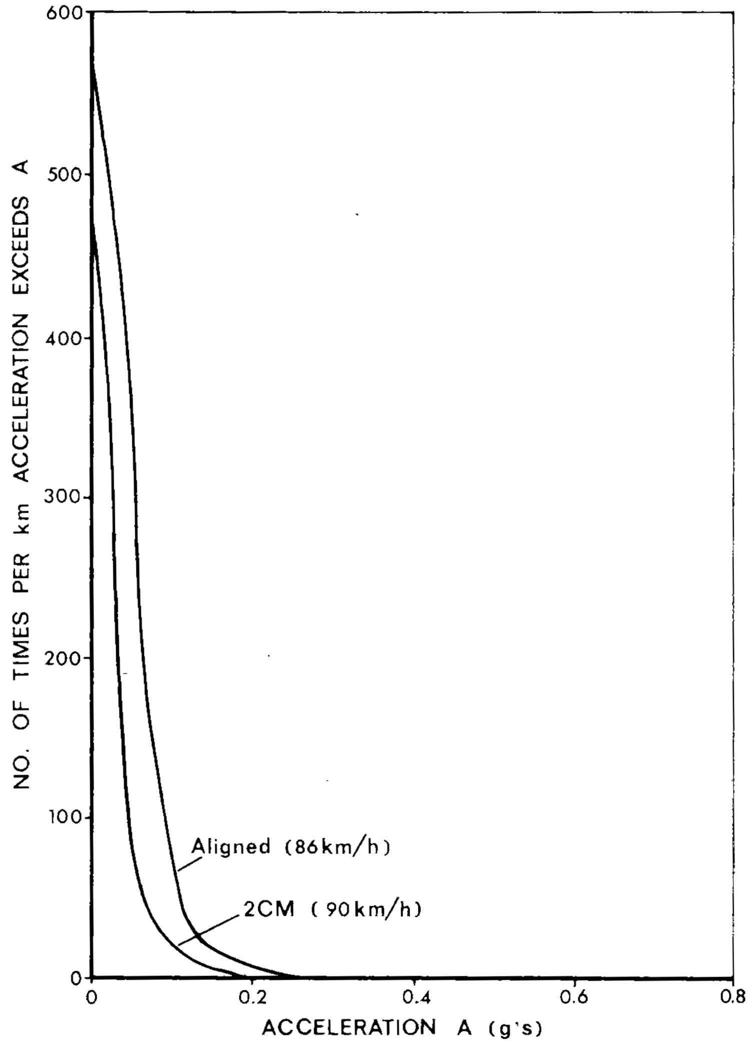
(1) JLX and JLY wagons are identical except for the centre plate. The JLX has a 12 inch centre plate and is suitable for bogie exchange purposes. The JLY has a 14 inch centre plate suitable for 2CM bogies.



Test Location : Between Liverpool and Campbelltown
Test Vehicle : JLY Louve Van at tare

FIGURE A.1

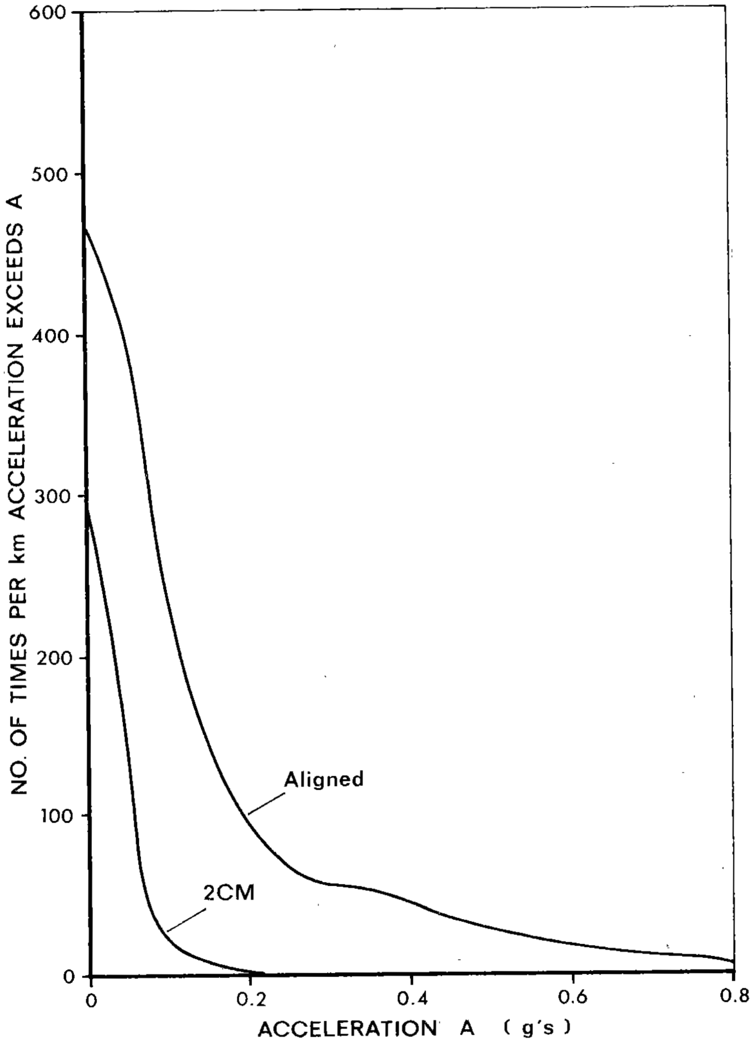
COMPARISON OF VERTICAL ACCELERATIONS OF 2CM AND ALIGNED BOGIES AT APPROXIMATELY 90 km/h



Test Location : Between Liverpool and Campbelltown
Test Vehicle : JLY Louvre Van at tare

FIGURE A.2

COMPARISON OF LATERAL ACCELERATIONS OF 2CM AND ALIGNED BOGIES AT APPROXIMATELY 90km/h

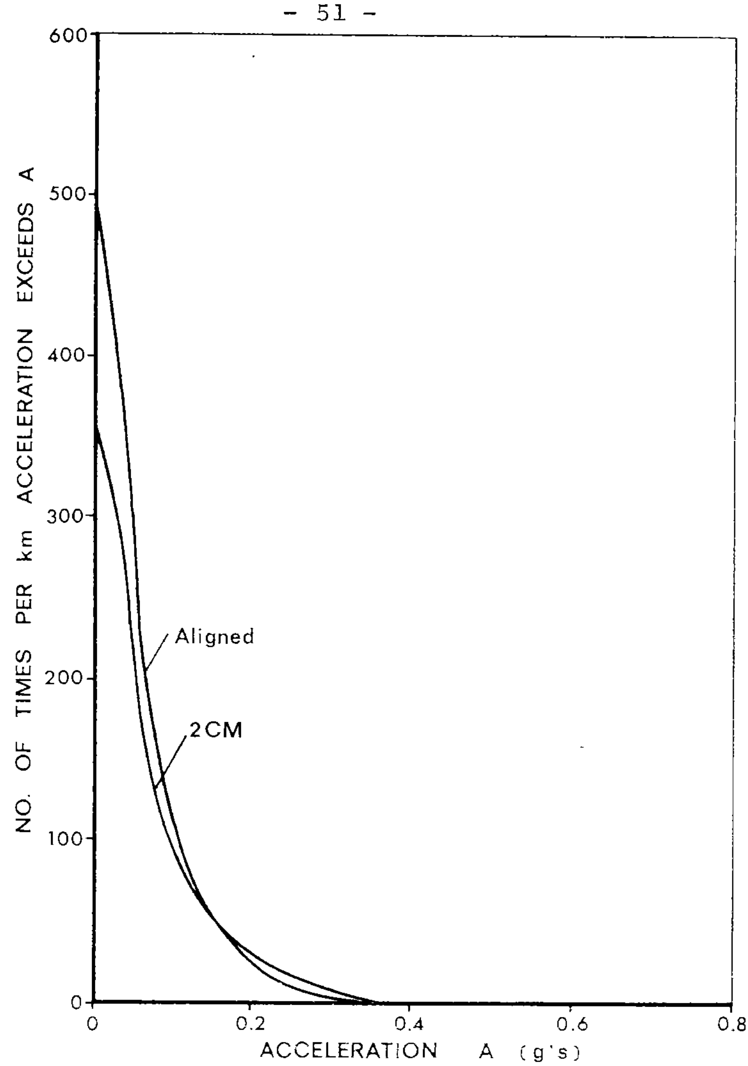


Test Location : Between Liverpool and Campbelltown

Test Vehicle : JLY Louvre Van at Tare

FIGURE A.3

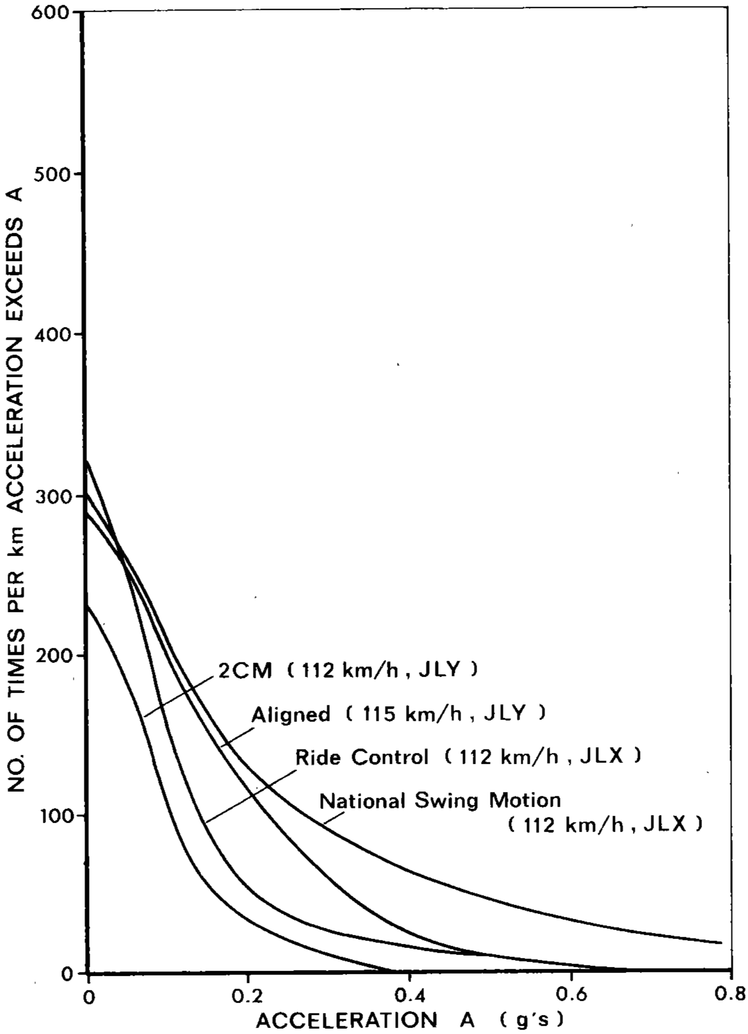
COMPARISON OF VERTICAL ACCELERATIONS
OF 2CM AND ALIGNED BOGIES
AT 101 km/h



Test Location : Between Liverpool and Campbelltown
Test Vehicle : JLY Louvre Van at tare

FIGURE A.4

COMPARISON OF LATERAL ACCELERATIONS
OF 2CM AND ALIGNED BOGIES
AT 101 km/h

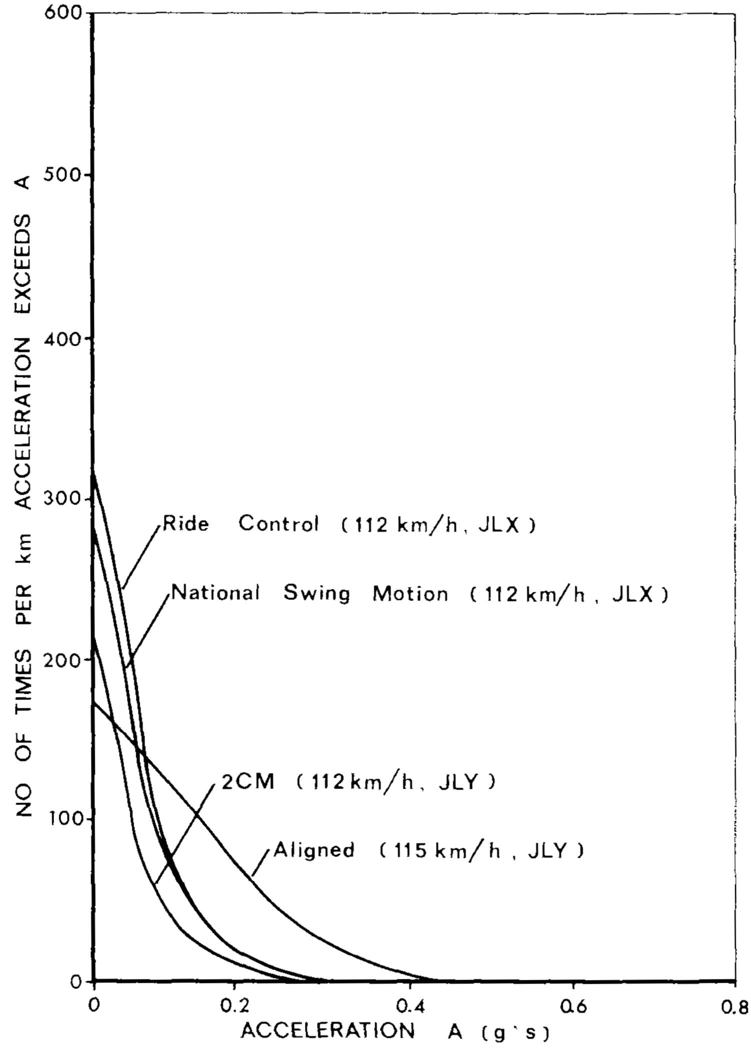


Test Location : Between Liverpool and Campbelltown

Test Vehicle : JLX or JLY at tare

FIGURE A.5

COMPARISON OF VERTICAL ACCELERATIONS
OF VARIOUS BOGIES AT APPROXIMATELY 112 km/h



Test Location : Between Liverpool and Campbelltown
Test Vehicles : JLX or JLY at tare

FIGURE A.6

COMPARISON OF LATERAL ACCELERATIONS OF VARIOUS BOGIES AT APPROXIMATELY 112 km/h higher values of acceleration. For example the maximum vertical acceleration recorded for the 2CM bogie at 90 km/h was 0.35 g, whereas the Aligned bogie generated accelerations up to 0.6 g.

Although the 2CM bogie shows lower accelerations than the Aligned bogie, the NSWPTC considers that a desirable limit for accelerations is 0.5 g so that the Aligned bogie is only marginally worse than the NSWPTC standard of performance.

If this standard is accepted then the improved performance of the 2CM bogie is of little value and the 2CM bogie is only marginally better than the Aligned bogie. BTE estimates suggest that impact damage to freight can occur for accelerations in excess of about 0.75 g. Relationships between abrasive damage and acceleration magnitudes are not known. Packaging is normally designed for a known hazard, and little or no work has been done to establish what is a desirable acceleration environment for packaging design. In view of this, both the Aligned and the 2CM bogies would cause no impact damage for the conditions applying for Figure A.1. The relative abrasive damage cannot be accurately estimated. However, if the simple assumption is made that abrasive damage is proportional to the product of acceleration magnitude and the number of acceleration peaks then the damage would be proportional to the area under the curves in Figures A.1 and A.2. In that case the 2CM would cause less damage than the Aligned bogie. No monetary values can be put on this damage.

In Figure A.2, where the lateral accelerations are recorded, the 2CM bogie has generally lower frequency of acceleration events than the Aligned bogie. The maximum acceleration and frequency of accelerations are quite low in both cases so that in this speed range there would be little to choose between the two bogies as far as lateral accelerations are concerned.

Figures A.3 and A.4 are for the same bogies operating at 101 km/h. In the vertical direction (Figure A.3) the 2CM bogie shows a clear superiority, with the Aligned bogie showing a significant number of accelerations in excess of 0.5g. In the lateral direction (Figure A.4) the two bogies have almost identical distributions.

Figures A.5 and A.6 compare the performance of a number of bogies at about 112 km/h. In the vertical direction the superiority of the 2CM bogies at higher speeds is illustrated. The highest recorded acceleration for the 2CM is about 0.45 g whereas the Ride Control bogie has accelerations up to 0.75 g and the Aligned bogie has accelerations up to 0.8 g. These latter two accelerations would be sufficient to give a high risk of impact damage. In the lateral direction the bogies have fairly similar distributions. The 2CM bogie has generally lower accelerations. The maximum lateral accelerations for all bogies are in the range 0.275 g to 0.4g.

A comparison of the lateral responses of the Aligned and 2CM bogies at 90, 101, and 112 km/h as shown in Figures A.2, A.4 and A.6 respectively is of interest. At 101 km/h the two distributions are almost identical, however at the other speeds the 2CM bogie has a distribution below that of the Aligned bogie. As the speed increases the total number of impacts per kilometre decreases for both bogies. The maximum recorded magnitude increases with speed throughout the speed range for the Aligned bogie, whereas the 2CM bogie shows a peak in acceleration amplitude at 101 km/h. This suggests that the 2CM bogie is experiencing a resonance effect at this speed on this track.

During these tests, all accelerations were measured on the floor of the wagon. The forces exerted at the track, however, are the significant forces from the point of view of the effect on track maintenance. Nevertheless, it would be reasonable to assume that the accelerations experienced by the wheelsets would be directly related to the accelerations measured on the floor of the wagon. If this is so then the accelerations of the 2CM wheelsets can be expected to be generally lower than those for 3-Piece bogies. Since the unsprung mass of a 2CM bogie is much lower than for a 3-Piece bogie, the track forces would also be much lower. This would have a beneficial effect on track maintenance costs.

Unfortunately the relationships between track maintenance, bogie maintenance, cargo damage and bogie dynamic characteristics has not been established in even the most tentative fashion.

The NSWPTC estimated the ride index from the accelerometer traces used in producing the curves in Figures A.1 to A.6. The Australian National Railways Commission (ANRC) also measured the ride index of the 2CM, Aligned and Ride Control bogies. A comparison of the two estimates is given in Table A.1. The estimates are not completely comparable since the measurements were done on different sections of track and were done in different ways. The NSWPTC estimates were based on an examination of the worst 7 per cent of the accelerometer readings. The ANRC estimates were made using a British Rail Ride Index Meter. This device calculates the ride index at periodic intervals of time. The final value of the ride index is then an average of the separate estimates. The variance of the sample of estimates is also shown in Table A.1.

The two measurements are not consistent. For the 2CM bogie the NSWPTC and ANRC measurements agree for the vertical direction but differ markedly in the lateral direction. However for the Aligned bogie the two methods agree for lateral direction but differ significantly in the vertical direction.

TABLE A.1 - COMPARISON OF RIDE INDEX MEASUREMENTS

Speed km/h	NSWPTC		ANRC(a)	
	Lat	Vert	Lat	Vert
		2CM		
90	3.0	3.7	-	-
100	3.1	3.6	4.6(7.9)	3.5(5.6)
		ALIGNED		
86	3.8	4.5	-	-
91	-	-	3.5(12.3)	-
100	4.0	5.2	3.9(12.7) (b)	3.3(7.4) (b)
100	-	-	3.1(7.7) (c)	3.4(5.9) (c)
		RIDE CONTROL		
100	-	-	3.8(19.2)	3.5(4.2)
90	-	-	3.5(9.3)	-

(a) The figures in brackets are the variances of the measurements.

(b) The bogie in this test was due for overhaul.

(c) The bogie in this test was in new condition.

Another point of interest in these figures is the relative magnitudes of the lateral and vertical values. In the NSWPTC figures the lateral ride index is consistently lower than the vertical ride index. The ANRC results are the opposite in all but one case. This could be a result of the different tracks on which the two sets of tests were made.

A feature of the ANRC results is the large value of the variance. For example, the Ride Control bogie at 100 km/h has a variance of 19.2 in the lateral direction. This indicates that many of the individual ride index values must have been as high as 8.0. The tests of the 2CM bogie showed a relatively low variance compared to the tests of the other bogies.

The ride index method of assessing vehicle performance was originally developed for passenger vehicles. The major spectral components of the vehicle response are weighted according to the subjective effect each frequency has on passengers and the relevance of ride index to freight vehicle performance must be questioned. A ride index based on the weighting of spectral components according to their effect on cargo would be better. The comparison in Table A.1 indicates that even if this is done, the different methods of calculating ride index, and the use of different tracks make valid comparisons difficult, if not impossible.

Apart from cargo oriented spectral weightings, the spectral response of the vehicle needs to be related to a known input, rather than the current method of performing the test on a piece of track which may or may not be typical of the track where the vehicle will be put into service. This presents difficulties but needs resolution if tests performed at various locations are to be compared.

Tentative conclusions to be drawn from these tests are that:

- in the range of speeds from 80km/h to 96km/h the performance of the 2CM bogie is superior to the Aligned bogie but as the improved performance exceeds the informal standards of the NSWPTC the value of this margin of performance cannot be established. However, because of its lower unsprung mass, the 2CM bogie would impose far lower forces on the track structure.

- at higher speeds, the performance of the 2CM bogie is markedly superior to the other bogies tested. In fact, the 2CM bogie is the only bogie which meets the NSWPTC informal standard of 0.5g acceleration limit at speeds above 85km/h.

A.2 ROLLING RESISTANCE

The NSWPTC measured the rolling resistance of OCX wagons equipped with 3-Piece bogies and OCY wagons equipped with 2CM bogies. The reduced lateral sliding of rigid frame bogies as compared to 3-Piece bogies [1] suggests that the rolling resistance should be lower for 2CM bogies. In fact this was verified by test.

The tests were done in two stages. The first stage involved measuring the rolling resistance of the bogies on the route between Sydney and South Grafton. This route is generally undulating with steep gradients and sharp curves. Due to the nature of the terrain the only conclusive results were obtained on rising gradients.

The results showed that 2CM bogies have a rolling resistance 8.0 N/tonne less than 3-Piece bogies. This was for a gradient of 1 in 80 with 15 chain curves.

The second stage measured the rolling resistance on the route from Parkes to Ivanhoe. This route is generally straight and level. The results of this test are shown in Figure A.7.

In each set of tests the same locomotive was used. Each test train had the same number of wagons, the same containers were used and placed in each train in the same location. Each wagon was weighed separately and it was the measured weight which was used in estimating the rolling

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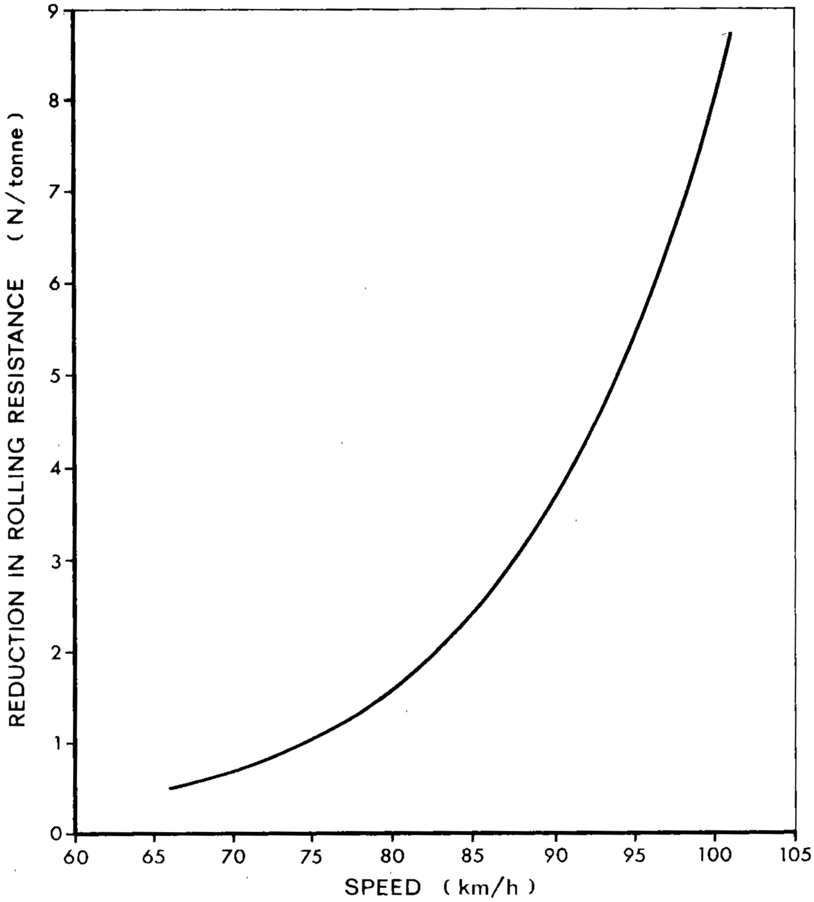
(1) J.L. Koffman, op.cit., p.381.



Tested with OCX and OCY wagons on track between Parkes and Ivanhoe

FIGURE A.7

REDUCTION IN ROLLING RESISTANCE OF 2CM BOGIES COMPARED TO 3-PIECE BOGIES AS A FUNCTION OF SPEED resistance differences.

Weather conditions were said to have remained essentially constant during the tests and were therefore assumed to have had no effect on the results.

The conclusion to be drawn from these tests is that on straight and level track, the 2CM bogie develops about 2.5 per cent less rolling resistance than 3 Piece bogies. In hilly terrain, 2CM bogies seem to develop about 1.5 per cent less rolling resistance although there is some question about the accuracy of these test results. The estimation of these percentages took into account the increased mass of the 2CM bogie and the different speeds normally applying on the two types of terrain. The calculations assumed the average gross weight of 45.6 tonnes for a wagon equipped with Ride Control bogies. Annex B gives the calculations in detail.

The effect of the reduction of rolling resistance is a reduction in fuel consumption for a given train speed. Fuel savings are estimated in Annex B.

A.3 STRESS TESTING

Tests and analyses were carried out on the 2CM bogie frame at the BHP Melbourne Research Laboratories. These analyses involved a computer study of the frame stresses. These results are summarised in Tables A.2 and A.3. These

TABLE A.2 - THEORETICAL ANALYSIS OF 2CM BOGIE SIDEFRAME[a]

Loading(b)	Maximum calculated stress ($lb.in^{-2}$)	Maximum allowable stress ($lb.in^{-2}$)
Transverse loading, 0.5C		
Tension	8 470	12 500
Compression	8 470	12 500
Vertical loading, 1.5C		
Tension	11 220	12 500
Compression	6 240	12 500
Combined Loading,		
1.5C vertically, 0.5C transversely, 0.3C longitudinally		
Tension	13 920	16 000
Compression	12 890	16 000

(a) J.A. Cooper, Design and Testing of 11 x 5½ Fast Freight Bogie Components, Commonwealth Steel Company Limited, Waratah, September 1973, p.13.

(b) C = 43 120 lb.

TABLE A.3 - THEORETICAL ANALYSIS OF 2CM BOGIE BOLSTER[(a)]

Loading(b)	Maximum calculated stress ($lb.in^{-2}$)	Maximum allowable stress ($lb.in^{-2}$)
Transverse loading, 0.8P		
Tension	8 780	12 500
Compression	8 780	12 500
Vertical loading, P		
Tension	10 460	12 500
Compression	12 170	12 500
Combined loading		
P vertically, 0.25P transversely		
Tension	13 010	16 000
Compression	13 220	16 000

(a) J.A. Cooper, op.cit, p.18.

(b) P = 83 240 lb.

results show that the theoretically calculated stresses meet all the design requirements. The specifications against which these stresses were checked are:

- AAR specification M-202 for bolsters
- AAR specification M-203 for side frames
- ANZR specification C2932 (identical to AAR specification M-203)
- NSWPTC - Rail Division specification No. 2543.

The stresses allowed by these specifications are summarised below.

AAR Specification M-202 (Bolsters)

The basis for calculations is a vertical load P, defined by:

$$P = 2C - 2\,000\,(d - 4)$$

And if C = axle capacity (43 120 lbs or 19 250 kg) and d = journal diameter (5.5 ins or 123 mm), then P = 83 240 lbs or 37 160 kg.

The maximum stress created by a vertical load P (acting anywhere from centre to 8 inches (203mm) from centre, or anywhere from centre of spring support to 23 inches (584 mm) from bolster centre) or a transverse load of 0.8P (acting on centre) shall not exceed 12 500 lb in^{-2} (86.2 MPa). In

TABLE A.4 - RESULTS OF 2CM BOGIE SIDEFRAME STATIC TESTS[a]

Test		Result		
		Test No 1	Test No 2	AAR Spec M-203
		Transverse Test:		
Deflection at	31 000 lb	0.028 in	0.040 in	0.078 in max
Set after	52 000 lb	0.0015 in	0.004 in	0.011 in max
		Vertical Test:		
Deflection at	102 000 lb	0.021 in	0.016 in	0.045 in max
Set at	194 000 lb	0.0015 in	0.006 in	0.011 in max
Elastic limit		212 000 lb	204 000 lb	183 000 lb min
Ultimate load(b)		560 000 lb	560 000 lb	539 000 lb min

(a) J.A. Cooper, op.cit, pp.29,32.

(b) Tests stopped at 560 000 lb.

TABLE A.5 - RESULTS OF 2CM BOGIE BOLSTER STATIC TESTS[a]

Test	Result		
	Test No 1	Test No 2	AAR Spec M-202
Transverse Test:			
Deflection at 88 000 lb	0.027 in	0.0275 in	0.075 in max
Set after 166 000 lb	0.018 in	0.017 in	0.025 in max
Vertical side bearing test:			
Deflection at 129 000 lb	0.024 in	0.023 in	0.055 in max
Set after 208 000 lb	0.015 in	0.0010 in	0.025 in max
Vertical centre plate test:			
Deflection at 129 000 lb	0.043 in	0.0465 in	0.075 in max
Set after 249 000 lb	0.002 in	0.0015 in	0.025 in max
Ultimate load(b)	580 000 lb	460 000 lb	458 000 lb min

(a) J.A. Cooper, op.cit, pp.29-32.

(b) Tests stopped at loads shown.

addition the maximim vertical and transverse stresses (combined) resulting from the same vertical load P and transverse load 0.25P shall not exceed 16 000 lb in^{-2}(110 MPa).

AAR Specification M-203 (Side frames)

The basis for calculations is the axle capacity C, where C = 43 120 lb (191 800 N). For a combined load of 1.5C applied vertically to the sideframe and 0.4C applied transversely the stresses nowhere in the casting are to exceed 16 000 lb in^{-2} (110 MPa).

NSWPTC - Rail Division Specification No. 2543

The basis for calculations is the load W, where W is the load on the component considered. For a vertical load W and transverse load 0.5W or lateral throw-over force of 0.3W acting horizontally at the centre of gravity of the vehicle (6 feet(1.8m) from top of rail), the total stress in the castings must not exceed 16 000 lb.in^{-2}. When considered separately, each force must not create a stress greater than 12 500 lb.in^{-2}.

Static tests of two bolsters and sideframes were undertaken in accordance with AAR Specifications M-202 and M-203 respectively for an axle load of 43 120 lbs (19 250 kg). The tests were carried out on a Mohr and Federhaff Static Loading System. A summary of the results is shown in Tables A.4 and A.5.

The 2CM bogie bolster and sideframe satisfied all requirements of the relevant specifications.

Another test determined stresses in the transom under various loading conditions. The loads simulated were:

- brake reaction forces
- lateral wheel forces
- vertical wheel forces arising from track irregularities.

Figure A.8 describes the load application points while Table A.6 gives a summary of the maximum stresses measured during the tests of the brake reaction forces and the lateral wheel forces.

The test results for the third loading situation were shown on a series of graphs in the BHP report. These graphs are not reproduced here, but it is sufficient to say that none of the stresses or deflections were considered by the testing officers to be excessive.

The final test was a dynamic test. The frame was clamped at three axleboxes and the fourth axlebox was oscillated from 0 to 0.375 inches for 25 million cycles. This test simulated one year of operation under extreme service conditions. The simulation was based on the operation of the bogie under a

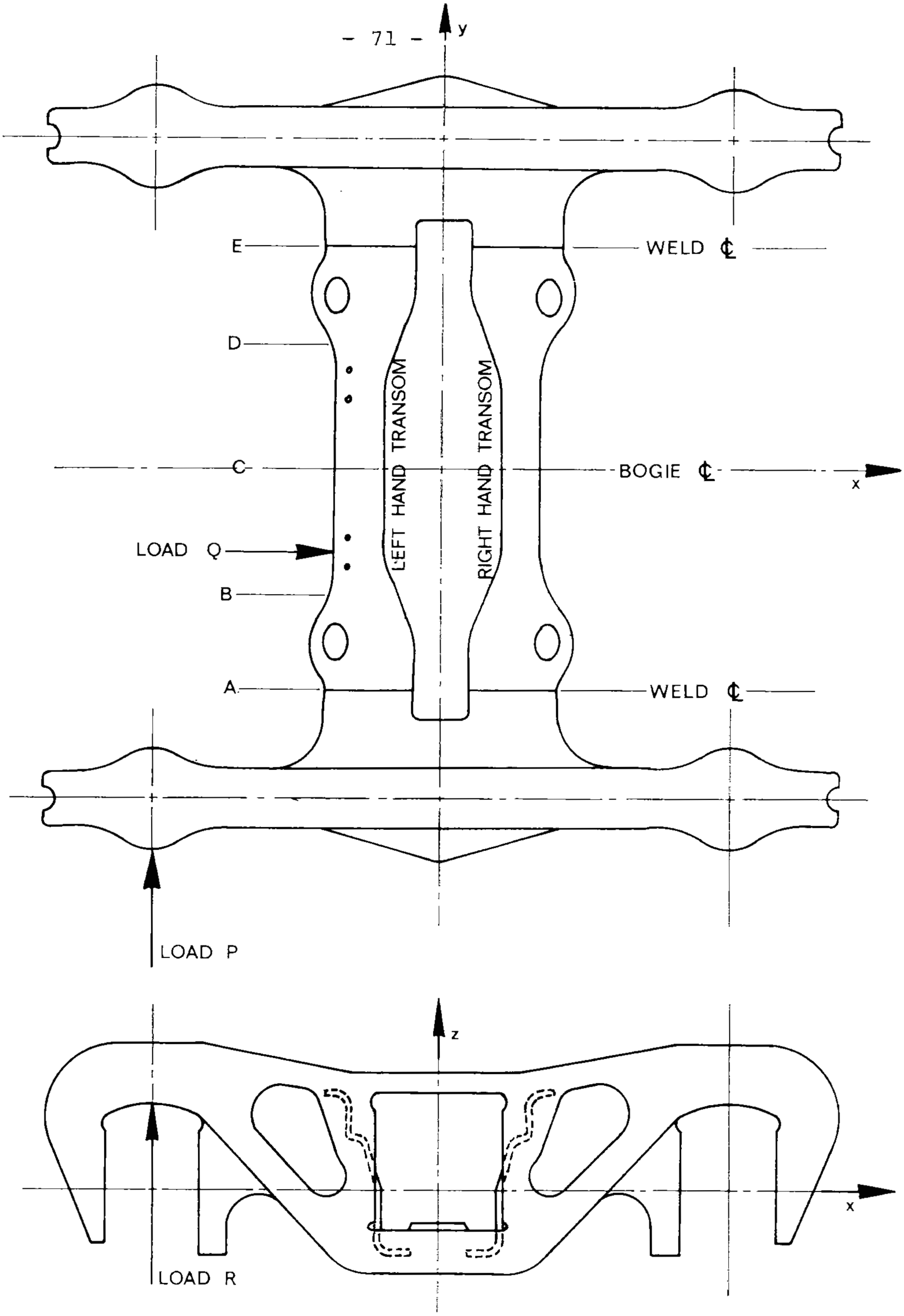


FIGURE A.8

POSITIONS OF TEST LOADS ON BOGIE FRAME

TABLE A.6 - SUMMARY OF MAXIMUM STRESSES MEASURED DURING TRANSOM TESTS[a]

Load (lb)	Maximum stress due to load applied at	
	P[b] ($lb.in^{-2}$)	Q[c] ($lb.in^{-2}$)
2 500	1 570	2 820
5 000	3 150	5 650
7 500	4 730	8 470
10 000	6 300	11 300
12 500	7 870	14 120
15 000	9 450	n.a.

(a) J.A. Cooper, op.cit, pp 39-42.

(b) Maximum stress occurred on edge of top flange at bogie centreline ('C', Figure A.8). This loading simulated lateral wheel forces applied at 'P'.

(c) Maximum stress occurred on edge of top flange at weld centreline ('A', Figure A.8). This loading simulated brake reaction force applied at 'Q'.

very flexible vehicle over a track with 0.5 inch irregularities. The maximum principal stresses recorded under this mode of operation were measured along the edges of the top flanges of the transoms. These were 3 300 $lb.in^{-2}$ (22.8 MPa) tension at the transom centreline and 1 900 $lb.in^{-2}$ (13.1 MPa) tension at the welds. No fatigue cracks were initiated as a result of the test.

The testing officers concluded that the frame of the 2CM met all the design and static test requirements of the relevant specifications.

Furthermore, considering the low stresses and deflections under load, as calculated and measured, there is evidence that the 2CM is considerably stronger than the specifications demand and thereby somewhat overweight.[1]

A.4 SERVICE EXPERIENCE

The first four bogies put into service were inspected after they had travelled about 400,000 kilometres. The wheels in general were in good condition and the amount of wear was about 2mm. No worn wheel profiles were available to the BTE. This amount of wear suggested that the wheels could

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(1) Support for the contention is given by the SNCF Y25C rigid frame bogie. This bogie which has been used by BR with 22.5 tonne axle load weighs 4.4 tonne compared to the 5.1 tonnes of the 2CM bogie. See J.L. Koffman, Bogie Designs for Modern Wagons, Modern Railways, June 1969, pp.304-308.

run much further before turning became necessary.

A slight amount of wear was noticed in parts of the brake gear but was generally negligible. Some welds on the liners welded to the wearing surfaces were broken. Bogies with additional welding at these points were not affected.

The main difficulty experienced so far seems to be the breaking of welds that secure the manganese steel centre pivot liners. Further work needs to be done to correct this problem.

The maintenance requirements expected at this stage are the replacement of pins and bushes at five year intervals and the replacement of the bolster friction liners at ten year intervals.

ANNEX B

CALCULATION OF FUEL SAVINGS

In a survey of train rolling resistance (1) the BTE recommended the following formula for the resistance of freight trains on level tangent track:

$$R_r = 6.4 + 129/w + 0.03V + KV^2/W$$

Where R_r = running resistance (N/tonne)

w = axle load (tonne)

W = total train weight (tonne)

V = speed (km/h)

K = 0.27 for TOFC wagons

= 0.16 for COFC wagons

= 0.12 for other freight wagons

The grade resistance was shown to be:

$$R_g = 98.1\ \theta_g \text{ (N/tonne)}$$

Where θ_g = percentage grade

The curve resistance is given by:

$$R_c = 6988/r \text{ (N/tonne)}$$

Where r = radius of curvature (m)

During a recent study of permanent way maintenance costs the BTE gathered information on curves and grades in

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(1) I. Williams, Train Performance Characteristics - Preliminary Surveys, Unpublished, December 1974.

the New South Wales system. Where the track was curved in the sample of track examined, the radius of curvature had an average value of 470 metres. The sections of track in the sample were curved for about 37 per cent of their length. Where the track was not level it had an average grade of 1.15 per cent and the sections were essentially level for 32 per cent of their length, that is, the track was graded over about 68 per cent of its length.

Other systems operate over terrain which generally requires fewer grades and curves in the track. The percentage of curved, and hilly track in New South Wales would therefore be a reasonable upper limit for use in the rolling resistance calculations. The relationship between percentage curved and percentage graded is assumed to remain constant i.e. the track has significant grades for about twice the length it has curves.

In Annex A it was shown that in the BTE wagon study, the average gross weight of X type wagons was 45.6 tonnes. This gives an average axle load of 11.4 tonnes. Assuming that the average speed on level tangent track is 88 km/h then the contribution to train rolling resistance, R_r, by X type container wagons is:

$$R_r = 6.4 + 129/11.4 + 0.03 \times 88 + \frac{0.16 \times 88 \times 88}{45.6}$$

$$= 47.5 \text{ (N/tonne)}$$

Assume that on curved hilly terrain the average speed is 50 km/h. The resistance, R, on this terrain will be:

$$R = R_r + R_g + R_c \text{ (N/tonne)}$$

Where $R_r = 28.00$ (N/tonne)

$R_g = 98.1 \times 1.15 = 112.82$ (N/tonne)

$R_c = \frac{6986}{470} = 14.87$ (N/tonne)

So that $R = 28.00 + 112.82 + 14.87 = 155.7$ (N/tonne)

As noted, the track is assumed to have significant grades for about twice the length it has curves. However it it reasonable to assume that 50 per cent of the grades are up grades and 50 per cent of the grades are down grades. This means that the proportion of track with significant up grades is about the same as the proportion of track with curves.

The average rolling resistance is therefore given by:

$$R = (1-p)\ 47.54 + p(155.7)$$

$$= 47.54 + 108.15\ p \text{ (N/tonne)}$$

Where p = proportion of track with grades and curves.

Therefore, the average rolling resistance for a 45.6 tonne X type wagon equipped with 3-Piece bogies is estimated to be:

$$R = 45.6\ (47.54 + 108.15p)$$
$$= 2167.8 + 4931.6p\ \text{(N)}$$

On level tangent track, at 88 km/h, a wagon equipped with 2CM bogies has a rolling resistance which is 3.11 N/tonne less than a wagon equipped with 3 Piece bogies (Annex A.2).

On hilly terrain the NSWPTC tests showed that a 2CM bogie equipped wagon had a rolling resistance which was 8.01 N/tonne less than that of a wagon equipped with a 3 Piece bogie.

The rolling resistance of a wagon equipped with 2CM bogies is therefore given by:

$$R = (1-p)\ (47.54 - 3.11) + p(155.69 - 8.01)$$
$$= 44.43 + 103.3p\ \text{(N/tonne)}$$

The average gross weight of a wagon equipped with 2CM bogies will be about 2 tonnes heavier than one equipped with 3-Piece bogies. The total rolling resistance for a wagon equipped with 2CM bogies is therefore given by:

$$R = 47.6\ (44.43 + 103.25p)$$
$$= 2114.9 + 4914.7p\ \text{(N)}$$

The savings in rolling resistance is shown in Table B.1 for various values of the proportion of curved track (p) up to the assumed limit of about 0.4.

It is seen from Table B.1 that the proportion of curved track is not a significant variable considering the magnitude of the resistance savings.

Since locomotive power is equal to the drag times train speed, the power saving, P_s, is given by:

$$P_s = \text{(Resistance Saving) (Average Train Speed) (1/3600) kW}$$

Where Average Train Speed = (88-38p) km/h, p being the proportion of curved and graded track.

Assuming a specific fuel consumption of 0.285 kg/kWh (1) and fuel density of 0.82 Kg/l, the fuel saved by the use of 2CM bogies, S, would be:

$$S = \frac{(0.285\ \text{kg/kWh})\ (P_s/\text{Average Train Speed})}{(0.82\ \text{kg/l})}\ \text{l/km}$$

So that

$$S = 9.654 \times 10^{-5}\ \text{(Resistance Saving) l/km}$$

Given a cost of 3 cents/litre, fuel savings are shown for various values of p in Table B.2.

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(1) ibid, p.21.

TABLE B.1 - ROLLING RESISTANCE AVERAGE GROSS WEIGHT WAGONS [a]

EQUIPPED WITH 3-PIECE AND 2CM BOGIES

Proportion of Curved Track	Rolling Resistance(e)				
	3-Piece(b) bogie	2CM(c) bogie	Saving in Resistance		
			per wagon		per 1000 trailing tonnes(d)
	(N)	(N)	(N)	(%)	(N)
0.00	2167.8	2114.9	52.9	2.44	1163.8
0.10	2661.0	2606.4	54.6	2.05	1201.0
0.20	3154.1	3097.8	56.3	1.82	1238.2
0.30	3647.3	3589.3	58.0	1.62	1275.3
0.40	4140.4	4080.8	59.7	1.46	1312.5

(a) 45.6 tonnes for wagons using 3 Piece bogie; 47.6 tonnes for wagons using 2CM bogie.

(b) $R = 2167.8 + 4931.6p$.

(c) $R = 2114.9 + 4914.7p$.

(d) 22 wagons per train.

(e) Rolling resistance calculations have allowed for increased mass of 2CM bogie and lower operational speeds on curved and graded track compared to level tangent track.

TABLE B.2 - FUEL SAVINGS ARISING FROM USE OF 2CM BOGIE FOR DIFFERENT PROPORTION OF CURVED TRACK

p	Fuel Savings(a) per wagon
	cents/km
0.0	0.0153
0.1	0.0158
0.2	0.0163
0.3	0.0168
0.4	0.0173

(a) Assumes fuel cost of 3 cents/litre.

ANNEX C

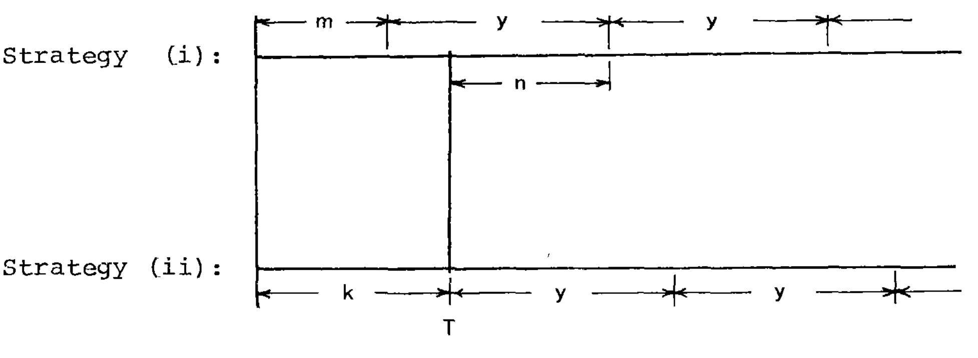
ESTIMATION OF RESIDUALS

An opportunity cost approach was used. The residual value of an asset at any time of its life is defined to be the opportunity cost of not having that asset at that time. The residual value at time T is calculated as the difference between the present values of the cost streams generated by the following strategies:

(i) continued use of the asset in its current use until its optimal replacement, then the use of new assets in perpetuity under an optimal replacement policy;

(ii) replacement of the current asset immediately, then use of new assets in perpetuity under an optimal replacement policy.

The two strategies are depicted graphically:



Where T = time at which residual value is calculated (normally at the end of the evaluation period)

k = length of the evaluation period

y = life of the asset

m = year of capital investment in the asset

n = residual asset life at time T

c = capital cost of investment

i = interest rate

The present value for Strategy (i) at time T is given by:

$$PV1 = \frac{C(1 + i)^{y-n}}{(1 + i)^{y} - 1} \qquad (C.1)$$

The present value for Strategy (ii) at time T is given by:

$$PV2 = \frac{C(1 + i)^{y}}{(1 + i)^{y} - 1} \qquad (C.2)$$

The residual value at time T is then given by:

$$PV2 - PV1 = C\,\frac{(1 + i)^{y} - (1 + i)^{y-n}}{(1+i)^{y} - 1} \qquad (C.3)$$

For the purposes of the evaluation, the present value of the residual at the beginning of the evaluation period is required. This is given by:

$$C \frac{(1 + i)^{y-k} - (1 + i)^{y-n-k}}{(1 + i)^{y} - 1} \qquad (C.4)$$

However: $n + k = m + y$

or: $y - n - k = -m \qquad (C.5)$

Substituting equation (C.5) into (C.4) gives the following expression for the present value of the residual:

$$C \frac{(1 + i)^{y-k} - (1 + i)^{-m}}{(1 + i)^{y} - 1} \qquad (C.6)$$

To be strictly correct the maintenance costs of the asset should also be included in the two strategies. In this case, where the asset is assumed to have a life of 25 years and the evaluation period is 20 years, the present value of the residual is about 9 per cent of the capital costs when a discount rate is 7 per cent. For a 10 per cent discount rate, the present value of the residual is just over 6 per cent of the capital costs. The error in excluding maintenance costs in the residual calculation is therefore small.