INTEGRATED FREIGHT CAR TRUCK DESIGN CONCEPT

Harry Tournay
Transportation Technology Center, Inc.
Pueblo, Colorado, USA

ABSTRACT
The increasing use of wayside detection and improved information on wagon performance has resulted in improved insights into the root causes for poor wagon, bogie, and component performance, particularly the poor performance of wheels, which cost the North American industry more than $800 million per year for wheel replacements. Knowledge of poor wheel performance has also led to improved insight into the root causes for certain rolling contact fatigue phenomena in rails. Many of these wagon/bogie/component and rail phenomena are systemic in nature, relating to vehicle suspensions, brakes, bogie/carbody interface phenomena and wheel/rail contact conditions. Consequently, the conceptual design approach is focused on integrating these functions.

The Association of American Railroads, through their Strategic Research Initiatives Program, has tasked Transportation Technology Center, Inc. (TTCI) to develop improved bogie design concepts for a so-called integrated truck (bogie) as a future standard for the North American wagon fleet.

First, the proposed design concept addresses means to eliminate high impact wheels (HIW), which is seen as the critical element in any design for heavy axle loads into the future. The development of HIW has been directly associated with curving and low rail contact of the lead wheel developing high traction. Then, the traditional requirements for empty wagon hunting stability are addressed, together with those associated with the loaded wagon, an issue of consequence in North America and associated with body instabilities.

Subsequently, the requirements for the body/bogie interface (pivot center and side bearers) are addressed, together with those of an efficient bogie brake rigging to avoid overheating of wheel treads.

An improved bogie design will reduce wheel damage and promote the development of increased axle loads, leading to improved capacities into the future.

INTRODUCTION
The increased use of wayside detection, the emphasis on improved wagon and bogie component performance, as well as the anticipated future demand for increased capacity and performance has placed increasing emphasis on further improving the performance of the three-piece truck, which is the workhorse of the North American freight wagon fleet. Although the three-piece bogie is remarkable in its current excellent performance under high axle load conditions (32.5-tonne axle load) and low maintenance costs, the following performance improvement opportunities have been identified:

Wheel Life
The current annual cost of wheelset replacement in North America is approximately $800 million. Figure 1 shows the main causes for wheel replacement.

Figure 1. Main Causes for Wheel Replacement in North America
Wear is a more desired form for wheel replacement than tread damage (wheel flats, shelling, etc.) because it is predictable, easily measurable and, within established wear limits, does not result in catastrophic failure. Sixty-five percent of all wear-related wheel replacements (18 percent of all wheel replacements) are for high flanges, which is the most desirable of wear modes because it results in the minimum of material removed to restore the profile. Twenty-two percent of wear-related wheel replacements are for thin flanges, a less desirable mode because it invariably results in the most material being removed.

Average wheelset life can vary from less than 300,000 kilometers (km) to above 1.2 million km. Two identified causes for this performance variability are:

- **High impact wheels (HIW).** HIW occur generally in the North American wagon fleet and have been attributed to unreleased handbrakes as well as thermal mechanical shelling (TMS).\(^1\)\(^2\) Unreleased handbrakes are considered an operational issue, to be addressed through improved detection and processes. TMS has been identified as being associated with a combination of overheated wheels and poor vehicle tracking. Both of these phenomena are being addressed through an integrated approach to brake and suspension design.

- **Asymmetric wheel flange wear** has recently been found to substantially reduce wheel life in the high mileage, high productivity coal fleet. A root cause appears to be the action of the brake rigging and brake blocks on the wheel treads, causing them to wear asymmetrically with a consequent degradation in the tracking properties of the wheelsets and bogies and resultant accelerated, asymmetric wheel flange wear. Improved brake rigging and brake block designs are being proposed to resolve this problem.

**Wagon Hunting Stability**

The hunting stability of the three-piece bogie has been substantially improved in recent years by both increasing its warp (lozenge) stiffness through the use of improved friction wedge designs and by increasing the rotational constraint of the bogie to the wagon body through the use of constant contact side bearings as well as, for higher train speeds (greater than 120km/h), the use of bogie rotational dampers. Recently a body instability (termed loaded car hunting) has been experienced on a certain wagon type; loaded car hunting has been associated with a combination of high load and inertia wagon bodies, high wheelset contact conicities, and a breakdown in the warp stiffness of the three-piece truck. The higher contact conicities are thought to be associated with the aggressive action of the brake block on the wheel tread. The breakdown in bogie warp stiffness under high body loads appears to suggest that an alternative means is needed to obtain bogie warp restraint.

**Brake Performance**

The need for improved brake performance has been associated above with TMS, asymmetric wheel flange wear, and loaded wagon hunting. In addition, forces and constraints on the brake block result, on occasion, in the brake blocks wearing in a taper shape as well as, becoming laterally misaligned on the wheel tread and overhanging the tread, overheating the field corner of the tread, heating the flange of the opposing wheel of the wheelset, and resulting in a flange being worn on the block and wear of the brake head (shoe). An improved brake rigging is being proposed to alleviate these problems.

**Maintenance Predictability**

Observed poor performance is invariably associated with outlier performance of the bogies/wagons. An objective of the integrated freight car concept is also to identify and rectify those factors responsible for outlier performance.

A review of the factors listed above and responsible for poor performance suggests that solutions require an integrated design approach and is the subject of this paper.

**Thermal Mechanical Shelling**

TMS has been associated with high tractions on the wheel tread during curving with the wheel contacting the low rail.\(^1\)\(^2\) Contact stresses and associated tractions across the contact patch have been measured above the shakedown limit using an instrumented wheelset and associated with the
generation of two crack bands on the wheel tread (Figure 2). A hypothesis has been developed to suggest why the material between the crack bands breaks out to form HIW.2

![Figure 2. Measured Traction on the Wheel Tread](image)

A preliminary quasi-static curving study has suggested that the primary cause for high tractions on the low rail is the lateral creep force generated as a result of the angle of attack due to the nonradial position of the lead wheelset in the curve (Figure 3).

![Figure 3. Angle of Attack of the Lead Wheelset and the Resulting Lateral Creep Force developed on Low Rail Contact](image)

Current studies and tests are in process to establish the limits for traction levels to avoid crack development on the wheel tread under the prevailing dynamic forces.

Figure 4 shows an example of the dynamic traction force spectrum on the tread in an 800m curve for two different axe box (bearing adapter) constraints. The ratio of normal to traction loads is plotted against contact frequency; since flange contact, or near-flange is made, this spectrum represents that seen on a band of material on the circumference of the wheel. Of particular note:

- Average tractions can be considerably reduced by introducing longitudinal resilience and clearance at the axle box indicated by the term improved suspension.
- Maximum (dynamic) tractions are not reduced appreciably, although their incidence is reduced.
This frequency spectrum can now be used, together with the incidence of curves on a particular route and the wheel diameter, to quantify the probability of a “contact encounter” between an element of material on the circumference of the wheel tread at different traction levels.

Given the incidence of curvature on a typical curved route on the Eastern Seaboard in North America, it is estimated that the number of contact encounters above, 0.28 (a possible shakedown limit given the prevailing axle load) is of the order of 260 cycles/100,000 km. This is in comparison to 22 cycles/100,000km. This contact frequency also needs to be evaluated in relation to the tread wear attributable to the brake blocks.

The problem of evaluating the fatigue spectrum on the wheel tread is thus not trivial and work in this respect continues in 2011 and will be used to determine the optimum axle box (bearing adapter) constraints and clearances to prevent the formation of HIW.

**Asymmetric Wheel Flange Wear**

Asymmetric wheel flange wear has reduced the wheel life on some gondola and hopper wagons in unit train coal service in North America. This is a recent phenomenon associated with wagons built after 2004; wagons of this vintage are generally of lighter tare (aluminum construction), have been fitted with an improved steering (so-called M-976) bogie, and have a slightly increased brake ratio. Figure 5 shows typical increases in wheel replacements due to thin flange. Wheel replacements due to thin flanges have increased from a level at or below 10 percent of all removals to over 50 percent for gondola wagons. A survey reveals that wheelsets replaced for thin flange invariably have one wheel of the wheelset with a flange on minimum thickness while the opposing flange on that wheelset is on maximum thickness.

**Figure 5. Wheel Replacements due to Thin Flange**

Inspection of wagons experiencing asymmetric wheel flange wear show (Figure 6):

- Flange wear on particular wheel positions in a wagon (circled in red in Figure 6)
- These worn flanges are associated with:
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- A lozenged orientation of the brake beams in the bogie
- The orientation of the bogie brake pull rod and reaction link to the body

![Figure 6. Asymmetric Wheel Flange Wear Patterns](image)

Further observations link the asymmetry of the wheel flange wear to asymmetric wheel tread wear (Figure 7). A number of hypotheses have been developed to suggest the root causes for the wear patterns observed.

Hypothesis 1

- The asymmetry of the forces on the bogie brake rigging results in opposing lateral forces on the brake beams.
- These forces, together with the clearances between the rigging and the bogie frame and the “gap” between the brake block and the flange, result in lateral migration of the block on the wheel tread (Figure 8).
- The abrasiveness of the shoe on the wheel tread wears the tread asymmetrically. The bogie loses its tracking ability.
- Asymmetric flange contact and wear results

![Figure 7. Asymmetric Wheel Tread Wear Patterns associated with Asymmetric Wheel Flange Wear](image)

![Figure 8. Asymmetric Wheel Tread Wear Patterns associated with Asymmetric Wheel Flange Wear](image)
This hypothesis goes a long way to explaining the observations in service; however, it does not explain why the phenomenon is prevalent on coal wagons and not other wagons in the North American fleet.

Hypothesis 2
- Asymmetric brake rigging results in an applied moment to the bogie
  - This moment must be either:
    - Reacted at the truck/carbody interface (center plate and constant contact side bearings), or:
    - Result in rotation of the truck under the carbody to generate reactive steering forces at the wheel/rail interface
- A lightweight wagon (empty aluminium coal gondola or hopper cars) may not produce sufficient load on the truck/carbody interface to sustain the moment applied by the brake rigging (Figure 9).

![Figure 9. Brake Rigging Forces on the Bogie Reacted by the Side Bearings](image)

This hypothesis would explain the higher incidence of asymmetric wheel flange wear on coal cars and possibly the better performance of hopper cars because they are heavier than coal gondola cars. A third hypothesis was proposed, which may have merit.

Hypothesis 3
- Rotary tipping (dumping) of all gondola coal wagons and a large number of hopper wagons may result in the brake beams of these wagons to slide laterally and over-ride the edge of the wheel treads on one side of the wagon (Figure 10). This motion may be exacerbated by the adapter pads in the improved truck, which hold the side frames more securely apart, producing a larger effective lateral clearance between beam and side frame.
- Subsequent lateral forces on the brake beams may centralize one beam in the bogie but not the other, resulting in the observed orientation of the brake beams.

![Figure 10. Rotary Tipping of All Gondola Coal Wagons](image)

This hypothesis would explain why one operator of hopper cars, which are never rotary tipped, does not experience any asymmetric wheel flange wear.
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Figure 10. Possible Role of Rotary Tipping on Asymmetric Wheel Flange Wear; causing the Brake Beams to Move Laterally in the Bogie

While the root causes for asymmetric wheel flange wear continue to be investigated to find cheap and effective cures for current bogie designs, it is suggested that future bogie designs incorporate the following features:

- Symmetrically applied forces to the brake rigging
- An asymmetrically shaped brake block that is wider toward the flange of the wheel Figure 11. This would allow the wheel flange to provide lateral guidance to the brake block and flange without introducing brake block material on the field side of the block that might override the field edge of the wheel tread.

Wagon Hunting Stability
Wagon hunting stability is always a concern when increased resilience is introduced at the axle box (bearing adapter) as is being contemplated in order to eliminate HIW.

Of particular concern when addressing hunting stability was the perceived increased contact conicity associated with wheel treads of wagons fitted with newer bogies. A survey indicates contact conicities greater than 0.6 (Figure 12) where traditionally, conicities of the order of 0.2 are expected and for which bogies are traditionally designed.

Further investigation suggests that these high conicities may also be associated with the aggressive action of the brake block on the wheel tread; this time in a symmetric manner:

Figure 13 shows a typical wheel profile with a conicity on revenue track of approximately 0.65. The profile shows accelerated flange wear resulting from two-point contact on flanging on the high rail in curves, which is being addressed with a new wheel profile design. In addition, there is a substantial amount of concentrated wheel tread wear. The region between these two regions of high wear is relatively unworn and is the cause for the resultant high conicity.
Originally, it was thought that the concentrated tread wear of Figure 13 resulted from the improved tracking of the improved steering bogie. However, resulting from the studies of asymmetric wheel flange wear and the role of asymmetric tread wear, it is now considered that the observed high conicities may result from the brake blocks. Figure 14 shows the typical shape of contact of a brake block on the tread as well as the wear shape on the profile of a wheel on a brake dynamometer. The imprint of the block on the wheel tread is apparent.

Recent trends have been for a narrower block which is also tapered; this results in a narrower imprint of the block on the wheel. This and the recent use of more aggressive brake shoes may possibly explain the recent development of higher contact conicities.

It is anticipated that the development of an alternative brake block shape to counter asymmetric wheel flange wear described above will also counter the development of higher contact conicities. This development will be further monitored with the block development and it will be assumed that bogie suspensions will only require controlling hunting for wheels with a maximum conicity of 0.2.
As mentioned in the Introduction, North American railroads have traditionally used a combination of friction wedges in the suspension to provide bogie lozenge (warp) stiffness and bogie rotational damping via constant contact side bearings or bogie rotational dampers (Figure 15). This approach provides adequate stability against hunting in the empty condition with the exception of service speeds greater than approximately 120km/h. In this case, additional bogie lozenge (warp) stiffness has been provided through the introduction of spring planks or cross bracing in conjunction with hydraulic rotational dampers.

The introduction of wagon bodies at higher (32.5-tonne) axle loads for lower density commodities (grain, box cars) has resulted in wagon bodies with appreciably higher yaw/roll moments of inertia. This appears to have resulted in a threshold being reached in loaded wagon hunting. Tests and analysis suggest that loaded wagon hunting is a body instability that results from a combination of:

- High body masses/moments of inertia
- High contact conicities
- Relatively low bogie lozenge (warp) stiffness

The last mentioned parameter appears to result from the first two parameters:

- The high mass body and moments of inertia appear to result in friction saturation of the suspension wedges; observations indicate that whenever the wedges are activated at track discontinuities (at points and crossings and at discontinuities in curves) the warp restraint provided by the wedges breaks down and loaded wagon hunting takes place
- Higher loads and conicities result in higher longitudinal forces to excite the wheelset and to break down the lozenge constraint provided by the wedges (this constraint being sufficient to constrain the wheelset under the forces produced in the tare condition)

Consequently, bogie configurations are being sought that will provide an alternative source of bogie lozenge stiffness, whether this be spring planks, cross bracing, or, in the ultimate, steering gear (bissels, cross anchors). Alternatively, a source of wheelset yaw control, through body-coupled linkages may be sought.

**Brake Performance**

Beyond the need for a laterally symmetrical application of the brake blocks, one of the most important attributes of the bogie brake system is the even application of brake forces in order to evenly heat all wheels within the bogie and not thermally overheat a single wheel. Overheated wheels have been associated with “stuck” bogie brake rigging. Stuck bogie brake rigging has been associated, in turn, with the guidance of the brake beam in the bogie and specifically by the reaction in the brake beam guides in the side frame.
A further identified performance requirement is for even (as against taper) brake block wear; taper wear limits the life of the block and results in wasted friction material. The root cause for taper brake block wear has also been associated with the guidance of block and brake beam and the reaction forces to the bogie and side frame.

A fundamental analysis of the rigging has been undertaken and tests are under way to identify those rigging configurations providing the most even brake forces (Figure 16).

![Static Shoe Force Results](image)

**Figure 16. Comparison of the Effectiveness of Different Rigging Combinations**

**Maintenance Predictability**
A continued effort is being made to understand the root causes for unpredictable maintenance and to identify outlier performance within the current North American wagon fleet. Many of the root causes for outliers have been discussed in this paper, but it is anticipated that further research will reveal more causes.

**CONCLUSIONS**
TTCI, through the Strategic Research Initiatives Program of the AAR, has identified future improved performance requirements for a so-called integrated freight car truck (bogie) for the North American wagon fleet. Improved design concepts have been identified and proposed in a specification that has been presented to the railroad industry, together with invitations to supply bogies for test and evaluation at the Transportation Test Center, Pueblo, Colorado, USA. Interim performance requirements and a specification indicating the test and evaluation process are available. Tests and evaluations will commence during the 2nd quarter 2011 and continue through 2012.

**REFERENCES**
Challenge C: Increasing Freight capacity and services