# Train Marshalling Process at Canadian Pacific

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## Canadian Pacific

### ABSTRACT

Train marshalling requirements were very basic and almost non-existent at the early stages of railroading. As trains got longer, heavier and the types of freight cars became diverse in length, type, capacity, loading patterns and end-of-car cushioning units, plus the advances in high adhesion locomotive technologies and Distributed Power, train marshalling came to the fore front as one of the most important factors for safe train operations. Different track profiles and combinations of heavy ascending or descending grades with high degree of curvature raised the necessity to consider different train marshalling techniques for different train types, those being uniform bulk, uniform Intermodal or mixed manifest trains. We can quickly appreciate how complex the train marshalling matrix could become, when all of these different factors begin to interact. For these varieties of conditions, simple manual train marshalling verifications would become very complex, cumbersome and extremely time consuming, and almost impossible to validate. These reasons prompted Canadian Pacific (CP) to develop its own unique train marshalling process and tools since 2003 and the project evolved over the next ten years into a complete train marshalling process called TrAM (Train Area Marshalling). Every train, regardless of its length, tonnage and destination gets screened through this process to ensure compliance with all marshalling requirements before it takes the Main Line. This paper will discuss the evolution of TrAM, including all the marshalling parameters that are deemed important for safe train operations. It will present the fundamentals of Train Dynamics and their importance and impact on proper train marshalling techniques.

### INTRODUCTION

The general term described as “Train Dynamics” is the understanding of the dynamic motion and forces that result from different train handling, train make-up, negotiation of various grade and curvature combinations, which influence the interaction of vehicles coupled in a train. Train dynamics must be well understood and considered for the safe movement of trains. Train dynamics got complicated with the introduction of new high-horsepower locomotives, and the introduction of various types of car designs, resulting in combination of various car lengths, tonnages and cushion-drawbar equipped cars. Thirty years ago, trains were much simple, consisting of mainly uniform car lengths, with similar tonnage capacities and general characteristics.
Because of the numerous track profiles (ascending, descending, undulating, coupled with sharp curves) that a train encounters on a single run, coupled with the infinite train consist combinations, it is more common that at certain times, the wrong parameters may align, accentuating the probability of impending derailment potential, even under proper train handling conditions. In-train forces, influencing the complex behavior of freight cars under four different conditions of motion (vertical, lateral, rotational around vertical & horizontal axis), further complicated by varying track conditions, result in very complex dynamic interaction. .

### IN-TRAIN FORCES

Understanding and evaluating in-train forces is one of the basic requirements of Train Dynamics. Their interpretation translates into proper train marshalling and the detail knowledge of how they affect train safety and derailment prevention. In-train forces consist of three distinct parameters, which should be kept low and at bay, in order to minimize lading damage, equipment failures and ultimately, derailment prevention. These three types of forces are categorized as follows:

**Longitudinal Forces** – resulting from Locomotive Throttle modulations, Train Resistance forces (Grade, curve and rolling resistance, acceleration/deceleration of train, Dynamic Braking (DB) modulations, and (DP) locomotive (Distributed-Power) placement. They are mainly divided into Draft (run-out) and Buff (run-in) forces.

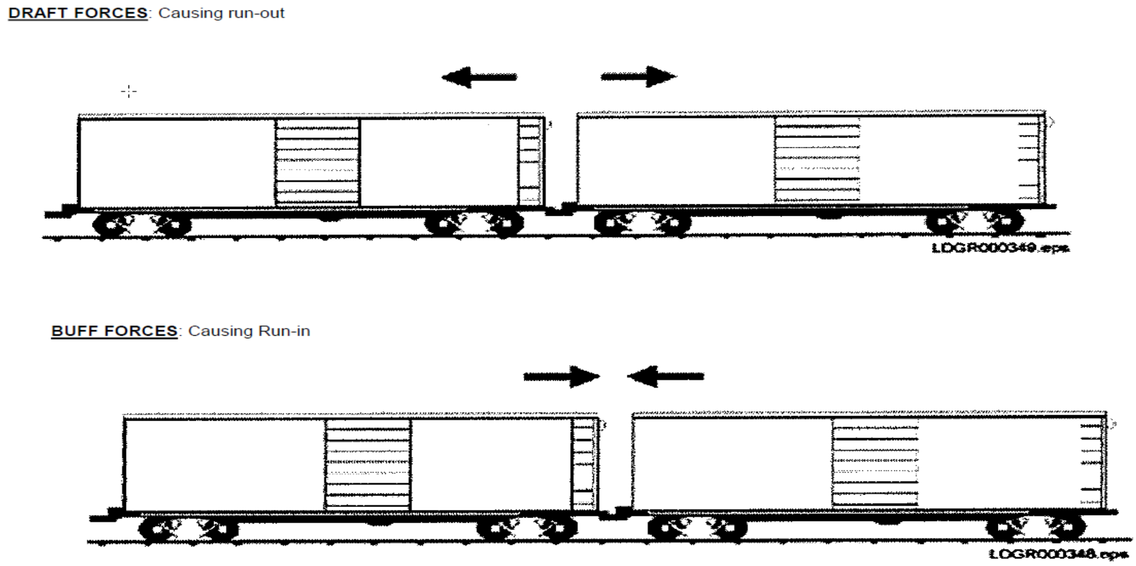



***Figure 1: Longitudinal In-Train Forces***

Excessive Draft and Buff forces are to be avoided, in order to prevent what are two undesired conditions of ***Sting-lining*** and ***Jack-knifing***. Sting-lining is the condition of high draft forces on the head-end of train (drawbar forces) which could potentially pull out lightly-loaded or empty cars marshalled on the head-end of train, during sharp curve negotiation. While jack-knifing is the result of excessive Buff forces lifting a lightly-loaded or empty car and pushing a string of such light cars over the high rail.

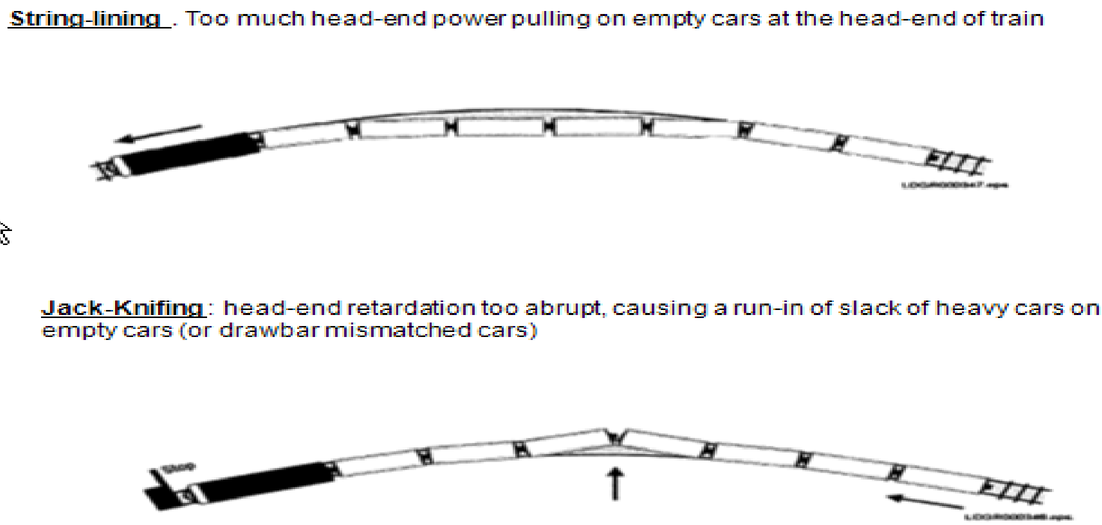



***Figure 2: Sting-lining and Jack-knifing Conditions***

**Slack Action** – these are sudden/instantaneous in-train forces, resulting from changes in steady-state draft/buff conditions. Steady-state forces could instantaneously change due to variations in grade and curve, changes in locomotive throttle/DB, train air brake application and release, train acceleration/deceleration. Slack action results simply in different velocity of vehicle in different parts of the train.

**Lateral Forces** – are a component of longitudinal forces (draft & buff). They are caused primarily by excessive coupler alignment between two adjacent cars, as well as result from curving of wheels, thus generating flanging forces between wheel flange and rail head.

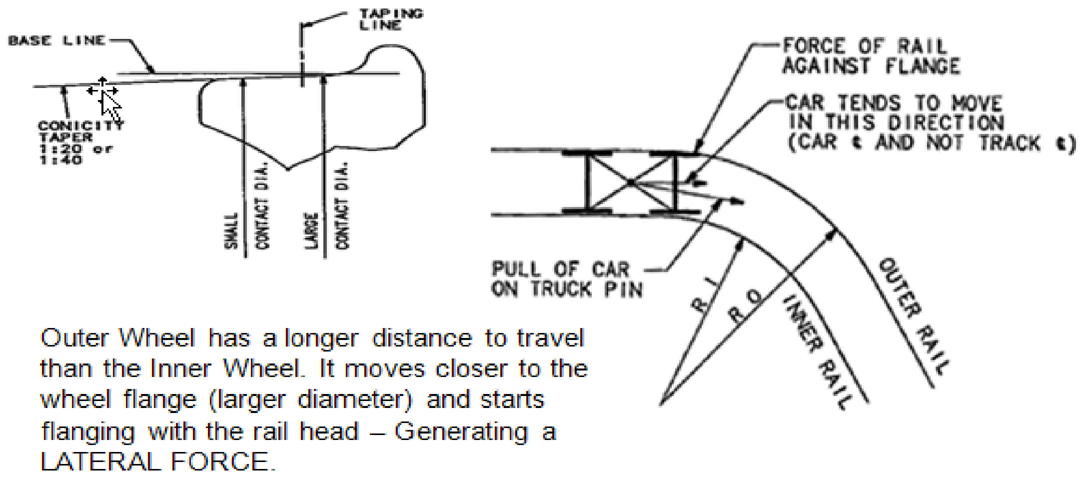



***Figure 3: Lateral Forces on Curves***

Vehicles negotiating curved track will generate lateral forces due to lateral shifting of wheelsets to high rail side (flanging). As indicated in Figure 3, the outer wheel has a longer distance to travel, compared to the inner wheel on the inner rail. Sharper curves have greater differences between outer and inner rail lengths As both wheels on the vehicle axle are not independently-rotating, the only manner which the wheel will “compensate” is by moving closer to its flange, to let the wheel roll on its larger diameter to cover the longer outer rail distance with the same rotation. This is the main reason why wheel treads have a tapered profile. The tapered profile can only compensate for very small curves (up to 2 degrees) above which flanging between wheel and rail will occur, thus generating lateral forces.

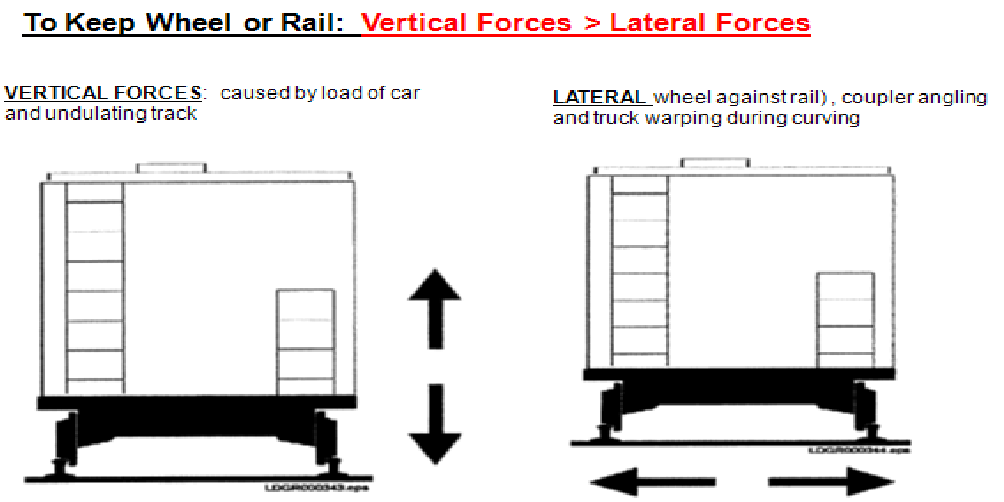
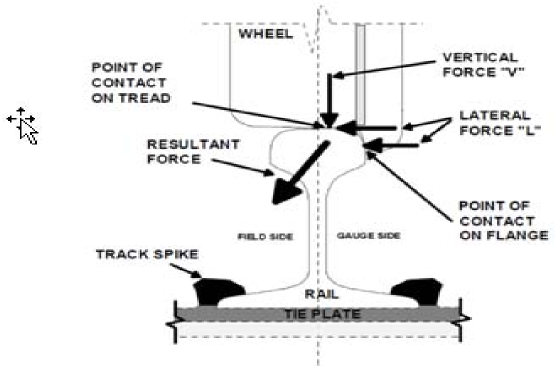



***Figure 4: Lateral & Vertical wheel/rail forces***

A train traveling on tangent and flat track will generate in-train forces mainly as result of Throttle or Dynamic Brake modulations and air brake applications and releases. On long ascending grades, the train will be "stretched" and generate Draft forces. The magnitude of this draft force is based on train trailing tonnage, locomotive consist adhesion, ascending grade, degree of curvature and train rolling resistance. Similarly, on long descending grades, the train will be "bunched" and generate what is called Buff forces. The magnitude of this Buff force is again based on, locomotive Dynamic Brake retardation, train trailing tonnage, and descending grade. In the absence of any track curvature, these Buff or Draft forces will not generate any significant amounts of Lateral force at the wheel/rail interface. Wheels will roll on the rail without any major contact with the flanges (except truck hunting). When Lateral forces are considerably high in magnitude, they can counterbalance the vertical loads on the wheels and either push the wheel flange up against the rail head (wheel climb), or lift the wheel, or spread the rail gauge. So, it is very critical from Train Dynamics perspective to keep control of the relationship between lateral and vertical forces. The Lateral/Vertical or L/V Ratio must be considered at all times for proper and safe train operation. The American Association of Railroads (AAR), through various field tests and derailment investigations, has determined the following threshold limits for L/V ratios:

- L/V > 0.82 (wheel lift impending)
- L/V > 0.75 (wheel may climb worn rail)
- L/V > 0.64 (poorly restraint rail may overturn)




Absolutely critical not to have Lateral Force above 80% of Vertical force,

or L/V < 0.82 for safe conditions

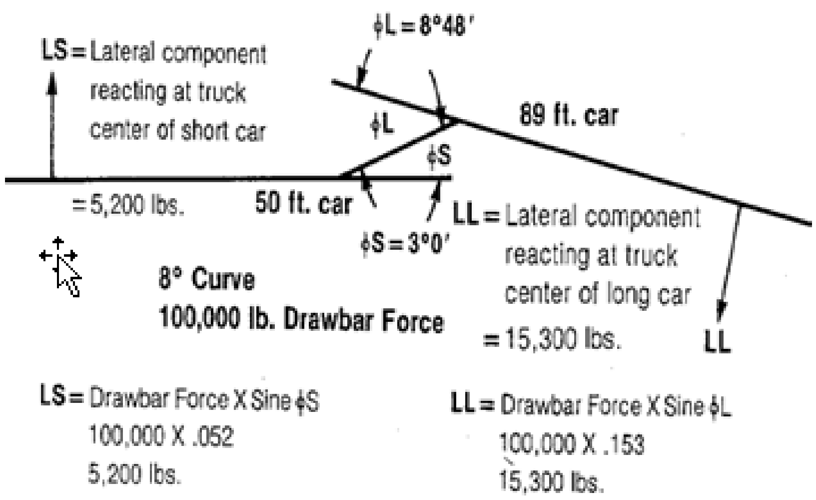
High Lateral Force will push the wheel flange up against the rail and could lift it up when insufficient Vertical Force exists to hold it down.

Wheel lift and derailment will occur.

***Figure 5: Critical L/V Ratio***

**Coupler Angularity -** On curves, coupler angularity combined with drawbar forces will produce a lateral force, which will act at the centre of each freight car truck negotiating the curve, and is directly proportional to the coupler angle and the amount of in-train drawbar force. When coupled cars are negotiating a curve, the greatest coupler angle will occur when long cars are coupled to shorter cars (long shank couplers coupled to short shank couplers). Therefore, this lateral force, generated by coupler angularity and drawbar force is equal to:

*LS = Drawbar force x sine(coupler angle)* *(1)*




The Lateral force generated by coupling angle is <u>**in addition**</u> to the lateral force resulting from the flanging of the wheel with rail on a curve.

It is important to keep cars with equivalent lengths coupled together and not mix short/long cars in train

Two cars of different lengths (with different coupler lengths) negotiating an 8 degree curve with a drawbar force of 100,000 lbs.

The car with the longer coupler will generate a higher LATERAL force due to the larger angle the coupler would take on the curve.

In this case, it will result in a combined lateral force of 15,300 lbs. at the leading truck, **<u>OR AN ADDITIONAL 3,800 LBS OF LATERAL FORCE AT EACH WHEEL</u>**.

***Figure 6: Coupler Angularity Generating Lateral Forces***

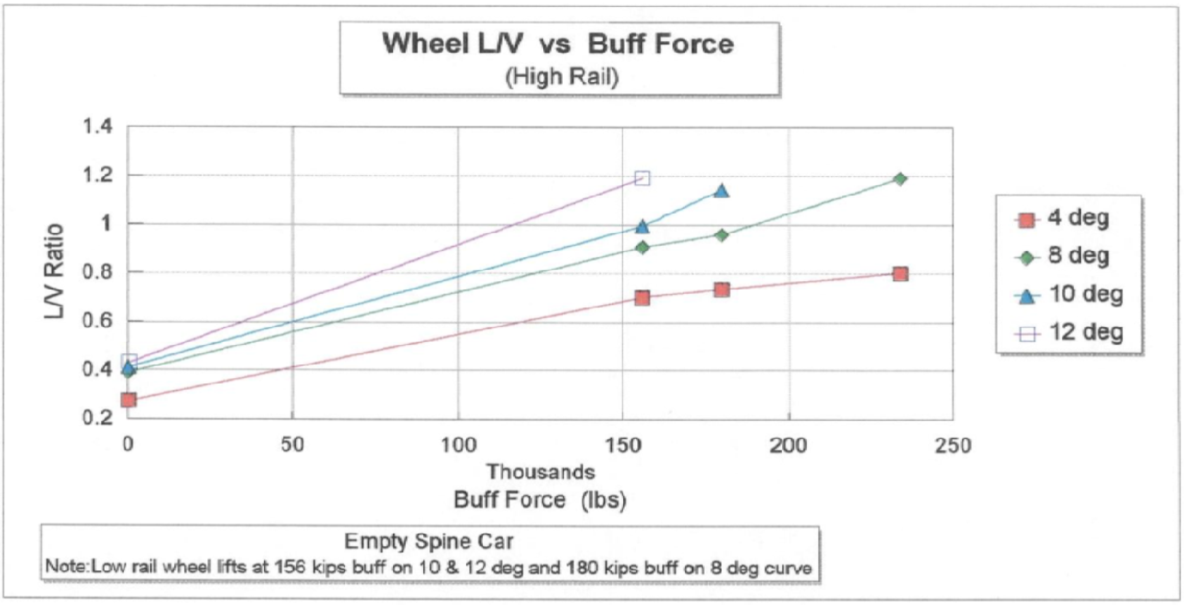



***Figure 7: L/V Ratio for an empty car on curved track***

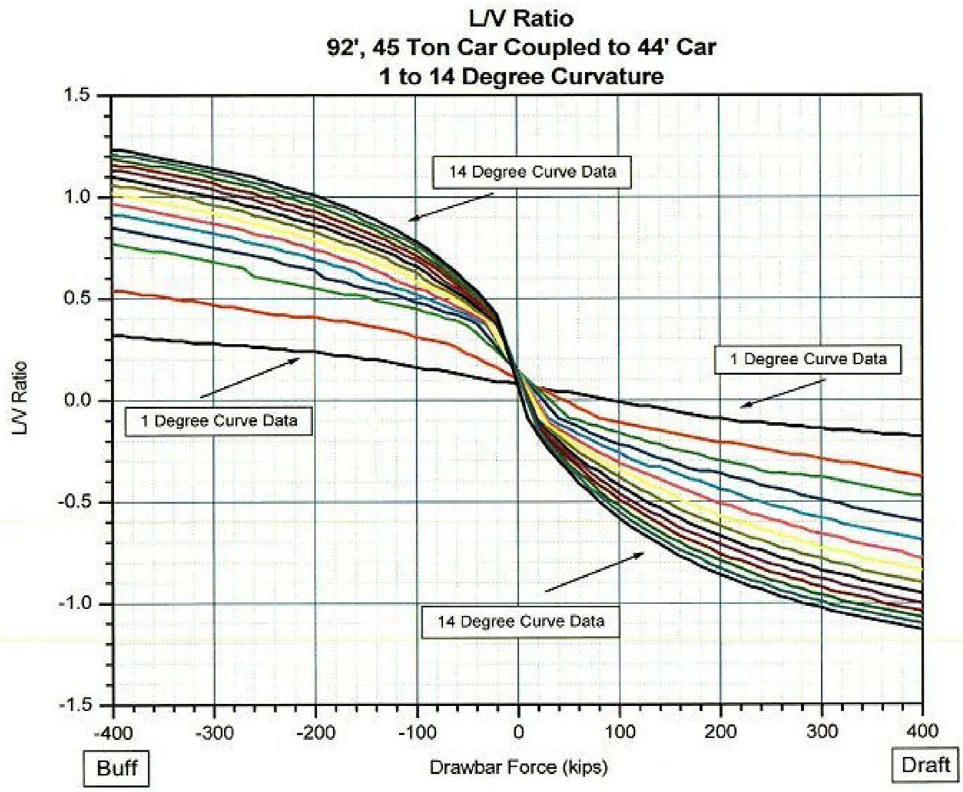



***Figure 8: L/V Ratio for long/short car combination on curved track (Source: Rail Sciences Inc.)***

As can be seen from Figures 7 and 8, L/V ratios will fast approach the critical 0.82 (or 1) level for an empty car on curves above 4 degrees. Long/short car combinations, even though partially-loaded, will reach L/V ratio of 1.0 when draft forces approach 300,000 lbs. and buff forces get to 200,000 lbs.

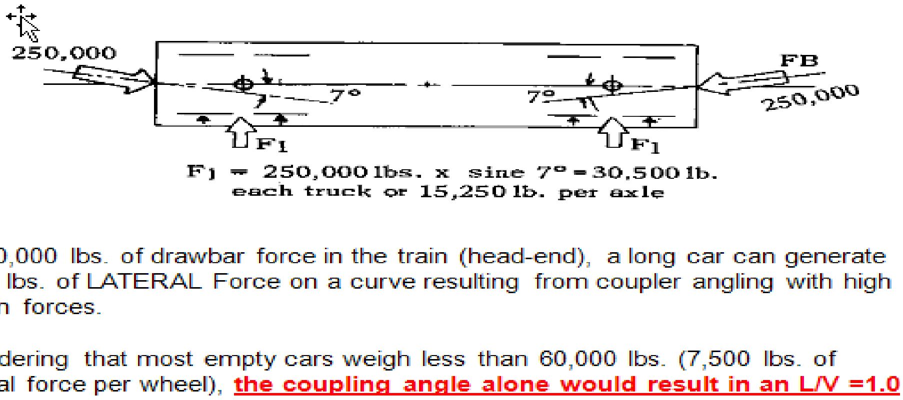



***Figure 9: Negative Effect of Buff Forces on Coupler Angularity***

Figure 9 shows how Buff forces can generate high lateral forces when in presence of high coupling angles between adjacent cars. This is the main reason behind having a lower safe threshold of 200,000 lbs. for Buff forces, as compared to 300,000 lbs. for maximum Draft forces.

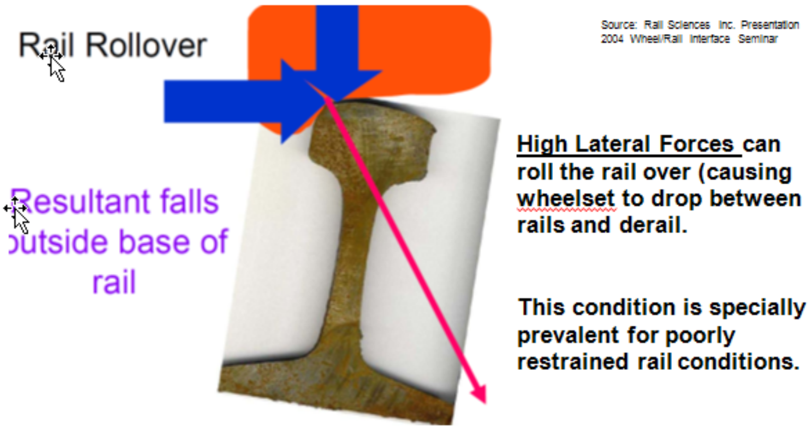



***Figure 10: Effect of High Lateral Forces on Rail Roll-Over (Source: Rail Sciences Inc.)***

When a series of cars are exerting high lateral forces, poorly restrained rail will have a tendency to roll-over, causing wide gauge condition and drop the leading wheel set between rails. Increased lateral force L will have the Resultant Force falling outside of the tie plate (vertical force being unchanged), generating a rail roll-over condition. The lateral load “L” is applied at a height “H” above the base of the rail and the vertical wheel load “V” is applied at a distance “B” from the field side corner. This relationship of L/V is equivalent to the B/H ratio of the rail. Rail roll over will occur when L/V > B/H. High rail gauge face wear will shift the V load position and reduce the B dimension, and reduce the B/H ratio. Tie plate cutting will increase the H dimension and reduce the B dimension (as cant increases), resulting in lower B/H ratio.

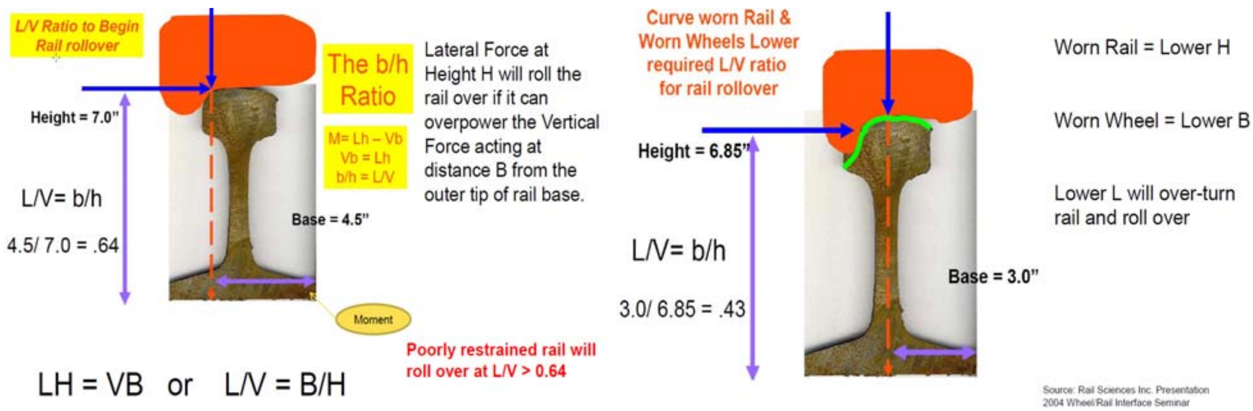



***Figure 11: L/V Ratio Relationship to B/H Ratio (Source: Rail Sciences Inc.)***

## TRAIN MARSHALLING RULES AT CANADIAN PACIFIC

Due to our challenging track profiles, such as 2.4% ascending and descending grades in Western Canada, alongside 10-12 degree curves on the main-line, coupled with pronounced 0.75% undulating track in Northern Ontario and in U.S. West, train marshalling was always given a serious consideration at CP. Trains were marshalled for the most severe track conditions and were set up for the extreme train make-ups, until 2002, where a completely new approach was undertaken to change the all-encompassing marshalling rules to become more Territory-specific, as well as introduce frequent reliance on Distributed Power. For this reason, a cross-functional team was formed between Service Design, Mechanical and Train Operations (Regulatory) Groups to undertake a "blank sheet" approach to train marshalling at CP. The project was a joint effort between CP and Rail Sciences Inc. (RSI). The result was new/fresh train Marshalling Rules which were territory/area specific and called TrAM (Train Area Marshalling Rules). TrAM was first introduced across CP on December 15, 2003 and in the US Operations on August 1, 2004. The need for newer marshaling rules came about as a result of changes in traffic mix, with more intermodal traffic than previously handled. Changes in car types, longer cars (cars over 65 feet in length), heavier cars ( increase in train density) and newer car types ( double-stack cars, spine cars) as well as an increased number of cars with end of car cushioning (EOC) units, such as center-beams, high capacity box cars, coil cars and multi-levels, generated the need for a comprehensive review of marshaling rules.

TrAM is a comprehensive set of train marshalling rules and supporting computer tools designed to permit the efficient use of Distributed Power (DP) in as many trains as possible beyond its traditional use in bulk trains. TrAM also applies marshalling restrictions in a territory-specific manner to avoid restrictive marshalling rules where they are not required. CP's train designs further evolved to longer and heavier trains, which required the use of DP in more than one location in the train (multiple Remotes). This triggered the design, development and implementation of an enhanced version of TrAM (TrAM 2) which got implemented in July 2009. TrAM 2 was building on over 5 years of solid experience and train marshaling knowledge. The introduction of Multiple Distributed Power Train models has enabled CP to extend the application of DP from 7000 ft. on bulk trains to 14,000 ft. on Intermodal DP Multiple-Remote trains. The process is based on Science, Simulations and Field testing to validate the long train concepts.

## LATERAL FORCE DETECTORS

Other than train simulations and field testing, starting in 2007, CP invested in 8 Lateral Force detector sites, developed by Kelsan Technologies. These sites have been instrumental to our long train strategy by measuring the forces that different train configurations exerted on the track infrastructure. By understanding these forces and their magnitudes, we have achieved long, distributed power train designs that are actually improving operational safety while achieving productivity. Lateral Force sites measure the magnitude of lateral forces with each train passing, obtaining thousands of train records, and giving enough evidence to show that longer trains, powered appropriately (distributed power), can be much more productive and much less destructive and safer than shorter conventional trains. These L/V detectors produced a "gold-mine" of data to confidently implement more diverse long trains designs.

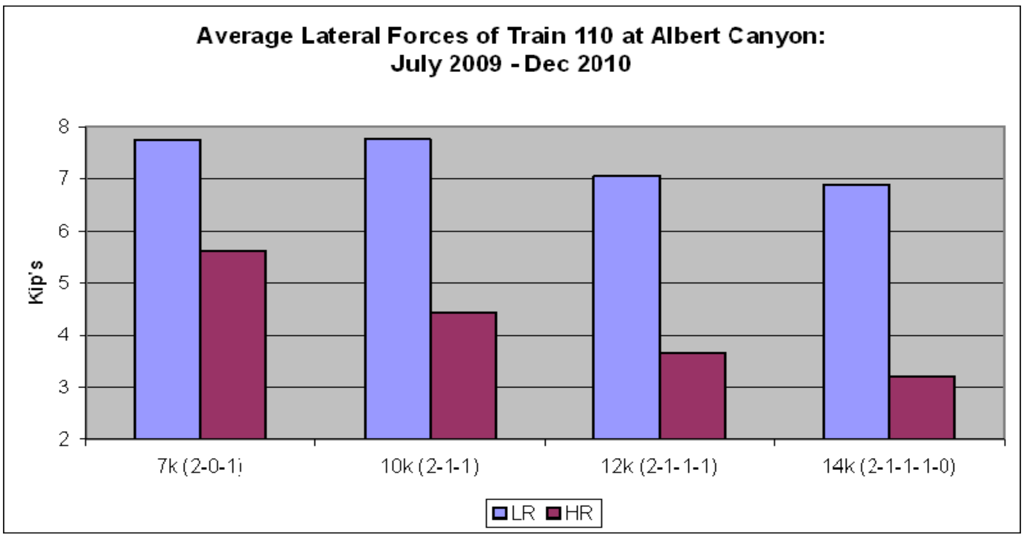
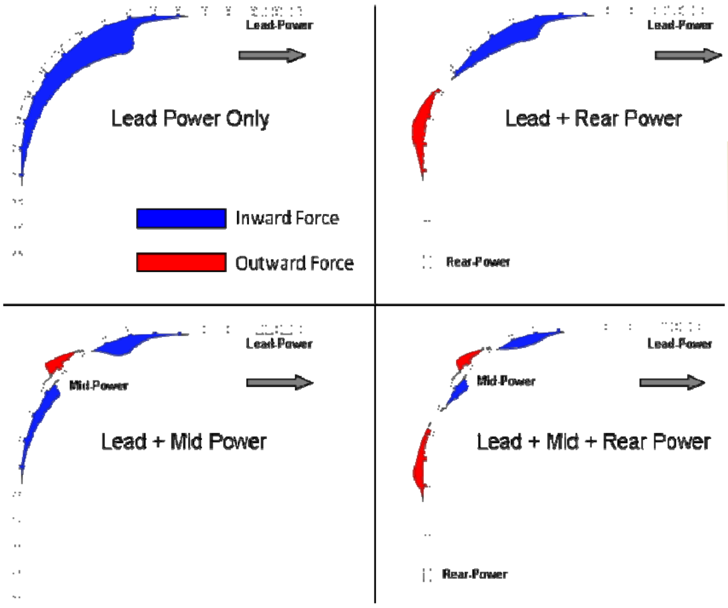
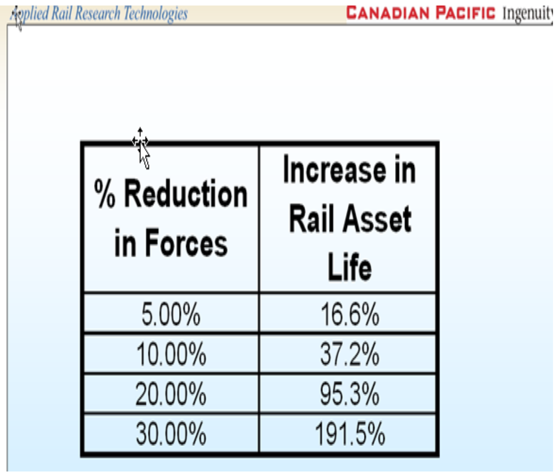



***Figure 12: Lateral Force Detector Data From Albert Canyon Site***

One such Lateral Force detector site is situated on the Mountain Subdivision in British Columbia, on the 2.4% ascending grade, on a 5 degree curve. Multiple passes of various train designs enabled us to clearly differentiate that the longer trains, set up with Multiple Remote locomotives, produced lower lateral forces for 14,000 ft. Intermodal trains, compared to single-remote 7,000 ft. trains. Figure 12 shows the details.

As indicated by Applied Rail Research Technologies (ARRT) Group, Figure 13 shows how a multiple Remote locomotive train design drastically reduces the lateral forces on the track, saving valuable maintenance dollars annually set aside for track maintenance purposes. ARRT research also indicates that a mere 10% reduction in lateral forces on track, extrapolates exponentially to an increase in rail asset life of as much as 37%.




| % Reduction in Forces | Increase in Rail Asset Life |
|---|---|
| 5.00% | 16.6% |
| 10.00% | 37.2% |
| 20.00% | 95.3% |
| 30.00% | 191.5% |

***Figure 13: Multiple-Remote Train make-up Benefits (Source: Applied Rail Research Technologies)***

This wayside lateral force L/V information gave rise to extended train lengths and trailing tonnages for coal, potash and Intermodal train operations.

**Potash Train Progress**


***Figure 14: Potash Train Developments***

Potash train make-up at CP has registered productivity gains up to 37% since 2008. The multiple-Remote power configuration reliably exceeded traditional haulage, year-round, due to superior locomotive adhesion footprint throughout the trains. Lateral forces for such a train design are actually lower than a single-remote 112-car grain train.

### Coal Train Progress

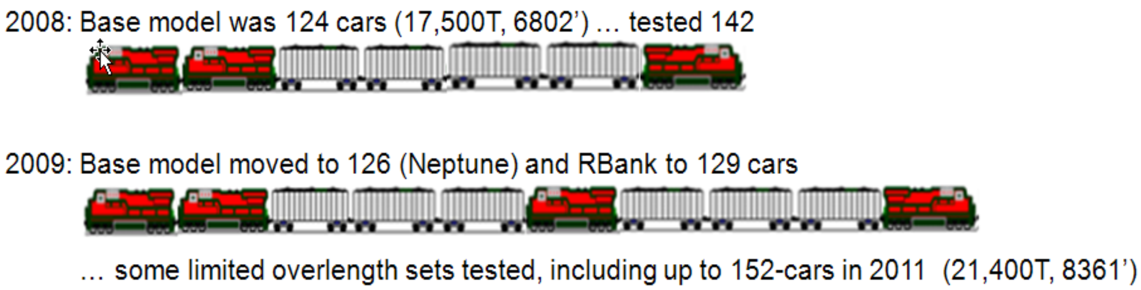



***Figure 15: Coal Train Developments***

Highlights for coal train service improvements have indicated a 152-car proven reliable year-round model, fully utilizing 4-locomotive haulage capacity and registering productivity gains of 23% since 2008.

### Intermodal Train Progress

Similar to bulk trains, Intermodal trains began benefiting from the utilization of Distributed Power, adopting TrAM rules. They evolved in length and DP set up since their concept was modular and easily adaptable to destination traffic requirements. A long 14,000 ft. train became a series of short 4,500 train sections coupled together by locomotives distributed throughout the train. To year-end 2010, over 500 transcontinental intermodal trains have operated in multiple-remote locomotive configurations. Field tests completed in Kenora, ON. enabled CP to safely extend the maximum distance between the lead locomotive and the farthest remote locomotive to up to 14,000 feet. The multiple-remote set-up kept in-train forces (buff and draft) within acceptable limits, and resulted in reduced forces, compared to conventional (head-end power only) trains or trains with just one remote locomotive configuration. Multiple-Remote set up also reduced the lateral forces to acceptable levels for some very light cars (empty stack cars on ascending grades around curved track). Finally, the power distribution concept dramatically extended rail asset life.

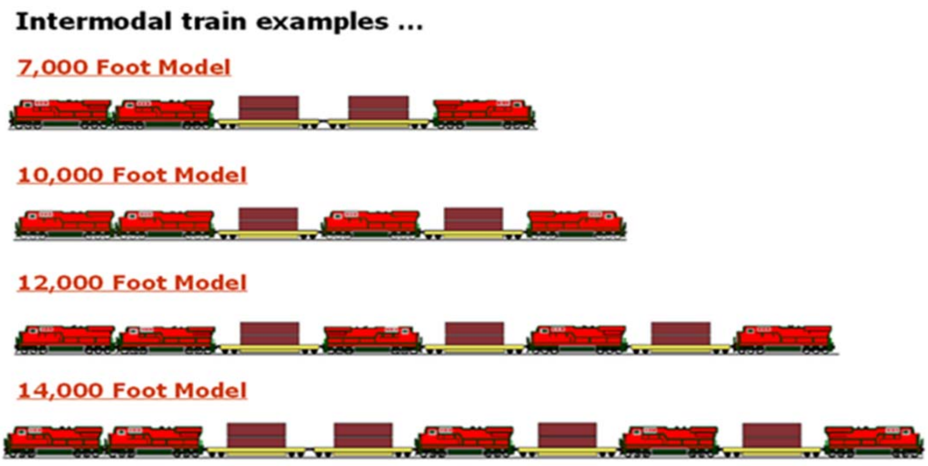



***Figure 16: Intermodal Train Development (Source - 2011 CP Health & Safety Conference)***

### TrAM (TRAIN AREA MARSHALLING) - WHAT IT IS AND WHAT IT DOES

In the early stages of TrAM development, it quickly became obvious that "tweaking" of existing marshalling rules was not going to bring the desired results. The decision was made to go back to basics and build up new marshalling instructions from a fresh start. The Cross-functional team was able to bring best practices of other Class I Railroads to the table. All agreed that the "physics" of train marshalling was relatively straightforward (take care of the excessive in-train forces and high L/V ratio) but the application to real train operation wa very complex, as there were a variety of track profiles, vehicle types and train configurations that needed to be taken into consideration. Prior to TrAM, CP's train marshalling rules took into account only the extreme conditions (track and train) and applied the same rules across the entire network,. The primary considerations for the rules designed to keep in-train buff and draft forces to acceptable levels (L/V ratio of 0.82 or lower) under a normal range of train handling and operating conditions, remained unchanged, however, they became territory-specific and applied differently based on the severity of track profile, train make-up and vehicle characteristics. For that exact reason, the CP network was divided into 5 "Areas" (Area 1 through Area 5) for the purposes of train marshalling. The division of the network was based on track profile, including characteristics such as grade, curvature, and undulations. While the principles of train marshalling for each area were similar, the train weight at which various restrictions applied did differ by Area. For example, Area 1 is the least restrictive, while Area 5 is considered the most restrictive. Typical physical characteristics of each Area are shown in the following table.

| Area | Typical most extreme Physical Characteristics in Area |
|---|---|
| 1 | 1.35% ascending grades, with 5 degree curves<br>1.26 descending grades, with 5 degree curves |
| 2 | 0.75% ascending and descending grades (undulating), with 10 degree curves |
| 3 | 1.3% ascending grades, with 6 degree curves<br>1.7% descending grades, with 11 degree curves |
| 4 | 1.3% ascending grades (undulating), with 8 degree curves<br>1.0% descending grades (undulating), with 8 degree curves |
| 5 | 2.3% ascending grades, with 11 degree curves<br>1.7% descending grades, with 11 degree curves |

General train marshaling rules state that light cars cannot handle high trailing tonnage because of string-lining and jack-knifing issues. Similarly, lightly-loaded articulated Intermodal cars (spine & double-stack) handle poorly in high curvature. There are several incidences where empty or lightly-loaded long cars (over 65 feet in length) would generate high coupler angles, resulting in high L/V ratios, especially when coupled to short cars.. For these exact reasons, here are the following sets of requirements that must all be taken into consideration when devising train marshaling rules:

**Trailing Car Tonnage** – Applies mainly to Mixed trains. On a Mixed, conventional train, the trailing car tonnage is the total weight of all the other cars following that car in the train. The trailing car tonnage of cars located behind the remote locomotive consist is determined in the same manner as it is for conventional trains. Trailing tonnage restrictions are applicable to generally light/empty cars (spine or double stack cars), as well as long cars (above 65 feet). On such cars, buff and draft forces need to be carefully considered, in order not to cause severe run-ins/outs and string-lining/jack-knifing issues. There are separate trailing tonnage requirements in each TrAM area for the same car, as an empty car could accommodate higher trailing tonnage in a less restrictive Area (such as Area 1). Trailing Car Tonnage check is important to prevents derailments caused by excessive L/V ratios.

**Threshold Tonnage –** Maximum train tonnage that can be handled without the possibility of causing a trailing car tonnage violation. Threshold tonnage applies to Mixed trains and differs by TrAM area.

**Draft forces –** must be considered in order to evaluate the maximum draft forces behind each locomotive position in the train. The system must flag those locations in train where maximum allowable draft forces are exceeded. Maximum draft force checks must be done in order to prevent train separations (broken knuckle, broken drawbar) caused by excessive draft forces, as well as excessive forces on the track structure. Due to the superior adhesion capabilities of modern AC locomotives, the maximum number of driving axles must always be considered in order not to exceed strength capabilities of vehicles and track.

**Buff forces** – must be calculated for positions ahead of each remote locomotive in train. There must be alerts in place to flag those locations in train where maximum allowable buff forces are exceeded, for reasons to prevent excessive forces on the track and prevent derailments caused by high buff forces acting on very light cars ahead of heavier cars (jack-knifing derailments).


***Figure 17 – Draft and Buff Forces***

When placing multiple remote locomotives in a train, the total train tonnage would be divided between each locomotive grouping. Depending on the weight/tonnage of each section of train between the locomotive groupings, the locomotives can be generating draft, buff or a combination of draft/buff forces. In order not to exceed the AAR/Industry standards for maximum Draft and Buff forces, train section tonnages and Remote locomotive placements must be done such that at no location in the train, the maximum Draft force would exceed the haulage capacity of 2 AC locomotives and the maximum Buff force should not exceed the haulage capacity of 1 AC locomotive.

**Remote Zone –** this calculation reviews the weight of a group of cars ahead of each remote locomotive position in a mixed train. The number of the group of cars depends on number of remote locomotives at that location. In order to avoid excessive buff forces on empty/lightly-loaded cars, the Remote Zone must meet minimum weight requirements for this position in the train. This check is essential in preventing derailments caused by buff forces acting on very light cars immediately ahead of the remote locomotive(s) (jackknifing derailments). The Remote Zone is the most restrictive portion of a Mixed DP Train. It is created to "cushion out" the in-train forces generated by the remote locomotive consist. The Remote Zone consists of 5 cars/platforms for one Remote Locomotive and 10 cars/platforms for two Remote locomotives coupled together.


***Figure 18 – Remote Zone***

**Maximum train length to last remote locomotive** – this distance must be calculated for each train length to its last remote locomotive, and flag trains which exceed the maximum distance. The placement of locomotives on a Distributed Power train is important to ensures that in situations of loss of radio communication between the controlling locomotive and the last remote locomotive, straight-away brake pipe reduction will cause the remote locomotive to return to idle, and prevent pushing excessively on a string of cars immediately ahead of the Remote locomotive(s). Given the significant increase in train lengths and weights, maximum distance between locomotives has become critical to manage the reliability of brake pipe signal propagation.

**Dynamic brakes** – Existing Dynamic Brake Rules continue to apply for conventional trains (must not exceed 200,000 lbs. of DB retarding force or a DB Factor of 20). In a train with Distributed Power, considerations must be given such that the maximum allowable dynamic brake that the locomotive engineer may use ensures that the additive effect of dynamic brakes between sections of the train does not cause the retarding force to exceed 200,000 lbs. anywhere in the train. The main reason for this check is to prevent excessive forces on the track structure, and excessive buff forces on vehicles. With multiple remote locomotives, DB effort can be additive between locomotive consists, if there is not sufficient tonnage between them, thus exceeding the maximum DB factor of 20. Instead of isolating DB on units when there is excessive DB retarding force anywhere in the train, we can establish a reduced DB setting that will ensure that 200,000 lbs. retarding force is not exceeded anywhere in the train. The system can then prompt the Locomotive Engineer not to exceed that particular DB setting.

**Distributed Power** – Operation of trains with Distributed Power provides a number of benefits from significantly reducing the in-train draft and buff forces, to enhancing brake signal propagation. Distributing the traction forces from being all grouped at head-end to various locations in the train enables for higher train tonnage capabilities without exceeding drawbar capacities. This power placement also reduces forces on track structure, by not concentrating all the tractive effort & DB on head-end of the train Air brake application and release commands are repeated at all Remotes distributed throughout the train, enabling quicker brake signal propagation and reduced in-train slack action and run-in/out forces. As a result, stopping distances are reduced by quicker propagation of brake signal. This also enables for improved train handling and better control of acceleration and deceleration, potentially Improving fuel consumption. However, other variables now become important factors to consider, such as the correct combination of Lead and Remote consist combinations, the maximum distances between locomotive consists, the requirements to reduce or cut out Dynamic brakes on certain number of locomotives (not to exceed maximum DB Factor of 20), to Remote Zone requirements and ensuring that minimum percentage of train weight is present in each train section.

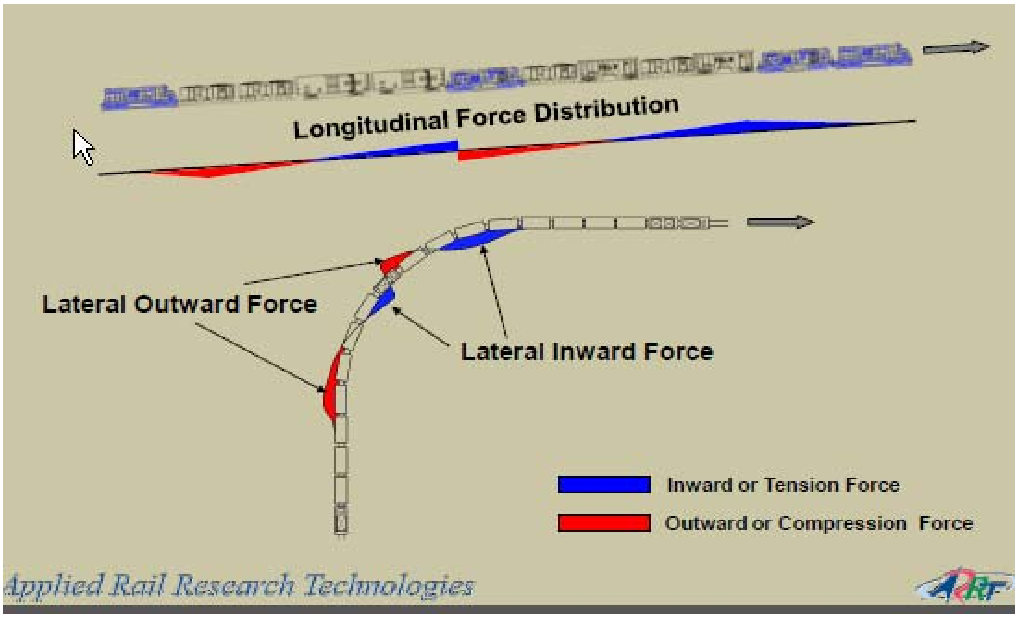



***Figure 19: Benefits of Distributed Power on in-train Forces (Source: Applied Rail Research Tech.)***

**Long Car & Short Car Combinations** - For long cars (over 65 feet), the length of the adjoining car or platform needs to be considered in order to arrive at a "car length factor" that will be used when determining the maximum trailing tonnage for that car combination. "Car length factor" is defined as the greater of the two length differences between one car or platform and the adjoining cars or platforms. String of cars in uniform lengths could tolerate a higher amount of trailing tonnages, while cars with high “Car Length Factor” (large differences in lengths for adjacent cars) would only be capable of handling lower trailing tonnages, due to their coupler misalignments and the resulting higher lateral forces that would be generated at the truck centers.

**Ascending Grade Weight Zone –** As train tonnage increases, surpassing the Threshold tonnage, coupled to conditions of high number of driving axles on the head-end (high Adhesion locomotives), it is essential to set up a train marshaling rule that would require the head-end 10 to 15 cars to be loaded to a certain weight, in order to avoid lightly loaded wheels (low vertical forces) from lifting from the rail in the presence of high lateral forces on curves, or avoid string-lining to occur.

**Cushion Drawbars** - In the past, trains were handling a lot less of these cars. As trains became heavier, unrestricted cushioned drawbar marshaling became an issue under certain emergency train handling situations. There are numerous industry examples of derailments in which cushioned drawbars were a contributing factor. Train marshaling rules must review train make-up based on number of cars with cushioned drawbars in train, and where they are located in the train relative to cars without cushioned drawbars. Cushion drawbar rules are important to prevent derailments and lading damage due to excessive in-train buff and draft forces caused by added slack action generated by multiple cars with cushioning units coupled together. Track locations with undulating track are particularly sensitive tor such train make-ups as the natural lay of the undulating track can by itself generate undesired slack action even under proper train handling conditions. Simulations can show that as trains get longer and heavier, increased slack action and the size of impacts generated by sections of non-CD cars on CD cars can create undesirable in-train forces in certain areas of undulating track. Whenever such undesired combinations of cushion drawbar cars cannot be avoided on a train, special considerations must be given to enforce speed restrictions as simple means of controlling slack action. The TOES simulations that follow indicate that the number of cushion drawbar cars and their placement in trains have major impact and influence on the magnitude of in-train forces generated during a train stop or retardation. Consider Figure 20, for a section of undulating track on CP’s Northern Ontario network, where trains with varying number of cushion drawbars and power distributions are simulated for in-train force characterization.

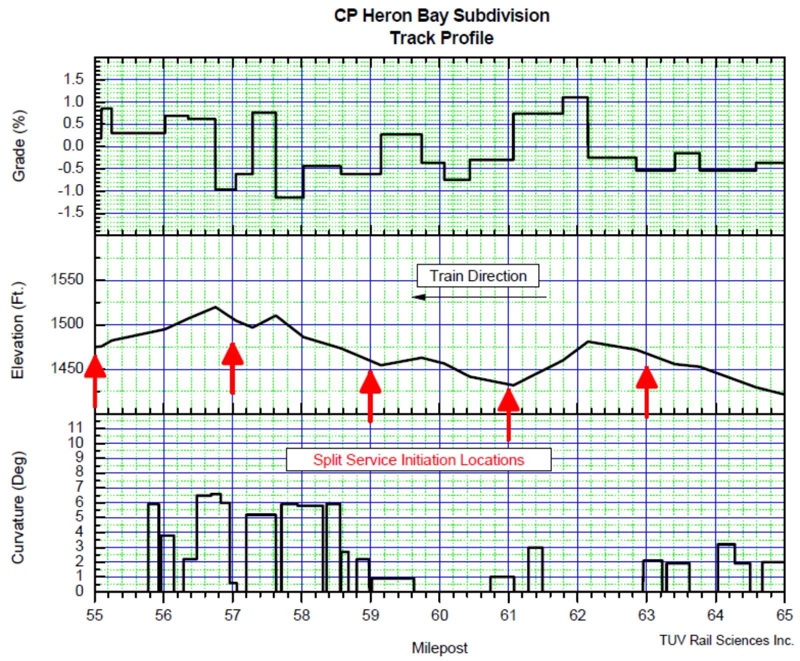



*Figure 20: Simulation Track Profile for Cushion Drawbars (Source: TUV Rheinland RSI Rail Sciences)*

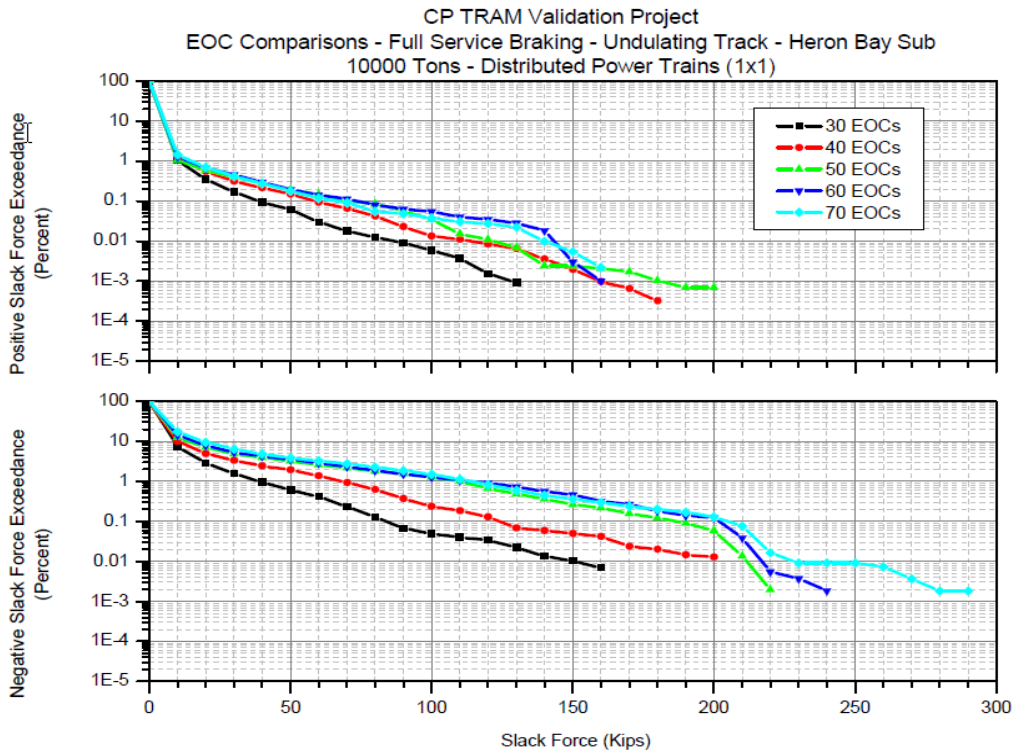



*Figure 21: Full Service Brake Stops (Source: TUV Rheinland RSI Rail Sciences)*

Figure 21 shows simulation results of trains ranging from 30 to 70 cushion drawbars coupled together being brought to a stop using Full Service brake application over the undulating track of Figure 20. As can be seen, the percentage of slack forces exceeding 100 klbs. of buff is higher for the train with 70 cushion drawbars compared to the one with 30 cushion drawbars. One way to reduce this undesired slack action is to distribute the cushion drawbar cars in equal amounts on either side of the Remote locomotive, as can be seen in Figure 22, with the benefits shown in Figure 23, resulting in lower percentage of slack action exceeding the 100 klbs. of .slack run-in  threshold.

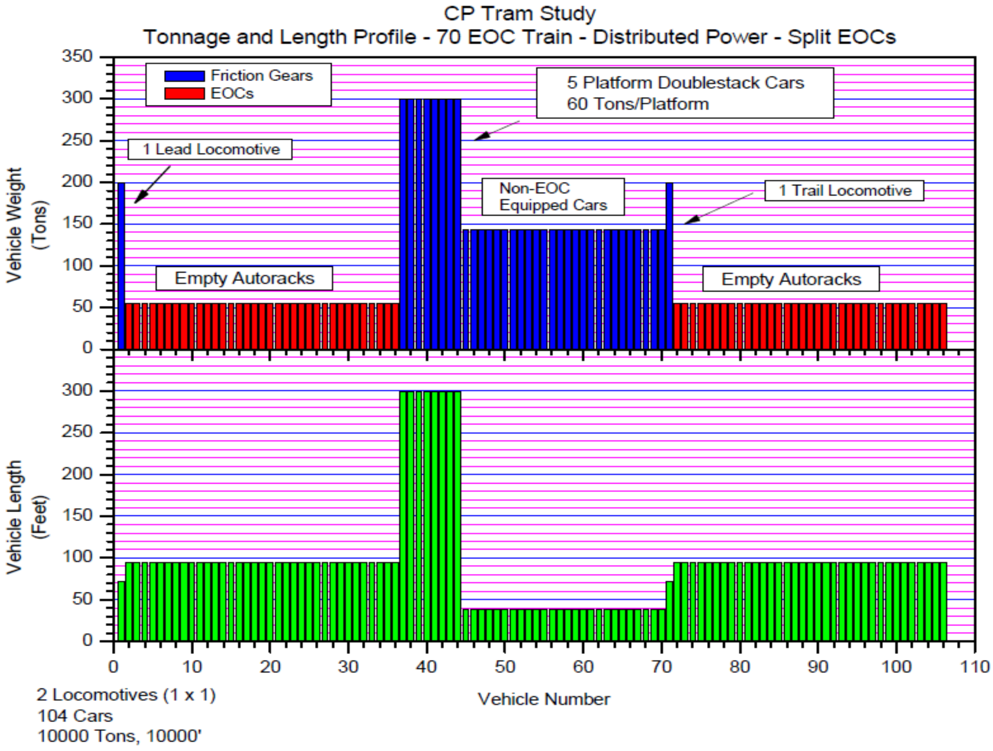



*Figure 22: Split cushion Drawbar Train Set-Up (Source: TUV Rheinland RSI Rail Sciences)*

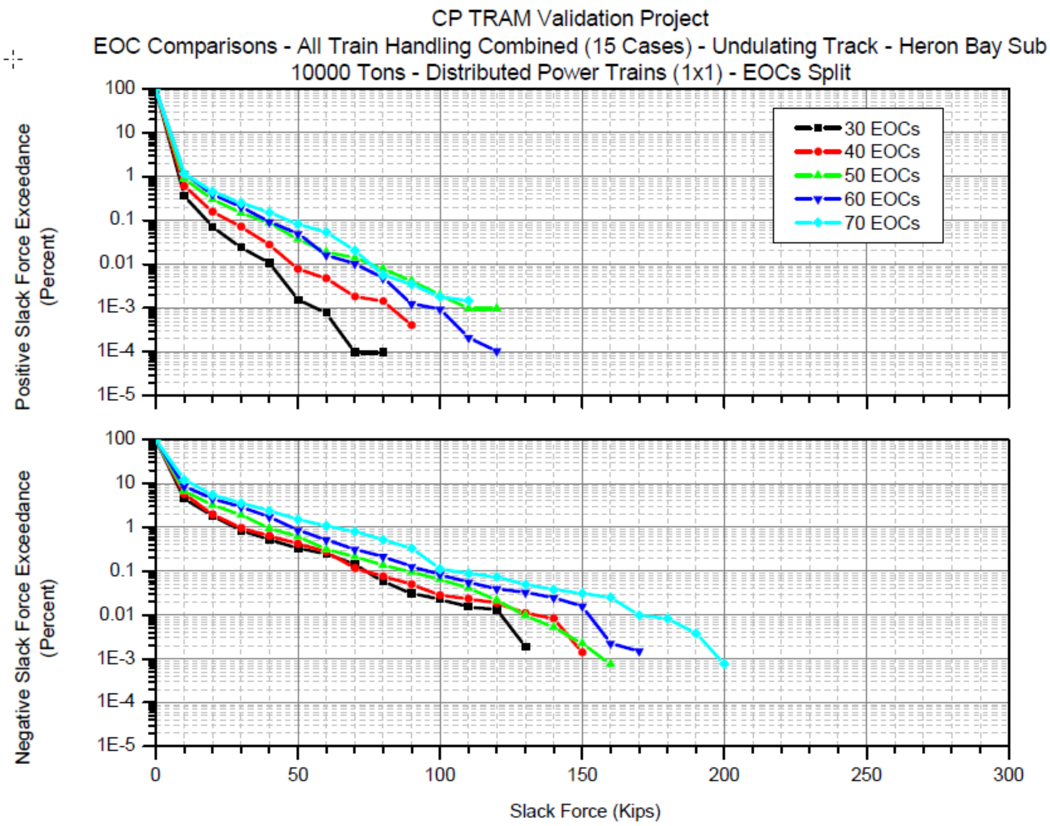



*Figure 23: Benefits of splitting cushion drawbars in train (Source: TUV Rheinland RSI Rail Sciences)*

Figure 24 also demonstrates the benefits to train handling and lower slack action resulting from separating half of the cars with cushion drawbars behind the Remote locomotive, towards the tail-end of the train. This is a simple train marshalling technique that can be adopted in order to handle large number of cushion drawbar cars in a train without any adverse effects on lading and undesired slack action in-train forces.

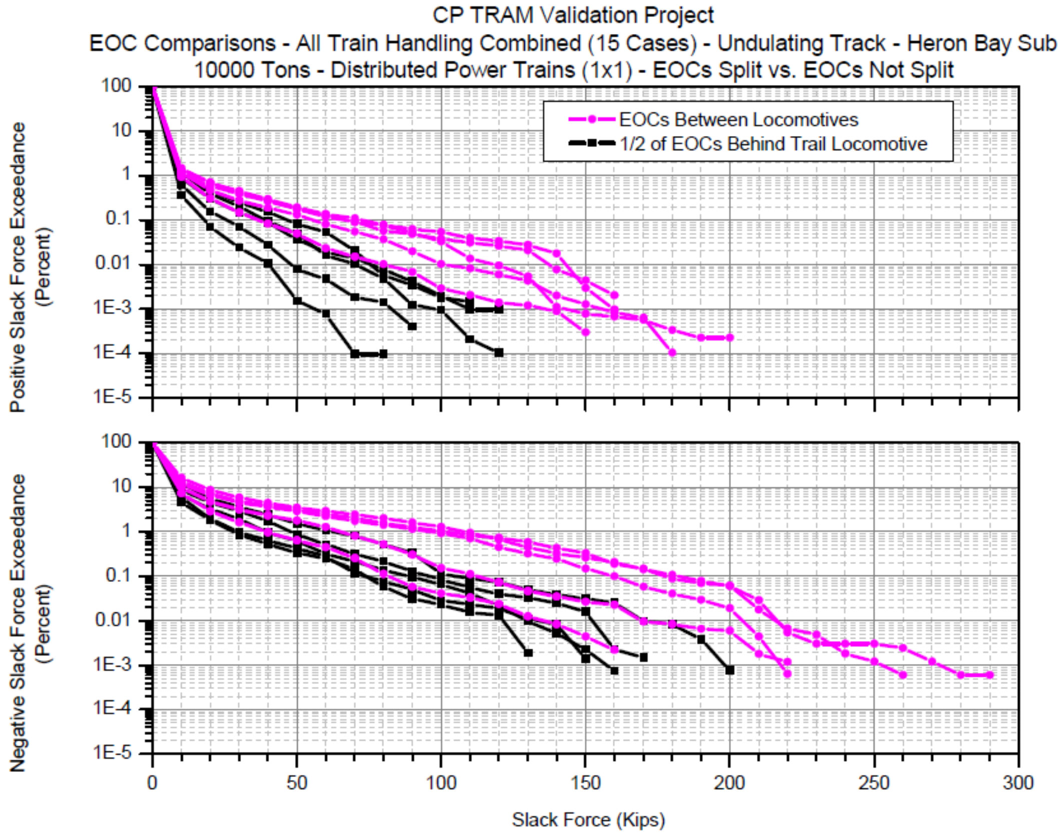



***Figure 24: Split cushion Drawbar Benefits (Source: TUV Rheinland RSI Rail Sciences)***

## CONCLUSIONS

Extending train lengths has been one of the primary targets of the Railway Industry. However, the obvious obstacles, such as challenging track profiles, variety of vehicle and locomotive configurations, make the train marshalling tasks quite complicated. For this exact reason, the science of Train Dynamics needs to be clearly understood and considered for safe operations of longer and heavier trains. Complexities of non-uniform trains can only be safely evaluated through solid Train Dynamics theories and proper Train Marshalling considerations. As indicated by multiple studies completed by Applied Rail Research Technologies (ARRT), "what is most important, is how the train interacts with the track; not so much its length or tonnage". From an operating, infrastructure and community perspective, properly marshalled heavy trains, preferably in Distributed Power configuration, would actually present a lower risk than the operation of shorter conventional trains. TrAM and Distributed Power at CP have effectively enabled the safe operation of long and heavy trains. We have a proven record of safe train operations and long trains contribute to this performance. CP is considered an Industry leader in using science and technology to support long train designs. We have developed proven processes that have demonstrated that a scientific approach would make train marshalling safer and make train lengths and weighs irrelevant parameters to safe train design and operations. CP has developed a body of evidence that has clearly shown that longer trains, powered appropriately and marshalled correctly, can be much more productive, and much less destructive.