Comments regarding in-train forces within “Manifest” and “Unit” trains, use of “Distributed Power” locomotives and freight train length

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Discussion with the
Transportation Research Board Panel
on
Safe Transportation of Liquefied Natural Gas by Railroad Tank Car-Phase 2

Information Gathering virtual meeting on Tuesday, November 9, 2021

Manifest and Unit trains defined

Manifest train

- Non-homogenous cars of different types, lengths and gross weights (i.e., loads and empties)
- With or without Distributed Power (DP)
- Cars equipped with either Draft Gear or End-of-Car Cushioning (to be described)

Unit train

- Homogenous car type (except “buffers”); all Loaded (including “buffers”) or all Empty
- Often with but sometimes without DP

“A train made up entirely of cars used to transport coal, grain, ore, potash, molten sulfur, soda ash, phosphate rock, oil, taconite, or other bulk commodities.

- *Empty Bulk Commodity Unit Train is made up entirely of empty cars.*
- *Loaded Bulk Commodity Unit Train is made up entirely of loaded cars.”*

Definition in quotation marks is from the Air Brake & Train Handling rule book of Union Pacific Railroad

Trains shown as icons moving in this direction >

F=mA

Railroad transportation involves the safe application (and/or management) of forces.

Propulsive forces

- Locomotive tractive effort at the rails, controlled by train's engineer
- Due to gravity (acceleration downhill), "naturally" occurring, must be managed

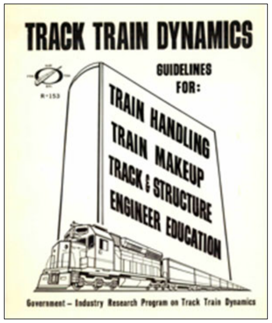
Retardation forces

- Automatic air brake forces on wheels, controlled by train's engineer
- Locomotive dynamic braking effort at the rails, controlled by train's engineer
- Due to gravity (deceleration uphill), "naturally" occurring, must be managed by engineer
- Due to curvature, wheel-rail resistance; aerodynamic (train make-up); etc
- Wind, etc, "naturally" occurring, must be managed by engineer

In-train forces

- Longitudinal force, coupler-to-coupler
- Slack action force, coupler-to-coupler
- Lateral force, wheel-to-rail

Topography of rail routes



*https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/15835/**1973**_TRACK%20TRAIN%20DYNAMICS%20TO%20IMPROVE%20FREIGHT%20TRAIN%20PERF.PDF*

Cresting Grade - A long ascending grade which rapidly changes to a long descending grade, both of significant magnitude (usually Heavy Grade), to require a change in the train handling procedures when the grade is topped.

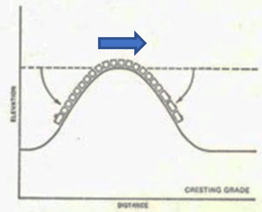


Figure 15. Cresting Grade

Heavy Ascending Grade - An ascending grade greater than 1.5%. Train handling procedures relating to a train running on heavy ascending grades assume the grades to be long enough that the retarding influence of the grade will be balanced by the power of the locomotive. (See Figure 17)

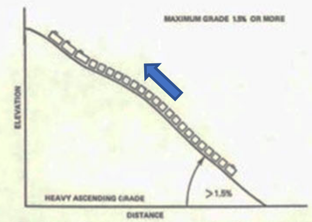


Figure 17. Heavy Ascending Grade

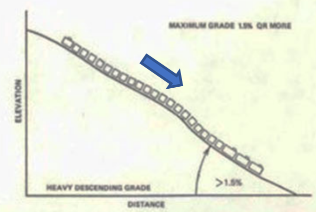


Figure 18. Heavy Descending Grade

Heavy Descending Grade - A descending grade greater than 1.5%. Train handling procedures for trains running on heavy descending grades assume that the grade is long enough that forces due to the grade, that tend to increase the speed of

Hump Knoll or Hogback - A rapid increase in grade followed by a decrease in grade sufficient to result in abnormal slack adjustment.

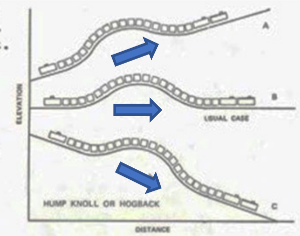


Figure 19. Hump Knoll or Hogback

Light Ascending Grade - An ascending grade less than 1.5%. Train handling procedures relating to a train running on light ascending grades assume the grade to be long enough that the retarding influence of the grade will be balanced by the power of the locomotive. (See Figure 21)

matic brakes, and

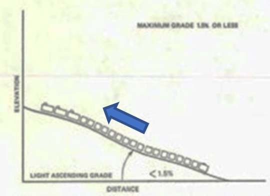


Figure 21. Light Ascending Grade

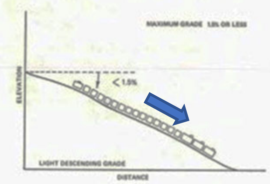


Figure 22. Light Descending Grade

Light Descending Grade - A descending grade less than 1.5%. Train handling procedures for trains running on light descending grades assume that the grade is long enough that forces due to the grade, that tend to increase the speed of the train, will be balanced by natural train resistance, automatic brakes, and dynamic brakes as required. (See Figure 22)

Sag or Dip - A rapid decrease in grade followed by an increase in grade sufficient to result in abnormal slack adjustment.

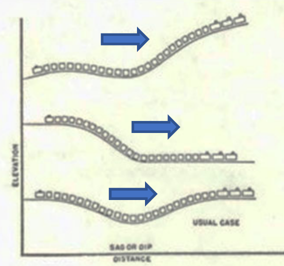


Figure 24. Sag or Dip

Undulating Grade - A track profile with grade changes so often that an average train passing over the track has some cars on three or more alternating ascending and descending grades. The train slack is always tending to adjust as cars on descending grades tend to roll faster than those on ascending grades.

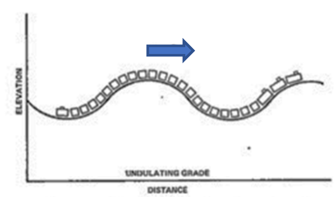


Figure 28. Undulating Grade

Comments on "Train Dynamics" by Aronian et al (Vancouver, 2013)

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(r), consisting of mainly uniform car lengths, with similar tonnage capacities and general characteristics.

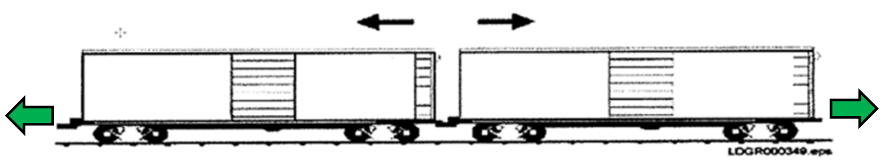
Because of the numerous track profiles (ascending, descending, undulating, coupled with sharp curves) that a train encounters on a single run, coupled with the infinite train consist combinations, it is more common that at certain times, the wrong parameters may align, accentuating the probability of 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.

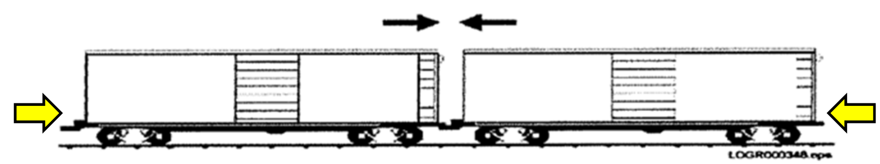
From: "Train Marshalling Process at Canadian Pacific", Aronian et al, Vancouver, 2013

In-train forces visualized (longitudinal Draft versus Buff)

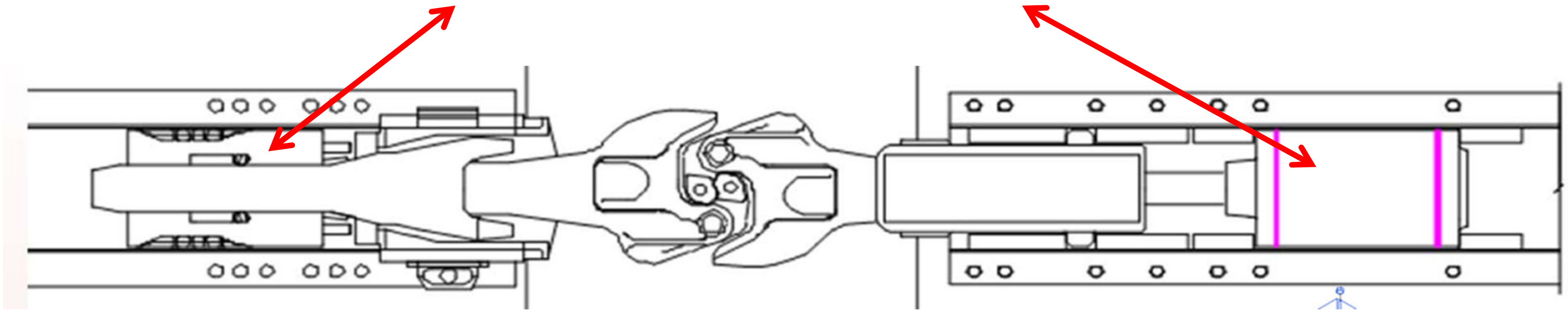
DRAFT (“stretched”)



BUFF (“bunched”)



Draft Gear (80% of car fleet) versus End-of-Car Cushioning (EOCC, 20% of car fleet)

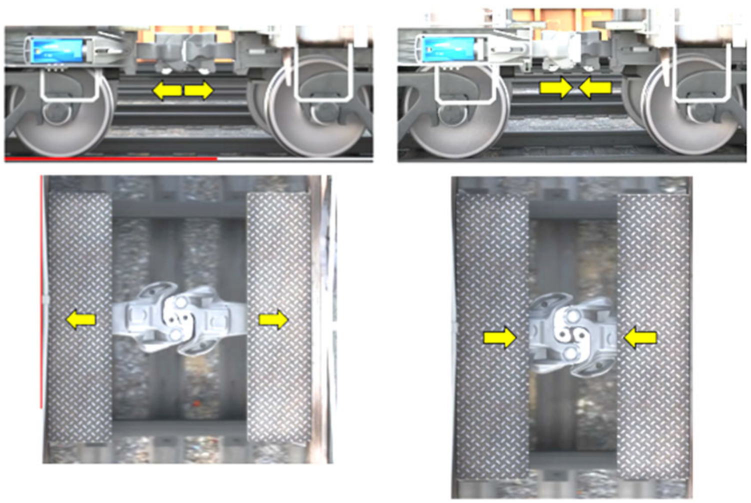


https://www.wheel-rail-seminars.com/archives/2015/hh-papers/HH-14%20J.%20Deppen%20WRI%202015%20HeavyHaul%20Master%20Slides.pdf

***Maximum ~6" total travel (1'/car)**

***Maximum ~15" maximum travel (2.5'/car)**

(*) Under maximum draft-and-buff load conditions



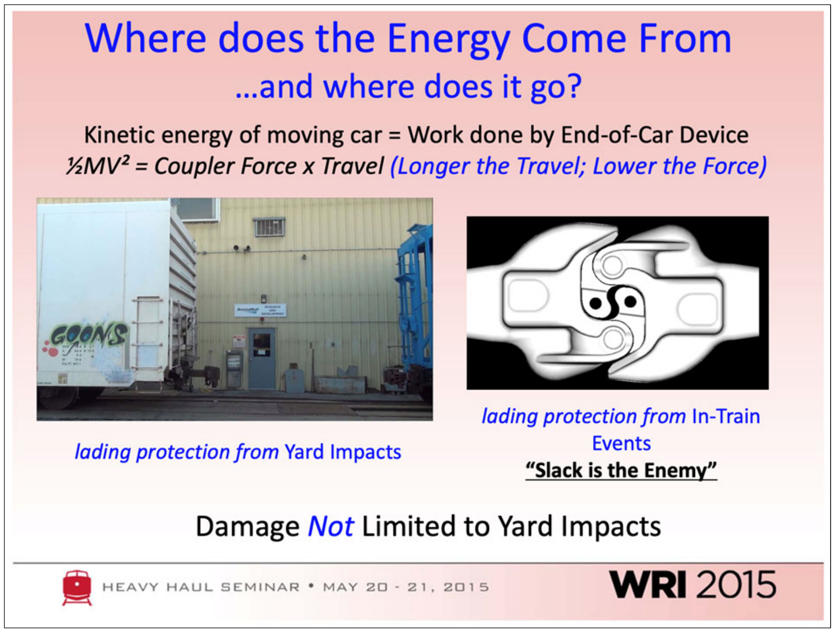
Photos from: https://www.youtube.com/watch?v=6gDehKbgctw

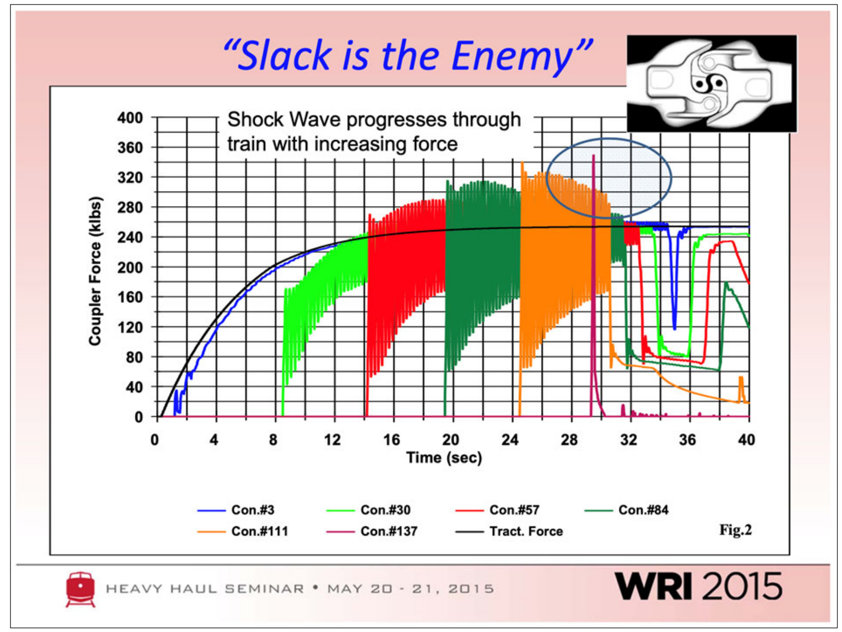
DRAFT ("stretched") BUFF ("bunched")

https://atlasrescueforum.proboards.com/thread/7838/autorack-couplers

BUFF ("bunched") DRAFT ("stretched")

Managing energy at the end of a car (“behind the coupler”): 2 diff. technologies



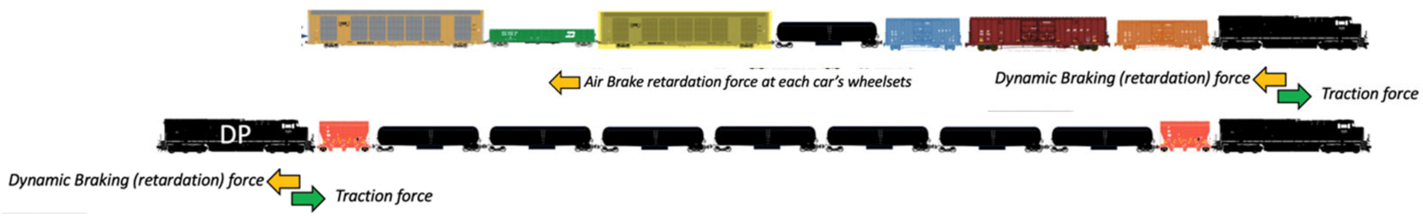


https://www.wheel-rail-seminars.com/archives/2015/hh-papers/HH-14%20J.%20Deppen%20WRI%202015%20HeavyHaul%20Master%20Slides.pdf

Three (3) types of in-train dynamic forces

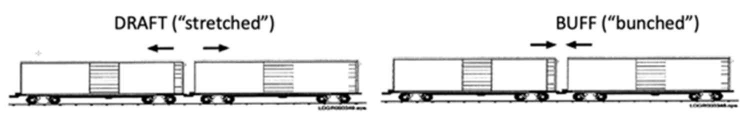
Longitudinal force (steady state “buff or draft”, *coupler-to-coupler*)

- Throttle & Dynamic Brake changes
- Train resistance (grades, curves, acceleration & deceleration forces)
- Use-and-placement (or absence) of Distributed Power (DP)



Slack action force (fast moving long.*, buff or draft, *coupler-to-coupler*)

- Change in velocity of individual cars/locos. within a train
- (*) “Force wave(s)” may move through train as fast as 500 fps
- Topography (heavy grade, rolling hills, etc) and/or air brake activity
- Placement and functioning of Draft Gear and End-of-Car-Cushioning

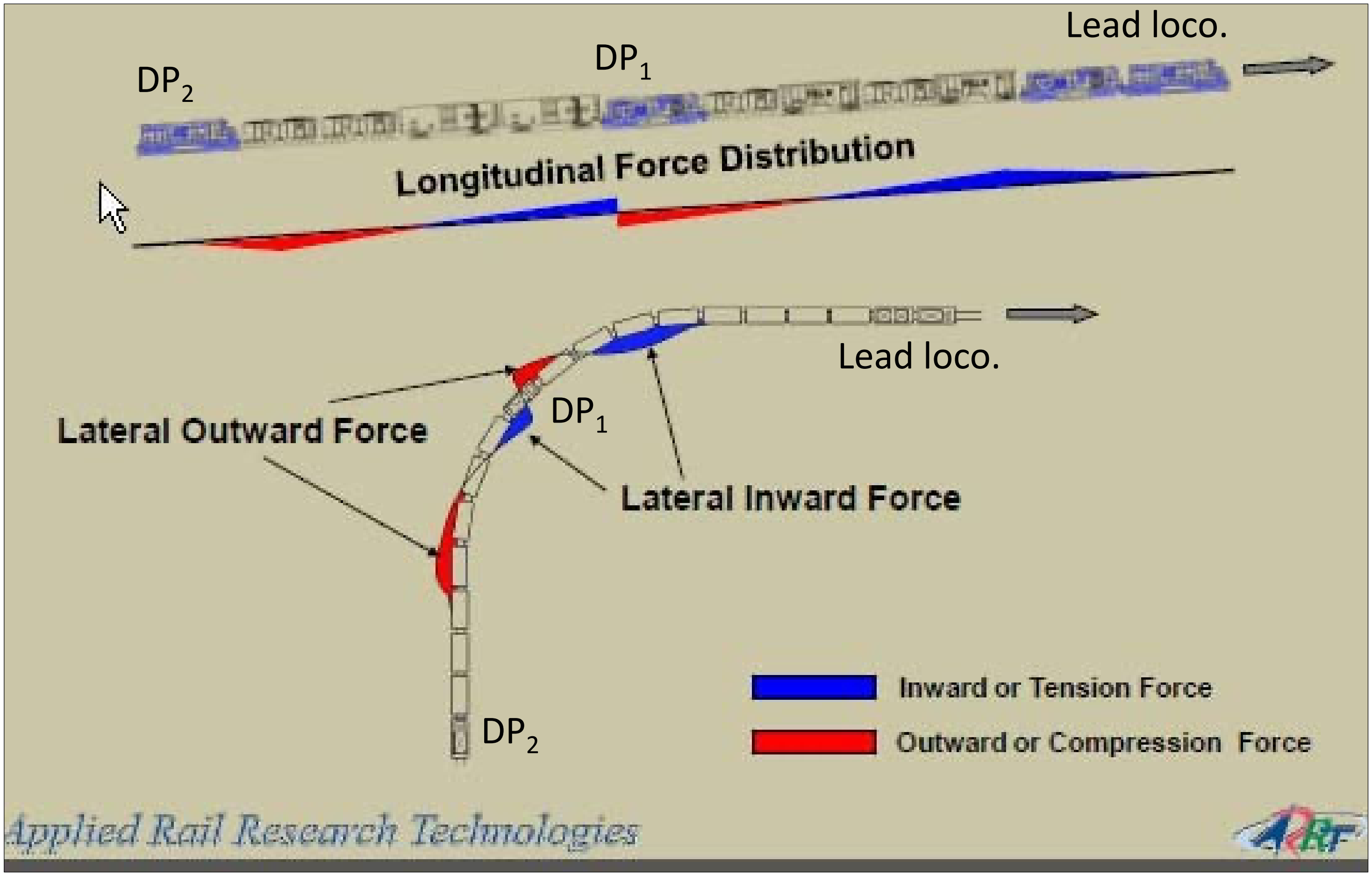


From: “Train Marshalling Process at Canadian Pacific”, Aronian et al, Vancouver, 2013

Lateral force (steady state or near-instantaneous, *wheel-to-rail*)

- Track curvature
- Coupler alignment (“coupler angularity”) between cars
- Movement of wheelsets through curves

Visualizing longitudinal and lateral in-train forces



From: "Train marshalling Process at Canadian Pacific", Aronian et al, Vancouver, 2013

Distributed Power ("DP")

Remote (via radio) control of locomotive(s) within a freight train

Started in 1960s on Southern Railway as "Locotrol"™

- One (1) remote locomotive unit or consist within a train

- Controlled from lead locomotive unit
- Control of train Brake Pipe pressure at 2 locations in-train

Enhanced in 1990s and evolved into "Distributed Power" (DP)

- Now 2-to-4 remote locomotive units or consists within a train

DP_D DP_C DP_B DP_A Lead

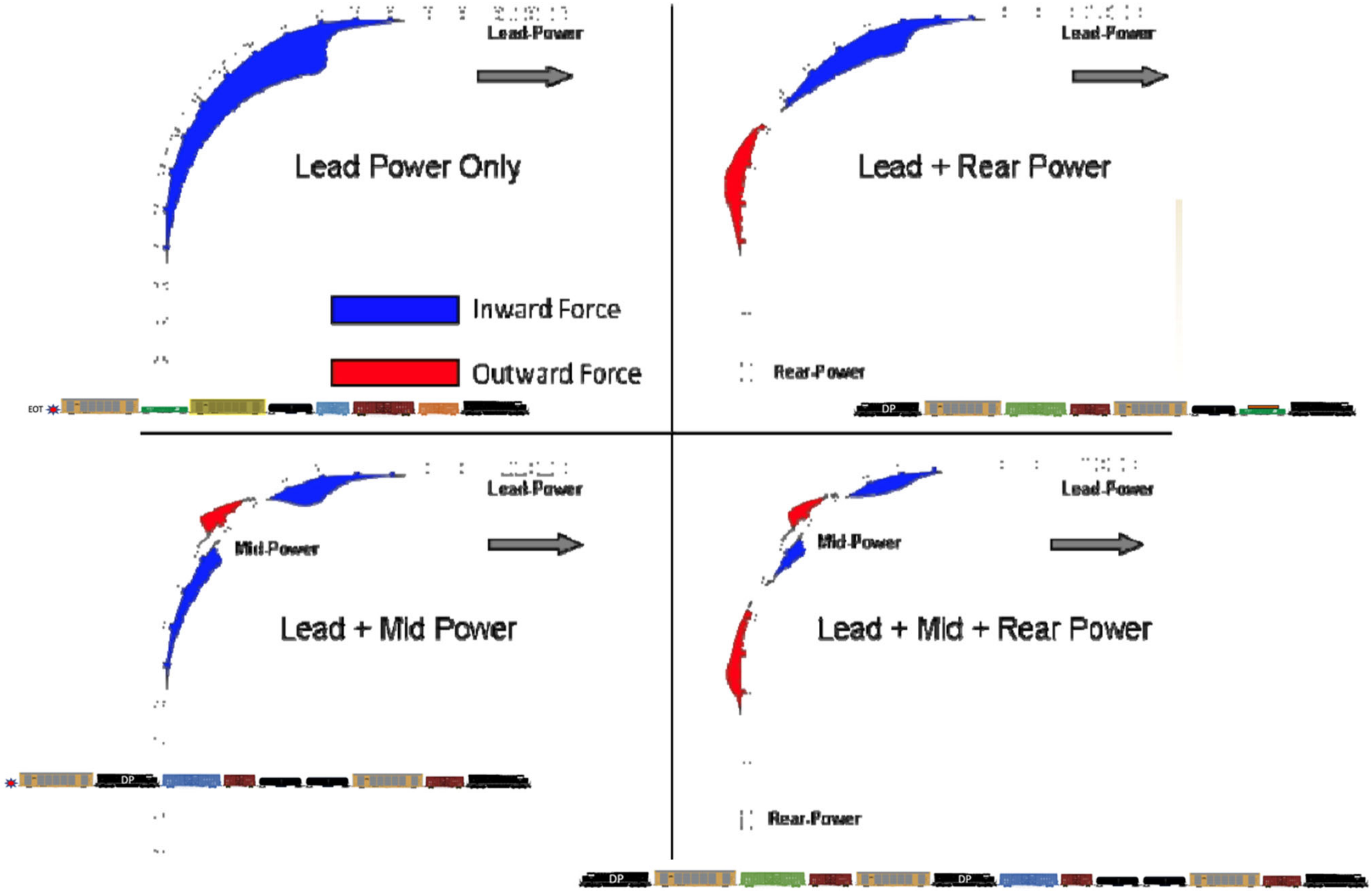
- Control of train Brake Pipe pressure at 2-to-5 locations in-train
- Increasing number of equipped locomotives since mid-1990s
- Especially beneficial w/ AC locos. (greater TE/DB)
- Growing universality of DP functionality between RRs

DP technology increasingly common across North America

- All 7 Class 1 RRs in Canada and U.S., plus Mexico
- Some variabilities in DP usage (% of trains "DP'd")
- Appears Class 1 RRs may be progressing toward more re loco. placement etc

Train icons from: "Train Marshalling Process at Canadian Pacific", Aronian et al, Vancouver, 2013

Using DP to reduce lateral in-train forces



From: "Train Marshalling Process at Canadian Pacific", Aronian et al, Vancouver, 2013. (train "icons" added)

One Canadian railroad's transition to longer trains with DP

Potash Train Progress

2008: Base model was 124 cars (17,800T, 6121') … tested 142

2009: Base model was 142 cars (20,400T, 6967') … tested 170

2011: Starting in July, base model moved to 170 cars (24,500T, 8357')

Coal Train Progress

2008: Base model was 124 cars (17,500T, 6802') … tested 142

2009: Base model moved to 126 (Neptune) and RBank to 129 cars

… some limited overlength sets tested, including up to 152-cars in 2011 (21,400T, 8361')

Intermodal train examples …

7,000 Foot Model

10,000 Foot Model

12,000 Foot Model

14,000 Foot Model

Example: adding a DP unit to rear of a train

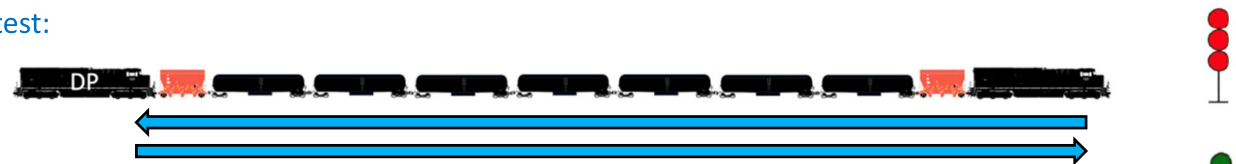
Adding a DP loco. (or consist) to the rear of a train requires time and equipment movements …

Inbound train … head-end power plus an EOT:

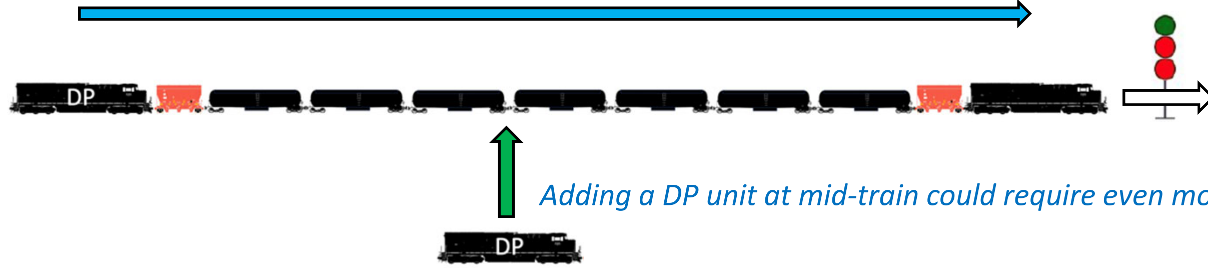
Move DP loco./consist to rear of train & couple to train (assumes lead unit is also DP equipped!)

Perform “DP linking procedure” between lead unit and controlling DP unit:

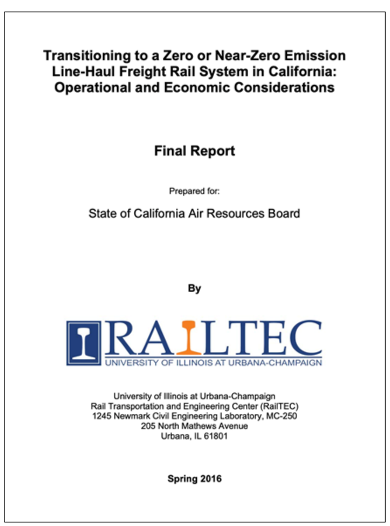
Perform air brake test:



Train ready to depart



Adding a DP unit at mid-train could require even more time


Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California: Operational and Economic Considerations

Final Report

Prepared for:

State of California Air Resources Board

By

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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Urbana, IL 61801

Spring 2016

“Locomotive exchanges” and estimated times to accomplish were discussed in detail in this 2016 UIUC report for California’s Air Resources Board

https://ww2.arb.ca.gov/sites/default/files/classic/railyard/docs/uoi_rpt_06222016.pdf

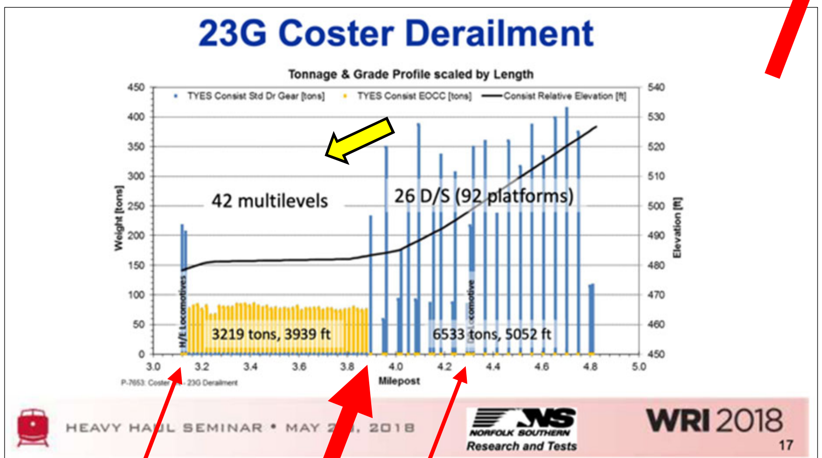
One derailment: Large block of "EOCC" cars followed by a large "tonnage block" (even with DP)

3219 tons of auto racks … followed by … 6533 tons of double-stack cars

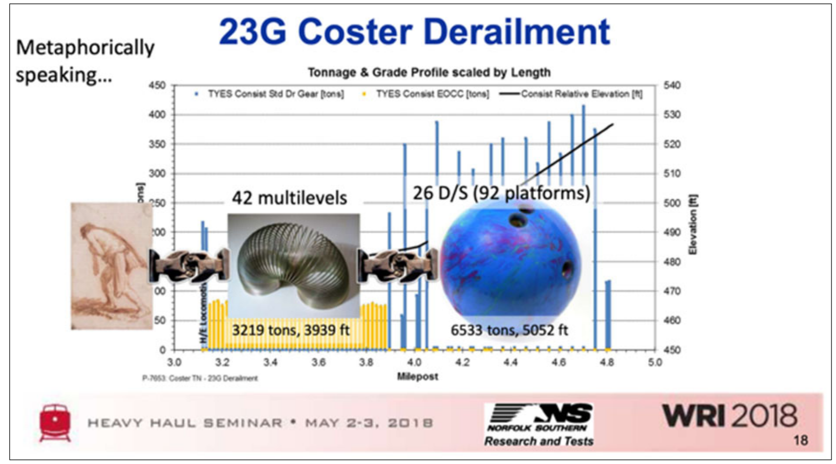
Long-travel End-of-Car Cushioning units

No-Slack Articulated-connections

Draft Gear



2 locos. **POD** **1 DP loco.**



Train moving downhill (to "left").
Prior to derailment (EOCC-equipped auto racks progressively in "buff") the DP unit was moving 2mph (2.9 fps) faster than the lead loco (based on post-accident analysis of event recorder data).

I.e., front of train was "dynamically shortening" and coupler angularity (and then lateral wheel force) caused the track gauge to spread.

Conclusions

- Buff forces are more likely to result in track damage and derailment than draft forces.
- Large coupler forces tend to result from type of equipment (EOCC blocks) and tonnage (not necessarily length).

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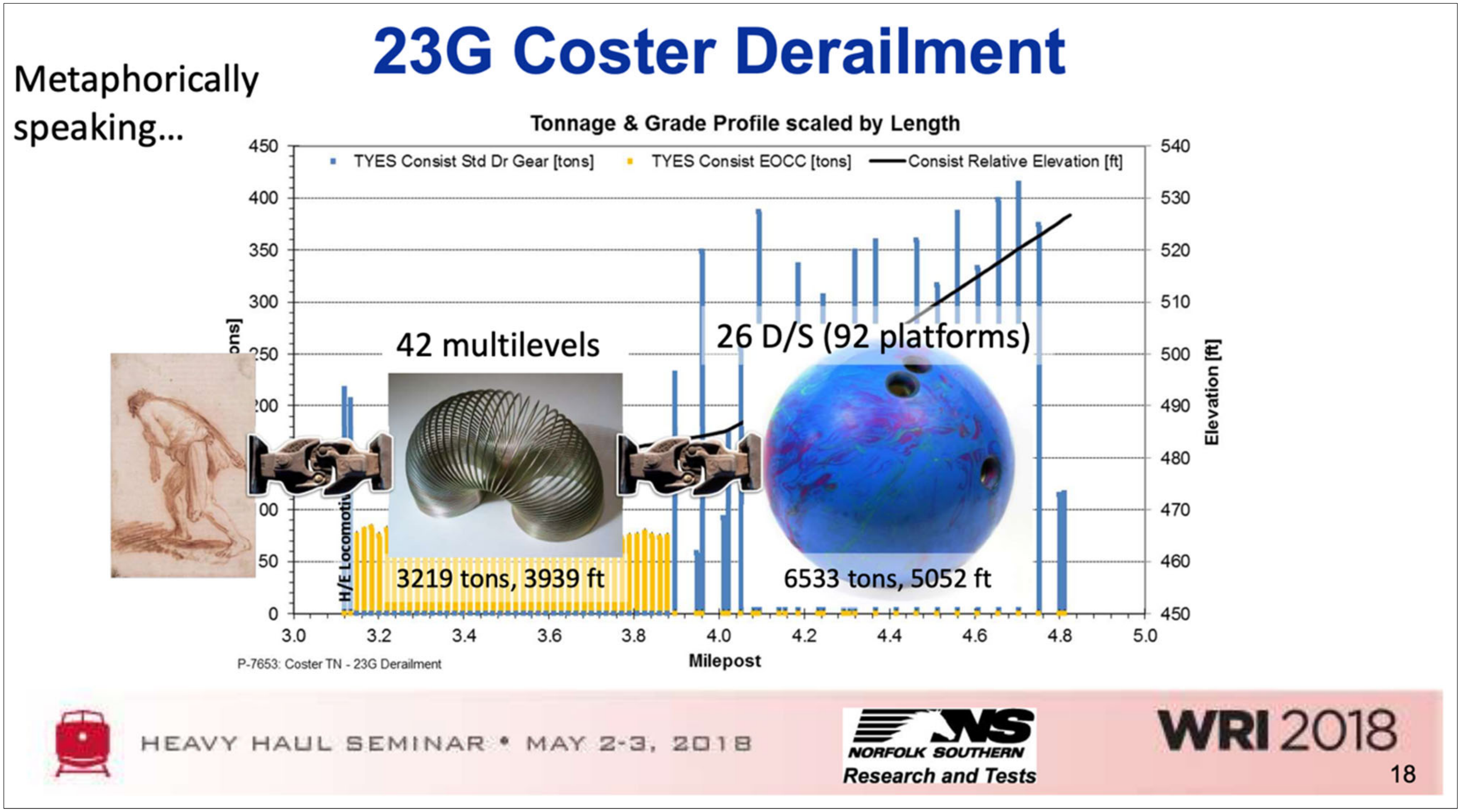
From: https://www.wheel-rail-seminars.com/archives/2018/hh-papers/presentations/HH01.pdf

Visualizing in-train dynamic forces in this one derailment …



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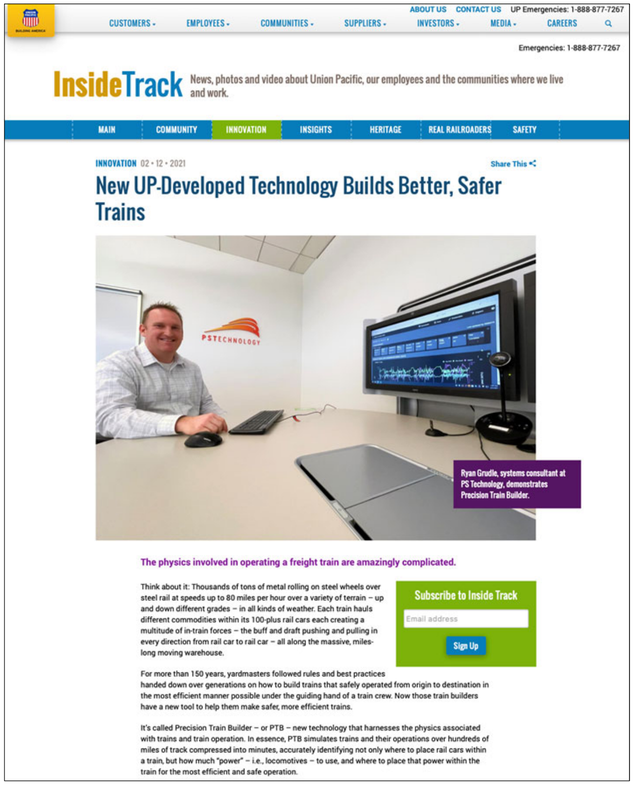
Pre-departure train analysis software



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MAIN COMMUNITY INNOVATION INSIGHTS HERITAGE REAL RAILROADERS SAFETY

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New UP-Developed Technology Builds Better, Safer Trains

Ryan Grudle, systems consultant at PS Technology, demonstrates Precision Train Builder.

The physics involved in operating a freight train are amazingly complicated.

Think about it: Thousands of tons of metal rolling on steel wheels over steel rail at speeds up to 80 miles per hour over a variety of terrain – up and down different grades – in all kinds of weather. Each train hauls different commodities within its 100-plus rail cars each creating a multitude of in-train forces – the buff and draft pushing and pulling in every direction from rail car to rail car – all along the massive, miles-long moving warehouse.

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For more than 150 years, yardmasters followed rules and best practices handed down over generations on how to build trains that safely operated from origin to destination in the most efficient manner possible under the guiding hand of a train crew. Now those train builders have a new tool to help them make safer, more efficient trains.

It's called Precision Train Builder – or PTB – new technology that harnesses the physics associated with trains and train operation. In essence, PTB simulates trains and their operations over hundreds of miles of track compressed into minutes, accurately identifying not only where to place rail cars within a train, but how much "power" – i.e., locomotives – to use, and where to place that power within the train for the most efficient and safe operation.

https://www.up.com/aboutup/community/inside_track/new-tech-builds-better-safer-trains-2-12-21.htm

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The physically accurate simulation becomes the ultimate predictive tool, allowing railroads to test trains before they operate. The result is the ability to run longer trains safely. This new technology is one reason Union Pacific has been able to increase its average maximum train length by 12% – to 9,154 feet – over the past year, resulting in much more efficient operations.

But there's an additional safety benefit. PTB is being used by UP's Safety Department to monitor train crews in real time as they operate over their territory, providing alerts when necessary, such as slowing down to reduce buff and draft forces. It's called a Virtual Ride Along (VRA) and is being beta tested now with a target of monitoring thousands of UP trains on the company's 32,000-mile network.

PST developed PTB working closely with UP's Safety and Operating departments, including those who actually run trains. "Operating a train is a very complicated thing to do," Grudle said. "Writing the AI to do that requires the mind of a locomotive engineer to get it right. It's an ongoing, interactive process."

A screen from the Precision Train Builder program. Users can compare theoretical train consist designs over actual train routes. Factors like weather, track adhesion and more are calculated.

Concluding thoughts

- Railroads continue to provide safe transportation of freight.
- “Unit” trains have different operating (train handling) requirements than “Manifest” trains.
- “Train make-up (marshalling)” decisions can affect train handling and/or dynamic forces.
- Successful train handling = safe application and/or management of “dynamic” forces.
- Dynamic in-train forces can be longitudinal, slack-related and/or lateral.
- Topography (a trains route) is a major factor in train make-up and handling, and dynamic forces.
- Proper use of Distributed Power (DP) can help to manage dynamic in-train forces.
- Freight train “size” (length and gross tonnage; amount of loco. power) has increased over time.
- Railroads have successfully applied various approaches to safely increasing freight train “size”.
- Changes in freight car design (length, weight) and/or equipment (draft gear versus EOCC) have continued making the continental freight car fleet less homogenous than in previous decades.
- Some dynamic in-train forces may be exacerbated under certain combinations of topography, train size, train make-up and draft gear v EOCC (“car type block” versus “tonnage block”).