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Quantifying the Magnitude and Direction of Freight Car Accelerations During Slack Action Events

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Abstract: Railroad conductors and brakemen ride on the sides of moving freight cars throughout the normal course of railroad operations, especially in railroad classification yards. These low-speed movements are typically at speeds of 10 MPH or less. Riders typically grasp a horizontal ladder rung, with the feet positioned on a lower ladder rung directly below the hands. Throughout the course of these movements, the rider encounters freight car accelerations in the longitudinal (x), vertical (y), and lateral (z) directions. A 10G triaxial accelerometer was used to quantify the typical range of accelerations that a freight car, and its rider, are subjected to during typical yard operations. Acceleration data was collected in four locations: North Platte, NE; Houston, TX; Roseville, CA; and Searcy, AR. Sampling in different geographic locations provided a variety of different train consists, train yard topography, and operating methodologies to help ensure that the data collected is representative of typical train yard movements. The triaxial accelerometry was analyzed to determine the typical causes of acceleration in each direction. The greatest acceleration magnitudes were found to occur in the longitudinal or fore-aft direction when the freight car draft gear was fully extended. Under real-world conditions, these longitudinal accelerations averaged 13.9 m/sec^2 with remote-controlled locomotives, and 5.8 m/sec^2 with conventionally-operated locomotives. This phenomenon, known as "slack action," occurs when a freight car undergoes a sudden change of speed. This information is being collected in an effort to better understand the accelerations that a conductor or brakeman interacts with while safely riding a freight car. Measured freight car accelerations may provide insight on the biomechanical demands of riding freight cars during slack action events.

Keywords: Railroad, Slack Action, Acceleration

1. Introduction

Hundreds of times a day, railroads across North America conduct short train movements, some with and some without riders. These train movements can be classified into "shoving or pushing movements" or "pulling movements". Usually, shove movements are ridden by workers to "protect the point" in accordance with Federal Railroad Administration rule 49 CFR 218.99. Pulling movements are usually ridden by workers as a means to efficiently transport themselves to the location of the next work task, which often includes operating manual track switches in preparation for the next shove movement. These movements are instrumental in the process of "building trains," which involves organizing and joining freight cars for safe and efficient transport to industrial operations across North America. However, no research has been conducted to quantify the accelerations experienced by railroad workers riding these movements. Thus, an opportunity exists to consider these accelerations in conjunction with a riders' grip strength and to examine riding techniques that maximize the riders' biomechanical advantage while performing this task. This paper will quantify the accelerations experienced by a person riding these train movements.

This research paper will use vernacular specific to the railroad industry. The authors believe these industry-specific terms should be defined for the reader:

- *Shoving or Pushing Movements* – means the movement of one or more cars with power unit in the rear pushing the cars where desired.
- *Pulling Movements* – means the movement of one or more cars with power unit in the front pulling the cars where desired.
- *Point* – means the area in front of a consist involved in a train movement. When conducting shoving movements, an engineer may not be able to see this area; therefore, a conductor must ride the leading car to ensure the track and surroundings are clear.
- *Engineer* – means the person operating the locomotive or power unit
- *Hostler* – means a person who operates a locomotive only in railyards
- *Conductor* – means the person responsible for directing the train's movement, coupling or uncoupling cars, operating manual track switches and ensuring cars are sequenced according to plan.
- *Consist of a locomotive and railroad cars ("consist" for short)* - means one or more locomotives coupled to a railroad car or railroad cars.
- *Slack Action* – means the amount of free movement of one car before it transmits its motion to an adjoining coupled car. This is further delineated into draft and buff forces.
- *Buff Forces* – means when the coupler, which acts through the follower, places the gear in compression against the car body's rear stops (i.e. two cars in compression).
- *Draft Forces* – means when the yoke straps are placed in tension as the gear is compressed between the rear of the yoke and the striker (i.e. two cars in tension).

Freight cars are connected to each other by a coupler mechanism and drawbar, which is connected to the freight car's draft gear (See Figure 1). The draft gear acts as a shock absorber by allowing the drawbar to slide in the fore-aft direction, effectively compressing or rebounding depending on the forces acting upon it. "Buff" forces cause the drawbar to be compressed while "draft" forces cause the drawbar to be extended. Changes in the movement of the train that cause the draft gear to compress or extend, can create a sudden acceleration or deceleration of the freight car, known as "slack action." The peak accelerations tend to occur when the movement of the drawbar tops or bottoms out.

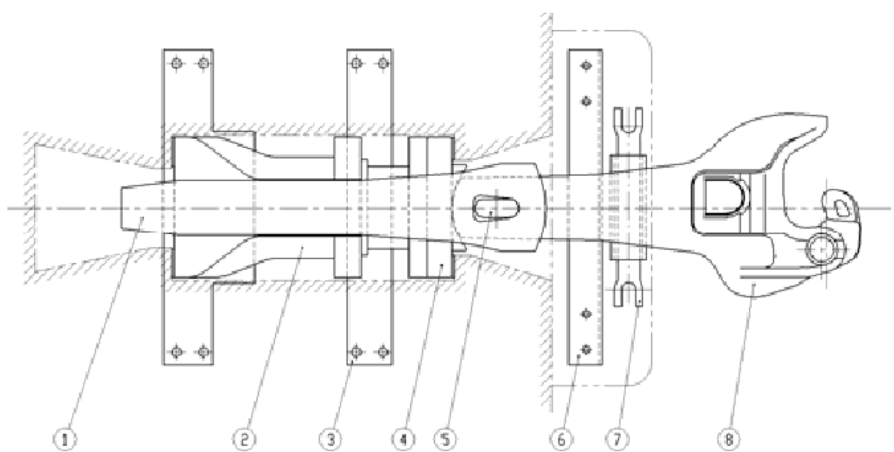

Figure 1. Coupling system assembly (Courtesy of Qing Wu, Central Queensland University, Centre for Railway Engineering, Rockhampton, Queensland, Australia, q.wu@cqu.edu.au). ①Yoke ②Draft gear ③Draft gear carrier ④Follower ⑤Yoke key ⑥Coupler carrier ⑦Coupler positioning device ⑧Coupler

Measurement axes: The acceleration axes were measured in relation to the movement of the car. Therefore, the x-axis was the longitudinal movement, or fore to aft. The y-axis was the vertical movement and the z-axis was the lateral movement, or side to side movement. Figure 2 shows a diagram of those axes.

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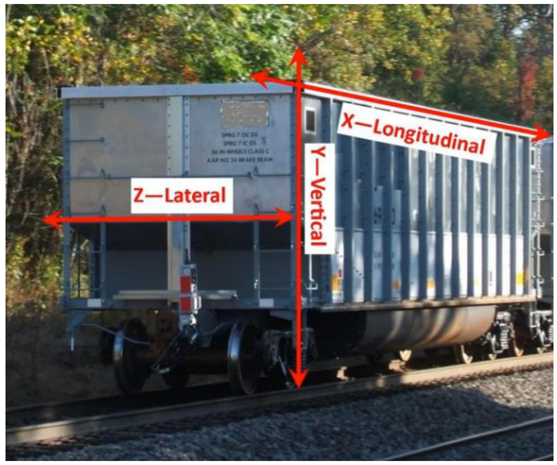

Figure 2. Coordinate system of measurement axes in 3-dimensional space.

2. Methods

In part one of this study (Fleming et al. 2019), we assess the accelerations associated with a limited number of train movements. In this study, the number of train movement samples increased from 39 real-world samples to 150 total samples. The additional 111 samples were collected in a controlled environment with repeatable trials. Train lengths varied from a single freight car to as many as 94 freight cars. Acceleration data was collected at Union Pacific Railyards located in North Platte, NE; Houston, TX; Roseville, CA; and Searcy, AR in an effort to acquire enough samples to conduct our analyses. Sampling in different geographic locations provided a variety of different train consists, train yard topography, and shove situations to help ensure that the data collected is representative of typical train movements that would be ridden by a conductor. Coupling data were not included because workers are prohibited from riding a car when coupling. The maximum acceleration in each direction was identified for each train movement. In addition, following data were recorded:

- Car ID
- Car Type
- Number of loaded freight cars
- Number of empty freight cars
- Total number of freight cars
- Mounting orientation of the accelerometer
- Whether the maximum acceleration resulted from buff or draft forces
- Whether movement was controlled by Remote Control Operator or an Engineer
- Direction of movement relative to the locomotive (forward or reverse)

Acceleration data was collected using a NEXGEN Ergonomics Biometrics Ltd DataLog Model MWX8 data acquisition device. The DataLog system uses a multimedia card to store data as it is collected in real-time. A DataLog indent cable was also used to keep track of relevant occurrences during data collection and to allow for synchronization with collected video. A Biometrics Series 2 tri-axial accelerometer, with a working range of +/- 10Gs, was used with the DataLog. The accelerometer was affixed to the freight car near the location of the handhold using a magnetic mounting plate and oriented such that the X-axis was in the longitudinal direction, the Y-axis was in the vertical direction, and the Z-axis was in the lateral direction. The accelerometer was set to record acceleration data in the range of 0-100Hz. The sampling rate was set to 500 Hz. A GlobalSat DG-100 data logger was used to collect GPS information throughout the duration of the data collection. Position, time, date, speed, and altitude information was stored to internal memory on one-second intervals. Two video cameras were used throughout the duration of the data collection: a Sony Handycam and a GoPro Hero. The video clips were synchronized, with the GoPro camera focused exclusively on the coupler to show the start and stop of each movement and the Sony camera showing the broader context of the train movement. See Figure 3 for a typical freight car instrumented for this study.

Figure 3. Equipment set-up.

3. Analysis

Software developed by Biometrics Ltd. was used to export the relevant acceleration raw data. Acceleration data files were imported to the Biometrics software and exported as comma-separated .TXT files with the data shown in the engineering units of meters per second per second (m/sec^2). The files were then imported to Excel for smoothing. Excel was used to apply
a simple moving average with a window size of 10 data points. The first smoothed data point is calculated by taking an average of the 1st through 10th data points, as described in Equation 1. The second smoothed data point is calculated by taking an average of the 2nd through 11th data points, and so on.

$$\text{Smoothed Data Point \#1} = \frac{(d1 + d2 + d3 + d4 + d5 + d6 + d7 + d8 + d9 + d10)}{10} \quad (1)$$

A 10-sample window represents 1/50th of a second and best represents the net acceleration of the rapidly-occurring slack events. This window size was also effective at removing the high-frequency vibration “noise” that is not representative of the translational movement felt during a slack event (in the case of the X axis) or other movement events (in some cases for the Y and Z axes).

Data smoothing was applied to all three axes of data and the peaks were located for each axis. Since the peaks could be in either the positive or the negative direction, the peak for a given axis was determined to be the largest absolute value acceleration. However, the polarity of the acceleration was maintained separately for analysis purposes. The smoothed accelerations in the remaining two directions were also recorded for the same moment in time. For each train movement, three peak events were noted: (Xmax,Y, Z), (X, Ymax, Z), and (X,Y, Zmax).

4. Results

Of the 150 freight car movements, 10 were conventional movements, meaning an engineer was operating the train from within the locomotive cab. The other 140 freight car movements were controlled by a conductor who was either standing on the ground or riding a freight car while using a remote control to operate the locomotive (RCL). The types of freight cars tested are shown in Table 1. For the 66 pulls and 84 shoves, the number of peak accelerations due to the effects of buff and draft movement of the freight cars is shown in Table 2.

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Table 1. Freight car types.

Freight Car Types	Number of Movements Measured
Box Car	7
Bulkhead Flat Car	21
Hopper Car	107
Gondola	6
Refrigerator Car	1
Tank Car	8
TOTAL	**150**

Table 2. Root cause of acceleration in the X-axis.

Movement Direction Relative to Locomotive	Root Cause of Acceleration (X-axis)	Number of Movements Measured
Pull	buff	29
	draft	37
Shove	buff	25
	draft	59
TOTAL		**150**

4.1 Buff vs. Draft

Analysis of the data was done using IBM® SPSS® Statistics, Version 25. An analysis of the data collected during real-world operating conditions shows that the x-axis (or longitudinal) acceleration appeared to have the most significant result of the draft & buff acceleration forces encountered ($p=0.001$, $\eta 2= 0.276$). Table 3 shows that the average x-maximum was between 4.6 m/sec2 and 12.2 m/sec2 depending on whether in the buff or draft direction. The test subject also noted that the accelerations in the x-axis were the greatest from a subjective standpoint. The y-axis appeared to be second with maximum accelerations averaging between 5.4 and 7.3 m/sec^2. However, the results were not considered significant and had only a moderate association ($p=0.057$, $\eta 2= 0.095$). The z-axis appeared to be insignificant and contributed the least to the accelerations observed. About 26% of the y-axis peak accelerations and 21% of the z-axis peak accelerations were due to the buff/draft movements of the freight cars. The other 74% and 79% of the respective y-axis and z-axis peak accelerations were due to the geometry of the tracks (frogs, joints, switches, grade crossings, and visible deformities such as pitting).

Table 3. Acceleration statistics by freight car movement type.

		X-axis MAX (m/sec^2)	Y-axis MAX (m/sec^2)	Z-axis MAX (m/sec^2)
buff	Mean	4.6099	5.3998	3.9683
	N	15	15	15
	Std. Deviation	2.41789	2.65652	1.71735
	Std. Error of Mean	.62430	.68591	.44342
	Minimum	.90	2.63	1.72
	Maximum	8.49	11.94	7.21
draft	Mean	12.2459	7.2733	4.7831
	N	24	24	24
	Std. Deviation	7.60919	3.03034	3.18936
	Std. Error of Mean	1.55322	.61857	.65103
	Minimum	1.38	3.19	2.41
	Maximum	31.91	15.65	15.59
Total	Mean	9.3089	6.5527	4.4697
	N	39	39	39
	Std. Deviation	7.16677	3.00178	2.72114
	Std. Error of Mean	1.14760	.48067	.43573
	Minimum	.90	2.63	1.72
	Maximum	31.91	15.65	15.59

4.2 Conventional vs RCL Movements

Our analysis in Table 4 shows that RCL movements create greater accelerations than Conventional movements. When interviewing conductors, they were not surprised by this because conventional movements allow the engineer to have direct control over the throttle whereas the RCL has automated throttle selections. The difference in the means between the two methods was statistically significant with moderate association ($p=0.012$, $\eta 2= 0.160$).

Table 4. Acceleration statistics by locomotive control type (conventional vs. RCL).

Movement Type	buff/draft	Mean X-axis MAX (m/sec^2)	N	Std. Deviation	Std. Error of Mean
Conventional	buff	3.1756	5	1.38608	0.61988
	draft	5.7978	5	3.43763	1.53735
	Total	4.4867	10	2.83125	0.89532
RCL	buff	5.3270	10	2.55459	0.80783
	draft	13.9427	19	7.53448	1.72853
	Total	10.9718	29	7.48070	1.38913

4. Discussion

Railroad employees are trained to safely ride moving freight cars. This case study of accelerations experienced while riding freight cars during movement events helps to provide meaningful data for railroad health and safety practitioners. Draft accelerations during RCL movements were shown to be the greatest contributor to freight car accelerations while riding. Armed with this knowledge, railroad employees can better anticipate these accelerations and health and safety practitioners can consider riding techniques, operating rules, and PPE options to help counteract freight car accelerations that are typically encountered.

A limitation of this study was that it was only conducted at Union Pacific railyards. Perhaps methods used by other railroads would change the outcome. However, because the FRA requires that shoving and pushing movements have point protection, the results for those types of movements should be similar. In a study by Weames, et al. (2019), the peak locomotive buff accelerations during one-mile-per-hour coupling events yielded substantially similar magnitudes to those measured here.

Train makeup, train size, train handling, coupling speed, track geometry, and the specific amount of draft gear buff and draft movement are some of the variables that can affect peak acceleration of freight cars during train movements. In the real-life railroad environment, these elements are not easily repeatable, for the execution of a controlled experiment. Since railyard operations include cars of all ages and design, these variables were not controlled.

Lastly, the forces involved in these movements are a direct reflection of the skill of the Engineer or Conductor who is affecting the train movement. In general, slower train movements result in lower slack action accelerations.

This investigation demonstrates that freight car accelerations can be measured during freight car riding tasks. The data collected and reported here is the first known acceleration data collected for this task and may assist with biomechanical modeling of slack action events along with general riding conditions. Such analysis, in conjunction with real-world temporal data, may allow for the assessment of muscle fatigue and could help to determine the clinical grip strength needed to perform the task studied here.

5. References

49 CFR § 218.99 (2008). *Code of Federal Regulations*. Transportation; Railroad Operating Practices; Shoving or pushing movements.

Railroading Glossary. (31 August 2014). Trains.com. Kalmbach Publishing. Retrieved from: https://web.archive.org/web/20140831175630/http://trn.trains.com/Railroad%20Reference/Railroading%20Glossary.aspx?letter=A

Weames, G. et al. (2019). *Accelerations of the Locomotive Cab Space and Locomotive Engineer During Coupling Events and Their Comparison to Typical Human Activity -A Case Study*. Proceedings of the 31st Annual International Occupational Ergonomics and Safety Conference. New Orleans, LA.

Wu, Qing & Spiryagin, Maksym & Cole, Colin. (2015). Advanced dynamic modelling for friction draft gears. Vehicle System Dynamics. 53. 10.1080/00423114.2014.1002504.