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Deterministic Hunting Speed Restrictions

Walter Rosenberger and Kenny Morrison

Key Findings:

- Wayside truck hunting detector data can provide a deterministic method that will optimize equipment speed restrictions and avoid hunting.
- Hunting Index (HI) data is converted into statistical defect rates: pass count per million truck passes above an HI threshold.
- Railroads can choose the HI threshold and the threshold defect rate suitable for their operations. The comparative performance of the unrestricted population informs that selection.
- Railroads can adjust existing speed restrictions for car groups as determined by actual hunting data.
- Railroads can continue using their wayside detector alerts to restrict any given car or cars using their established intercept and crew messaging systems.

As part of the Association of American Railroad's (AAR) Car and Truck Systems Strategic Research Initiative program, TTCI was asked to determine the conditions under which speed restrictions for high speed instability, better known as hunting, could be mitigated. TTCI focused this analysis on North American truck hunting detector (THD) data.

Hunting, a risk factor for derailments as well as equipment and lading damage, has an onset threshold train speed at which lateral oscillatory behavior begins. Hunting intensity generally increases with speed, and it subsides after speeds drop below the threshold speed. In addition to speed, the onset of hunting is a function of equipment condition and characteristics, as well as some track conditions and characteristics. Some cars tend to hunt at lower speeds, while others are stable at the highest allowable train speeds.

Historically, railroads managed hunting risks by speed-restricting entire groups or series of equipment based on past adverse experience, such as derailments or lading damage. Since each railroad had different experiences, and operated in different conditions, each railroad put different speed restrictions in place. Cars that might operate at 60 mph on one railroad might be restricted to 40 mph on another. A method for: 1) assessing hunting risks objectively and uniformly, and 2) applying any speed restrictions deterministically was needed.

TTCI surveyed North American Class 1 railroads for their equipment speed restrictions. These restrictions ranged from specific maintenance-of-way machines to entire classes such as equipped and unequipped gondolas, hoppers, and coal gondolas. Restricted speeds ranged from 30 to 55 mph, with less than 1 percent of all restrictions imposed below 30 mph. (Note: typical Class 1 manifest train speed limits are 50 to 60 mph and up to 70 mph for some intermodal trains.)

DEFINING HUNTING

The AAR *Manual of Standards and Recommended Practices* (MSRP) defines hunting in terms of carbody lateral acceleration: a peak-to-peak value of 1.5g or a standard deviation of 0.13g.[1] As measured by wayside detectors in regular service, hunting is defined by the Hunting Index (HI). The HI is the output of a vendor-proprietary calculation based on lateral wheel forces measured as a truck crosses a THD site. HI is a parameter well accepted by the industry to indicate hunting propensity.

Equipment maintenance can be initiated with a single HI absolute value reading of 0.50 or higher or two HI absolute value readings of 0.35 or higher in a 12-month span.[2] Previously, TTCI explored the relationships between car type, car condition, lateral accelerations, and HI values.[3,4]

DEFINING THE POPULATIONS

TTCI accessed five years' worth of THD pass data, representing 1,954,805 cars and 481,718,116 truck-detector passes. These cars comprise the vast majority of freight cars registered in the Railinc UMLER® equipment registry over the last five years. The equipment restrictions provided by the railroads comprised 236,826 cars, but only 109,656 passed a hunting detector in the last five years, resulting in 21,526,016 rows of data. The fact that less than half of the restricted cars appeared to be active indicated that the railroads' scope of restricted equipment was somewhat out of date, recognizing that some restricted equipment could be operating in captive service on a route never crossing a THD.

Cars were considered loaded if their "percent load" THD value was 50 percent or greater. Cars were considered empty, or lightly loaded, if their "percent load" THD value was less than 50 percent. Nominal speeds were defined in multiples of five (e.g., 40, 45, 50 mph). Pass data were binned by speeds ±2.5 mph from the nominal speed.

The reference population was defined as all THD passes by cars that were not listed in any railroad restriction, resulting in 465,253,888 rows of data. This population was the control group used for comparison with the restricted equipment groups. For purposes of this study, four restricted equipment groups were formed out of the various hunting restriction rules provided by the railroads. The restricted populations are defined below using AAR nomenclature:

- "E and G" – Equipped and unequipped gondolas (Exxx, Gxxx; 56,206 cars total); empty and loaded; typically restricted to 45 to 50 mph.
- "Flat" – Mechanical groups FMS; FB, FBS (bulkhead flats), FBC (centerbeam flats), and FDC (depressed, bulkhead centerbeams); AAR types Fx1x, Fx2x, Fx4x, Fx5x, Fx8x, Fx9x; F171 and F373 skeleton flats; 33,754 cars total; all types except F171 were empty; typically restricted to 45 to 55 mph.
- "H, J, and K" – Equipped and unequipped hoppers and coal gondolas (15,920 cars total); empty; typically restricted to 55 mph.
- "Heritage" – Various car types with certain heritage reporting marks (6,110 cars total); empty and loaded; typically restricted to 40 mph.

These population groups were broad for purposes of this study and can be refined as needed.

POPULATION HISTOGRAMS

HI data are usually shown as a scatterplot in terms of pass speed. That format is comprehensive for all passes, but it is difficult to describe the population statistically and to compare one population with another. In this analysis, the THD pass data for each population were grouped by speed at 5-mph intervals. The HI data for each speed were then binned into discrete values in intervals of 0.02, and the population was described as a count of passes in each HI bin. The count data were normalized by the total count to produce a percentage histogram, as shown in Figure 1. The horizontal axis shows the bins of HI values in intervals of 0.02. The vertical axis is the percent (log scale) of total THD passes for the populations shown.

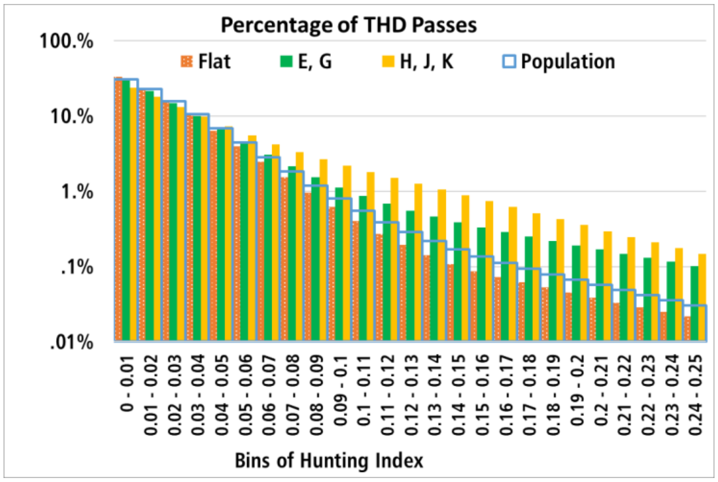

Figure 1. Normalized histogram for THD passes at 45 mph, empty

Figure 1 shows THD passes for E, G; Flat; and H, J, K cars at 45 mph in empty-lightly loaded condition. The three restricted populations (solid columns) differ from the comparison unrestricted data ("Population") and from each other above an HI of 0.05.

Absolute values of HI were used in this analysis, per industry practice. It is also important to note that the HI data were not normally distributed. This had implications on the statistical tools that were used to analyze them.

Statistical tests showed there were statistically significant differences between each car group and the unrestricted population. The differences may be statistically meaningful, but from the standpoint of hunting, not practically meaningful. This finding did not improve our understanding of which populations might be unnecessarily restricted. A better methodology would be to look at exceptions at higher HI levels using population percentiles and ultimately a defect rate analysis.

PERCENT ATTAINMENT (NON-EXCEEDANCE)

Table 1 shows the HI values for population percentiles defined by car group, loading condition, and speed. The green-yellow-red cell shading is based on the HI values from 0.20 to 0.50. For clarity, not all speeds and equipment groups are shown.

Table 1. Hunting Index (HI) values as a function of percentile rank

Speed [mph]	Per-centile	Loaded		Empty-Lightly Loaded			
		E, G	Popu-lation	E, G	Flat	H, J, K	Popu-lation
45	0.5	0.02	0.02	0.02	0.02	0.02	0.02
	0.75	0.04	0.03	0.04	0.04	0.05	0.04
	0.9	0.06	0.05	0.06	0.06	0.08	0.06
	0.95	0.07	0.06	0.08	0.07	0.12	0.08
	0.99	0.11	0.09	0.15	0.11	0.21	0.12
	0.999	0.17	0.14	0.31	0.20	0.34	0.23
50	0.5	0.02	0.01	0.02	0.02	0.02	0.02
	0.75	0.04	0.03	0.04	0.04	0.04	0.04
	0.9	0.06	0.04	0.07	0.06	0.07	0.06
	0.95	0.07	0.06	0.10	0.07	0.10	0.08
	0.99	0.11	0.09	0.21	0.12	0.20	0.12
	0.999	0.19	0.14	0.38	0.25	0.33	0.28
55	0.5	0.02	0.01	0.03	0.02	0.02	0.02
	0.75	0.04	0.03	0.05	0.04	0.05	0.04
	0.9	0.05	0.04	0.09	0.07	0.08	0.06
	0.95	0.07	0.06	0.13	0.08	0.12	0.08
	0.99	0.11	0.09	0.30	0.14	0.23	0.14
	0.999	0.23	0.16	0.46	0.32	0.40	0.32
60	0.5	0.01	0.01	0.03	0.02	0.02	0.01
	0.75	0.03	0.03	0.07	0.05	0.06	0.03
	0.9	0.05	0.04	0.12	0.08	0.14	0.05
	0.95	0.06	0.06	0.18	0.10	0.19	0.08
	0.99	0.13	0.09	0.34	0.19	0.29	0.15
	0.999	0.28	0.17	0.48	0.38	0.44	0.34

For example, 99 percent of empty flatcar passes at 55 mph had a HI ≤ 0.14. However, the last 1 percent of the data contains the responses of interest, where empty flatcars had HIs of 0.32 or more.

DEFECT RATE ANALYSIS

To transition from the percentiles of Table 1 to a defect rate, the percentiles and HI values interchanged, and the percentiles were replaced with the equivalent exceedance values. The exceedance values were then multiplied by 1,000,000 to create a rate per million truck passes. In statistical process control terminology, this would be a defect rate in units of parts per million (ppm). It has meaning as an upper control limit (UCL).

Table 2 shows the defect rates calculated for all speeds and loading conditions for the car groups under consideration. The user would set a threshold HI and a threshold defect rate. The colored cells are an example of using Method 2 described below, choosing the HI ≤ 0.35 and a maximum defect rate of 1,000 ppm for empty hoppers. This example suggests a speed restriction of 50 mph.

Table 2. Defect rates for the restricted populations compared to the unrestricted population, for given loading, speed, and HI value

Speed [mph]	HI	Loaded		Empty-Lightly Loaded			
		E, G	Popu-lation	E, G	Flat	H, J, K	Popu-lation
45	0.2	418	134	4,758	985	11,041	1,611
	0.25	145	49	2,499	477	4,652	737
	0.3	60	21	1,151	204	1,923	324
	0.35	30	8	448	99	778	128
	0.4	5	4	141	43	280	45
	0.45	-	1	29	8	87	15
	0.5	-	-	7	-	22	4
50	0.2	742	254	11,336	1,928	9,504	2,804
	0.25	333	112	6,532	925	4,346	1,455
	0.3	135	50	3,383	455	1,762	699
	0.35	59	21	1,519	229	636	300
	0.4	22	9	616	106	202	112
	0.45	5	3	222	36	73	36
	0.5	1	1	70	17	24	11
55	0.2	1,531	459	25,061	3,822	15,222	3,993
	0.25	734	217	16,316	2,308	8,002	2,238
	0.3	335	110	10,047	1,197	4,302	1,223
	0.35	144	53	5,711	629	2,138	614
	0.4	52	23	2,884	292	922	270
	0.45	23	9	1,174	135	282	101
	0.5	12	4	451	30	72	32
60	0.2	2,738	493	43,087	9,024	42,613	4,267
	0.25	1,453	234	26,609	5,060	19,316	2,499
	0.3	738	126	15,951	2,868	7,372	1,493
	0.35	381	65	8,729	1,560	3,686	838
	0.4	112	29	4,277	655	1,740	415
	0.45	42	12	1,928	337	868	177
	0.5	17	5	561	-	442	66

There are two ways to evaluate the defect rate:

1. Set the speed restrictions based on the car group's defect rate compared to the unrestricted population's defect rate. If a car group's defect rate is close to the population's defect rate for the same speed and HI level, set the restriction to that speed. For example, several railroads

restrict empty flatcars to 45 mph. The data in Table 2 show that empty flats have essentially the same defect rate as the unrestricted population up to 55 mph regardless of HI. Therefore, a 55-mph restriction might be more appropriate than a 45-mph restriction.

2. Set the speed restrictions based on a defect rate UCL in absolute terms. For example, a railroad could define a hunting threshold at 0.35, and set a defect rate UCL of 1,000 ppm. Then, enter Table 2 with that criteria. If the defect rate exceeds the UCL for a given speed, restrict the speed to the point that the defect rate is less than the UCL.

For example, using H, J, K cars (gold outline) with an HI limit of 0.35 (blue shaded cells) and a maximum defect rate of 1,000 ppm, these cars would be restricted to 50 mph (the green shaded cell, where the defect rate is 636). Above 50 mph, the defect rates exceed 1,000 ppm (red shaded cells). The HI of 0.35 and defect rate of 1,000 were chosen because the defect rate of the unrestricted population at 60 mph was just below that at 838 ppm. In other words, the defect rate at the chosen restricted speed was no greater than the defect rate for the unrestricted population at 60 mph.

Railroads could still handle any individual car that had a history of HIs greater than 0.35 with a single car exception message, and restrict the train on an individual basis as long as that car was within the consist.

CONCLUSION

A statistical analysis of HI data provides a means of deterministically setting speed restrictions for a car group as needed. The railroad can objectively define the criteria that will result in a speed restriction: HI threshold and an acceptable defect rate in terms of ppm. Railroads may still apply restrictions to individual cars as established by current intercept messaging protocols.

FUTURE WORK

With this methodology in place, more refined definitions of restricted car groups and characteristics could be evaluated. For example, FBC (center beam) flats could be evaluated distinctly from all other flats. All cars longer than 85 feet, or all cars with 33-inch wheels, could be evaluated. Any characteristic represented by a populated UMLER® field can parse the equipment for evaluation.

Moreover, definitions of restricted equipment groups could essentially be reverse engineered by identifying all equipment with a defect rate above a given threshold and HI, and then examining that population for common characteristics such as lack of constant contact side bearings, car length, and AAR type. Some cars will be identified because of their worn mechanical condition. It will take skillful insight to distinguish the nominal mechanical conditions defining a population from worn mechanical conditions.

This AAR initiative plans to: 1) identify the population characteristics associated with higher defect rates, and 2) evaluate their effect on hunting with NUCARS®* vehicle dynamics simulations. Additional simulations will identify which track-based characteristics (i.e., gage-corner contact, top-of-rail friction modifiers) either promote or suppress hunting.

**NUCARS® is a registered trademark of TTCI.*

References

1. *AAR Manual of Standards and Recommended Practices*, Section C-Part II, Specifications for Design, Fabrication, and Construction of Freight Cars, M-1001, paragraph 11.7.2, Association of American Railroads, Washington, D.C., 2015.
2. *Field Manual of the AAR Interchange Rules*, Rule 46.1.e. Association of American Railroads, Washington, D.C. Effective January 1, 2020
3. Tournay, H., S. Chapman, R. Walker. "Evaluation of Cars Registering Salient Hunting Indices at or above 0.25." *Technology Digest* TD06-025. AAR/TTCI, Pueblo, Colorado. June 2015.
4. Tournay, H., S. Chapman, R. Walker. "Evaluation of Cars Registering Salient Hunting Indices at or above 0.1." *Technology Digest* TD07-012, AAR/TTCI, Pueblo, Colorado, July 2015.

For comments or questions about this publication, contact Walter_Rosenberger@aar.com

