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SPATIAL ANALYSIS OF FREIGHT-TRAIN DERAILMENTS IN THE UNITED STATES

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ABSTRACT

Railroads significantly contribute to the national economy by moving over 40 percent of intercity ton-miles of freight. Meanwhile, train accidents can damage to infrastructure and rolling stock, disrupt operations, and possibly cause casualties and harm the environment. Therefore, accident prevention is a top priority for the railroad industry and the Federal Railroad Administration. Cost-effective railroad safety risk management relies on a good understanding of risk distribution on spatial and temporal scales. The literature predominantly focuses on national average train safety statistical analysis, without accounting for the spatial variation in train accident frequency. Based on recent train accident data on U.S. freight railroads, a spatial analysis of freight-train derailments was conducted. The analysis compares statewide freight-train derailment rates, and identifies leading derailment causes in each region.

INTRODUCTION

Safety is the lifeline of any rail system. One commonly used metric to evaluate rail safety is accident rate, which is defined as the number of train accidents normalized by traffic exposure (e.g., train-miles, car-miles, gross ton-miles or passenger-miles) [1, 2]. The Federal Railroad Administration (FRA) and U.S. Department of Transportation (USDOT) requires railroads to provide detailed reports on the accidents exceeding a specified monetary threshold of the damage to infrastructure, rolling stock and signals [3]. In addition, railroads also report their monthly traffic volume data (measured by train-miles) to the FRA. Using the accident count and traffic data, researchers analyzed accident rates by infrastructure quality [4], accident cause [5] or year [6]. Besides accident frequency, prior research also analyzed derailment severity, measured by the number of railcars derailed [1, 2, 7].

However, almost all of the previous studies focus exclusively on national average accident risk, without accounting for the possible spatial variation in accident occurrence. Little work has been conducted to understand how the accident rate in one state may differ from another, nor what the top accident causes in each region are.

SCOPE AND OBJECTIVES OF THE STUDY

To narrow these knowledge gaps, this research uses Geographical Information Systems (GIS) techniques and Statistical Inference Techniques to address the following research inquires:

1) How can statewide accident rates be statistically compared?
2) What are the leading accident causes in each state?

FRA maintains three major databases, each related to a different aspect of train operating safety: train accidents, employee casualties, and railroad and highway grade crossing collisions. A particular reportable event may require that reports be submitted to any or all of these, alone or in combination, depending on the circumstances. The Rail Equipment Accident/Incident Report (REAIR) form (FRA F 6180.54) is used by railroads to report all accidents that exceed a monetary threshold of damages to infrastructure and rolling stock (the form accounts for damage to on-track equipment, signals, track, track structures, and roadbed. The reporting threshold is periodically adjusted for inflation and increased from $7,700 in 2006 to $10,500 in 2014). FRA compiles these reports into the rail equipment accident (REA) database, which records rail equipment accident data dating back to 1975. In addition to the REAIR, the Highway–Rail Grade Crossing Accident/Incident Report (FRA F 6180.57) and Death, Injury, or Occupational Illness Summary (FRA F 6180.55a) are the other two principal railroad accident and incident reporting forms. A single accident may require more than one report. For example, if the accident involved a highway user at a highway–rail crossing, regardless of impact, a Form FRA F 6180.57 must also be completed. This study used data exclusively from the FRA REA database.

In the FRA REA database, there are four types of tracks recorded: main, siding, yard, and industrial tracks, which are used for different operational functions. Different tracks can have different types of accident, causes, and consequences. In addition, train accidents are classified into derailment, collision, highway–rail grade crossing incident, and several other less frequent types. Table 1 presents an analysis of train derailment frequency and severity by both the type of track and type of accident including data from 2000 to 2014. For all four types of track, derailment appears to be the main accident type on the national level. Thus in the following analysis, derailment frequency is analyzed on state levels on mainline and siding tracks from 2000 to 2014.

Table 1. Accident frequency and severity by accident type and track type, U.S. freight railroads, 2000-2014

Number of Freight Train Accidents

	Derailment	Collision	Highway-Rail	Other	Total
Main	6,026	429	1,929	874	9,258
Yard	4,220	524	14	518	5,276
Siding	632	33	7	66	738
Industry	1,286	76	9	190	1,561
Total	12,164	1,062	1,959	1,648	16,833

Total Number of Railcars Derailed in Freight Train Accidents

	Derailment	Collision	Highway-Rail	Other	Total
Main	51,993	1,793	901	685	55,372
Yard	19,763	998	10	737	21,508
Siding	3,353	116	5	68	3,542
Industry	5,793	121	12	119	6,045
Total	80,902	3,028	928	1,609	86,467

Average Number of Railcars Derailed per Train Accident

	Derailment	Collision	Highway-Rail	Other	Total
Main	8.6	4.2	0.5	0.8	6.0
Yard	4.7	1.9	0.7	1.4	4.1
Siding	5.3	3.5	0.7	1.0	4.8
Industry	4.5	1.6	1.3	0.6	3.9
Total	6.7	2.9	0.5	1.0	5.1

Railroads also report to the FRA their monthly train-mile data, which are available through the FRA Operational Data database. Train-mile data were used to analyze train derailment rate [13-15]. Based on railroad-specific traffic volume data, statewide traffic volume can be estimated.

STATISTICAL COMPARISON OF ACCIDENT RATES

The estimated freight-train derailment rate of each state can be calculated based on the accident and traffic data described above. Because train accident occurrence follows a random process [6], the empirical accident rate may not reflect the actual safety level of an entity. One main objective of this research is to develop a statistical approach to comparing whether the difference of accident rate between any two states (can be adapted to any two railroads) is statistically significant. The test used here is referred to as the conditional test (C-test), which was used in statistical literature [16, 17].

A conditional test (C-test) was developed to compare the mean Poisson rates (the number of events per interval or exposure). Below is a procedure for conducting a conditional test. The mathematical details of the C-test can be found in [16, 17].

Null hypothesis H_0: $Z_H = Z_{NH}$ (derailment rate in state H is equal to derailment rate in another state NH)

Alternative hypothesis H_a: $Z_H \neq Z_{NH}$ (derailment rate in one state is not equal to derailment rate in another state)

The C-test is performed through a binomial distribution model:

$$P(X_H \geq K_H \mid K_H + K_{NH}) = \sum_{i=K_H}^{K_H+K_{NH}} \binom{K_H + K_{NH}}{i} \left(\frac{M_H}{M_H + M_{NH}}\right)^{i} \left(\frac{M_{NH}}{M_H + M_{NH}}\right)^{K_H + K_{NH} - i}$$

The P-value in the C-test is:

$$P_C = 2 \times \min\left\{P(X_H \geq K_H \mid K_H + K_{NH}), 1 - P(X_H \geq K_H \mid K_H + K_{NH})\right\}$$

Where:

K_H = derailment count in state H;

K_{NH} = derailment count in another state NH;

M_H = traffic exposure (million train-miles) in state H;

M_{NH} = traffic exposure (million train-miles) in state NH;

P_C = P-value in the C-test;

The decision rule is that if $P_c < 0.05$ (95% confidence level), the null hypothesis of equal derailment rate would be rejected. It means that the two states may have statistically different accident rates.

For example, the freight-train derailment counts in the state of Illinois and New York were 467 and 127, respectively, from 2000 to 2014. Within the same period, the corresponding traffic volumes were 100.53 and 20.04 (million train-miles). Using the C-test, the P_c value is 0.002, less than 0.05, indicating that the two states had statistically different derailment rates during the study period (derailment rates are 4.7 versus 6.4 per million train-miles). Another example is that total derailment counts in Minnesota and Montana were 255 and 181, respectively from 2000 to 2014. The corresponding traffic volumes were 78.19 and 52.79 million train-miles. The P_c value is 0.57, indicating that the two states did not have statistically different derailment rates.

The statistical test was applied to the comparison of statewide derailment rates. The states labeled in the same color have statistically identical derailment rates. The states with "similar" derailment rates are:

- Louisiana, Massachusetts, Minnesota , Montana
- South Dakota, Missouri, Vermont, Illinois
- New York, Indiana , Maine, New Hampshire, Connecticut
- Ohio, Oregon, Kentucky
- Iowa, Utah
- Arizona, Idaho, Washington, North Carolina
- South Carolina, Alabama , Pennsylvania, New Mexico, Kansas, North Dakota
- Tennessee, California, Oklahoma, Arkansas
- Mississippi, Maryland, West Virginia

*The list excludes Delaware, Nevada, Rhode Island, Wyoming due to limited derailment count sample size or limited traffic

**The list excludes the following states, each of which has statistically different derailment rates from other states - Florida, Nebraska, Virginia, Texas, Wisconsin, New Jersey, Michigan, Colorado, Delaware, Wyoming, Nevada, District of Columbia.

LEADING DERAILMENT CAUSES IN EACH STATE

In this section, we analyzed the leading derailment causes in each state (Table 2). For about 80% (37 out of 46) states, the leading derailment cause was broken rails or welds (08T). For the states whose leading cause was not broken rails, all of them (9 out of 9) had broken rail as the second most frequent cause. These results illustrate the high frequency of broken-rail-caused derailments in all states in the United States. For about 9% (4 out of 46) of states, the leading derailment cause was track geometry defects (04T). For about 6.5% (3 out of 46) states, the first leading cause was wide gauge (03T). For about 63% (29 out of 46) states, the second leading cause was either track geometry defects or wide gauge. The top two leading causes contributed to more than 30% of all freight-train derailments in 40% of states (17 out of 46), and more than 20% of all freight-train derailments in 89% of states (41 out of 46) in the studied states.

Table 2. Leading Derailment Cause by State

Top Cause	Second Leading	State	08T	04T	03T	10E	09H	Other Causes	% Top Two Causes
08T	04T	TX	133	114	46	30	35	288	26%
08T	03T	IL	67	32	45	26	23	133	24%
04T	08T	CA	34	36	23	8	34	116	18%
08T	04T	KS	65	39	28	12	12	141	27%
12E	08T	NE	35	19	13	28	4	151	19%
08T	03T	PA	58	26	51	8	25	82	32%
04T	08T	MO	37	42	20	8	12	93	27%
08T	04T	IA	56	36	17	13	7	83	34%
08T	03T	OH	38	17	33	15	7	82	27%
08T	05T	MN	46	15	15	14	6	81	25%
08T	04T	OK	34	27	11	13	9	80	26%
08T	04T	GA	43	24	18	6	12	51	30%
08T	03T	AL	31	15	22	11	8	61	24%
08T	04T	AR	40	20	13	6	8	67	28%
08T	04T	CO	29	23	13	10	9	74	24%
12E	08T	WY	18	6	4	12	4	87	18%
08T	04T	LA	32	20	20	4	11	47	27%
08T	09H/05T	MT	21	9	4	9	13	69	26%
08T	01M	VA	38	5	14	8	8	60	28%
08T	03T	ND	24	7	11	14	1	59	22%
08T	10E	IN	30	5	11	16	5	53	26%
08T	04T	MS	34	21	19	4	15	28	31%
08T	04T/03T	WV	49	9	9	8	3	55	40%
08T	09H	OR	23	15	14	6	19	41	26%
08T	03T	MI	23	5	14	10	13	33	24%
08T	03T	AZ	38	1	10	6	9	31	33%
08T	04T/03T/10E	WI	25	15	15	15	5	34	48%
08T	04T	KY	33	7	5	5	6	43	27%
08T	03T	TN	24	5	10	5	9	37	25%
08T	03T	FL	31	4	18	13	4	23	37%
08T	10E	WA	13	9	9	10	3	45	18%
08T	03T	NC	33	4	9	5	9	34	33%
08T	03T	NY	22	5	11	10	9	31	26%
08T	04T	SD	30	17	11	4	0	26	41%
08T	03T/10E	NM	14	3	7	7	2	29	26%
08T	04T	ID	14	7	6	6	1	31	24%
08T	04M	SC	20	6	3	2	1	27	33%
10E	08T/09H	UT	3	1	2	6	3	26	19%
08T	03T	MD	10	2	7	3	2	16	29%
04T	08T	ME	9	13	3	6	5	7	38%
08T	10E	NV	13	1		6	4	14	33%
08T	03T	MA	11	1	3	2	2	13	29%
08T/03T	04T	NJ	4	3	4	2	0	7	35%
04T	08T	VT	2	6	1	0	1	9	35%
03T	08T	CT	3	0	4	0	1	4	46%
03T	08T	DE	2	0	3	0	0	4	46%

Notes: 08T=Broken Rails, 04T=Track Geometry Defects (excl. Wide Gauge), 03T=Wide Gauge, 10E=Bearing Failure (Car), 09H=Train Handling (excl. Brakes), 12E=Broken Wheels (Car), 05T = Buckled Track

Some states had a relatively limited sample size of derailment count or had little traffic, which may lead to greater statistical uncertainty. Thus, we aggregated statewide derailment count and traffic volume into seven regions (Figure 1) and analyzed the leading causes in each region. Considering that there might be seasonal effects on accident cause distributions, we also analyzed the leading derailment causes by season (Table 3).

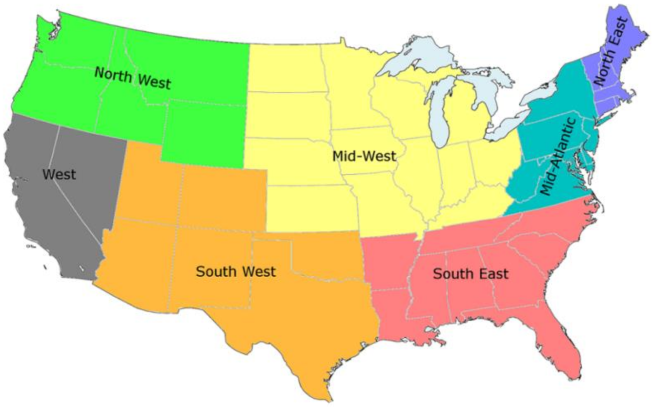

Figure 1. Regional Classification of the United States

Table 3.Top Causes by Region and Season

Region	08T	04T	03T	10E	09H	Other Causes	% by Top 2 Causes
Mid-West	509	256	238	180	101	1952	23%
spring	87	80	64	48	21	480	21%
summer	91	97	49	37	33	587	21%
autumn	176	39	39	27	25	404	35%
winter	155	40	86	68	22	481	28%
South-West	251	169	89	72	67	1060	24%
spring	43	41	28	24	19	268	20%
summer	45	51	22	11	23	326	20%
autumn	83	48	21	18	11	252	30%
winter	80	29	18	19	14	214	29%
South-East	288	119	132	56	77	847	26%
spring	57	37	30	14	18	207	26%
summer	46	40	41	12	20	249	21%
autumn	78	23	24	16	18	205	28%
winter	107	19	37	14	21	186	38%
Mid-Atlantic	183	50	99	39	47	505	31%
spring	36	12	25	7	14	134	27%
summer	26	22	23	10	10	133	21%
autumn	51	4	13	6	9	97	35%
winter	70	12	38	16	14	141	37%
North-West	89	46	37	43	40	503	18%
spring	19	11	17	13	10	131	18%
summer	13	18	6	10	8	128	17%
autumn	36	11	4	8	14	101	27%
winter	21	6	10	12	8	143	16%
West	34	36	23	8	34	260	26%
spring	7	13	3	6	11	74	17%
summer	3	11	6	1	10	68	21%
autumn	8	7	6	1	6	43	21%
winter	16	5	8	0	7	75	21%
North-East	26	20	11	9	9	73	31%
spring	12	9	4	3	4	24	38%
summer	4	6	2	0	4	28	32%
autumn	2	5	2	2	0	4	74%
winter	8	0	3	4	1	17	36%

The analysis shows that broken rails (08T) and track geometry defects (04T) caused a large proportion of freight-train derailments in each region and season. In order to understand the statistical distribution of derailment count by region and season, a chi-squared independence test [18, 19] was developed. For broken rails (08T), the χ^2 was 35.45 (df = 18) and the corresponding p-value was 0.0083 (<0.05). This means that the distribution of broken-rail-caused derailment frequency by region varies with the season. However, for track geometry defects (04T), the χ^2 was 27.65 (df =18) and the corresponding p-value was 0.067, indicating that its derailment distributions by region and season were independent .

The table shows that for broken-rail-caused derailments, autumn and winter had more accidents than spring and summer in the Mid-West. A similar pattern was found in the South West, Mid-Atlantic, South East and West.

For track geometry defects, there were more derailments in spring and summer than in autumn and winter in the Mid-West and South East. In the South West, North West and Mid-Atlantic, there were fewer track-geometry-failure-caused derailments during the winter than compared to other three seasons.

This analysis herein does not account for traffic volume by region and season. An expanded statistical modeling can be developed to calculate region-and-season-specific train derailment rate by accident cause.

CONCLUSION

A spatial analysis has been developed to explore the freight-train derailment frequency on mainline and siding tracks in the United States. A statistical methodology was used to compare whether the derailment rates in different states were statistically different. Also, the top derailment causes were analyzed in each state. Broken rail was the leading cause in most states, followed by track geometry defects or wide gauge. This indicated the importance of further improving infrastructure safety for derailment prevention. In addition to spatial effects, there are seasonal variations in the distribution of leading derailment causes. Broken rails caused more derailments in winter and fall, than in spring and summer. However, track geometry defects caused more derailments in warmer seasons.

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