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Natural Hazard Risks On Railway Turnout Systems

Serdar Dindar[a,b], Sakdirat Kaewunruen [a,b,]*, Min An[b], Mohd H. Osman[a,b]

[a]Birmingham Centre for Railway Research and Education, The University of Birmingham, Birmingham, B15 2TT UK
[b]Department of Civil Engineering, School of Engineering, The University of Birmingham, Birmingham, B15 2TT UK

Abstract

As an essential feature to enable rail operational flexibility, railway turnouts are special track systems used to divert a train from a particular direction or a particular track onto other directions or other tracks. Railway turnout is constructed on a complex geometry and grade, which makes it one of the most critical railway infrastructures. These characteristics pose various risks in rail operations. A considerable number of derailment incidents have occurred every year. Not only do these incidents yield operational downtime and financial losses, but they also give rise to the casualties and sometimes the loss of lives across the world. One of fundamental reasons is that railway industry barely pays attention to risk elements on railway turnouts. This paper thus presents how turnout components work as a system, the diversity of emerging risks considering natural hazards and global warming potential to the system. Additionally, in order to perform a well-designed quantitative-based risk analysis method for appropriate risk management of railway turnouts and crossings, focusing on aging, degradation and signalling faults on the systems, the research develops a number of new ideas.

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Keywords: Natural hazards; risks; railway turnouts; switch and crossing; systems thinking approach;

1. Introduction

Railway turnout system, as an essential feature to enable rail operational flexibility, is a special track infrastructure used to divert a train from a particular direction or a particular track onto other directions or other tracks. It is a structural grillage system that assembles steel rails, points (or called ‘switches’), crossings (or called ‘frogs’), steel

* Corresponding author. Tel.: +44 (0) 1214 142 670
E-mail address: s.kaewunruen@bham.ac.uk; sakdirat@hotmail.com

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plates, rubber pads, insulators, fasteners, screw spikes, beam bearers (either timber, polymer, steel or concrete), ballast and formation, as shown in Fig. 1 [1].

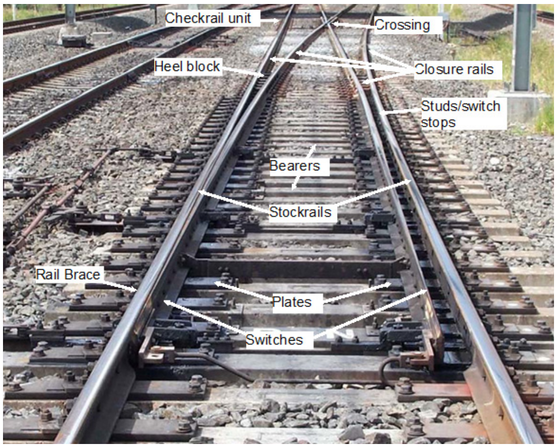

Fig. 1. Typical components of a turnout.

A railway turnout is a must-have structure in railway corridor whose crossing imparts a significant discontinuity in the rail running surface. High demand in railway operation, the railway operators have to increase the axle load, traffic density and speed of the operations [2]. The dynamic wheel/rail interaction on such imperfect contact transfer can cause detrimental impact loads on railway track and its components [3]. Therefore, turnouts tend to be one of the most vulnerable parts of railway.

2. Turnout Performance Criteria

Turnout characteristics: Each turnout is designed individually through unique situation, location and alignment considerations. These lead to a large range of diversity in type and function of each route and purpose of turnout, direction of diverging route from curvature of through route, super elevation throughout turnout, trailing or facing-point operation, and speed range and other tracking or ride quality situations. As a result, the characteristics of turnouts vary vastly.

Age of turnout components: The performance of components generally changes according to an exponential relation between rail age and cumulative tonnage on the rail [4]

Traffic load: It can be expected that there is an explicit correlation between the calculation of hazard rates of different failures and traffic density.

Environmental conditions: as a result of severe weather and extreme temperature, functions of component railway components are degraded more quickly than usual.

Proper maintenance strategies: a good practice of turnout maintenance provides that the system has a longer life span. Otherwise, the frequency of failure rates of the system inevitably increases.

3. The Impact of Climate

Although there is a heat debate on global warming, potentially serious changes, e.g. a gradual increase in the average temperature of the Earth's atmosphere and its oceans, have been identified. The changes are expected to show themselves through the intensity and frequency of extreme weather patterns such as high temperature waves, floods, and storm tides. Therefore, the associated potential effects (e.g., temperature, precipitation, sea level, and water levels) of climate change and extreme weather on components of turnout components could be one of the most crucial consideration to railway operation within the years ahead.

The turnout systems could be vulnerable to unforeseen changes in extreme weather or climate patterns. For instance, buckle is well-known phenomenon, developed by lateral forces formed through railway tracks exposed to high temperature. A little change in turnout geometry, e.g. buckling, has a high potential to result in train derailment. Rail buckles on the UK railway main tracks is shown to highly associate with extreme high temperatures [5]. It is expressed that an increased frequency of high temperature (greater than 25°C) occurrence is enough to occur buckling.

4. Methodology

The fundamental information is gathered from Federal Railroad Administration (FRA). The database is seen to be large enough to perform a risk analysis. Data from the years between 2006 and 2015 were selected as being the latest and recorded in detail. By examination of a ten-year period of FRA data, 2,321 derailment-related records are available. There is not any limitation to gather data (e.g. excluding derailments which do not incur significant costs). Therefore, all information is used to build a turnout database.

Although the data of 50 states that presently compose the United States, is available, the paper choses only Illinois as data provider. The reasons are as follows:

- Because of United States` 9.9 million km^2 area and mid-continental placement, a large number of states have simultaneously a widely varying climate, which makes almost unsuitable to understand the impact of climate patterns on turnouts.
- Illinois has extreme temperatures and precipitation changes through a year, whereas the climate is almost the same across the state.

Train Accidents Cause Codes in database are categorised into two separate group: Environmental-related† and component-related causes‡. Additionally, climate patterns through the selected period are gathered from U.S Climate Data Service.

5. Results and Discussions

169 of 2,321 derailment-related records are determined to occur at turnouts. The number of turnout derailments seems to fluctuate slightly through the years, whereas it is identified that there is a wide fluctuation on monthly-based as shown in Figure 2.

Figure 2 includes direct-weather and component-based causes. It can be said that derailment cases are relatively low in the calm months, including March, April, May, October and November, not having high precipitation and temperature as seen in Figure 3. However, derailment cases picked in June with the highest combination of extreme weather conditions. As a result, there seems to be a relation between occurrence of derailment and weather conditions.

Another aspect of results is shown to be that weather related reasons for derailment at turnouts accounts for nearly one-fifth of the entire derailments. This is open to discussion as data expresses only primary reasons. Therefore, a relationship could be available between component failures and climate patterns.

According to Table 1, it is hard to point out a correlation between climate and component failures. However, switch worn (T314) might be said to be fragile of extreme temperatures to be worn or broken. The temperature in winter season in Illinois is often seen to be minus zero whereas it reaches above 25 C^0 in June. In these months, the number of derailments related broken or worn switch tends to increase. Similarly, albeit not being as clear as T314, both T311 (damaged switch) and T319 (switch point gapped) have a similar trend. Therefore, it can be pointed out that most

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† Recorded causes; M101 (Snow, ice, mud, gravel, coal, etc. on track), M102 (Tornado), M103 (Flood), M105(Wind), M199 (other extreme environmental conditions), T001(Roadbed settled or soft), T002(Washout/rain/slide/flood/snow/ice damage to rail), T109(Track alignment irregular, e.g. buckling, sun kink)

‡ Recorded causes; T303 (guard rail failures), T305 (Retarder worn, broken), T307 (switch mechanism problems), T308 (stock rail worn, broken), T309 (hand operated- switch mechanism problems), T310 (switch connecting or operating rod is broken or defective), T311(switch damaged or out of adjustment),T313(Switch out of adjustment because of insufficient rail anchoring), T314(Switch point worn or broken), T315 (Switch rod worn, bent, broken, or Disconnected), T316 (Turnout frog (rigid) worn, or broken), T317(Turnout frog (self-guarded), worn or Broken), T319(Switch point gapped (between switch point and stock rail), T399 (Other frog, switch and track appliance defects).

switch failures are caused by high/low temperatures. On the other hand, precipitation is indicated to pick in May in Figure 3. There is no clear sign to discuss a direct correlation as no turnout component reacts in this month.

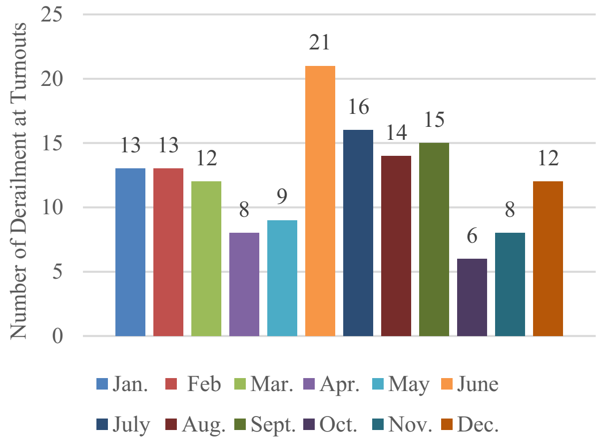

Fig. 2. Climate-related railway derailments by month of occurrence, from 2006 to 2015.

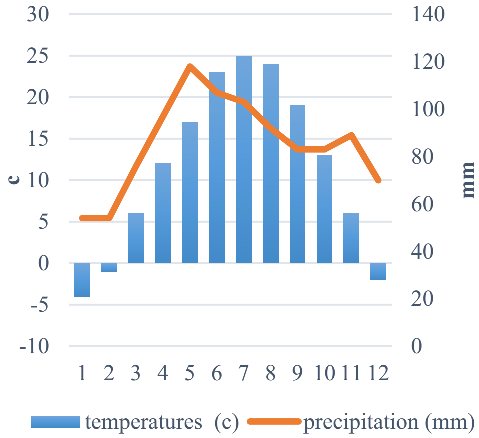

Fig. 3. Climate changes in Illinois by months [6].

Table 1. Distribution of reported component-based derailments at turnouts.

	T303	T305	T306	T307	T308	T309	T310	T311	T313	T314	T315	T316	T317	T319	T399
Jan								1		9					2
Feb			1	1		3			1	2					4
Mar								2	2	4	1	1		1	
Apr											5			2	1
May	2				1		1			2	1				
June	2							2	2	7		1	1	4	2
July						2		3	1	4				2	3
Aug								4		4				4	2
Sep	1	2		1		1		1	2	4				2	1
Oct		1						1	1			1		2	
Nov		1						2		4				1	
Dec					2					8				1	

It is recorded that there have been 31 derailment cases within the period. The distribution of these cases by failure codes is show in Figure 4. The irregularity in track geometry of turnouts (T109) dominates derailment cases in summer, while snow, ice, mud, gravel etc. on track (M101) outnumbers the others in winter by almost four to one. These two might be in a close relation to temperatures as it is known that the both occur providing that critical buckling temperature is exceed and the temperatures is enough low to happen many causes of M101.

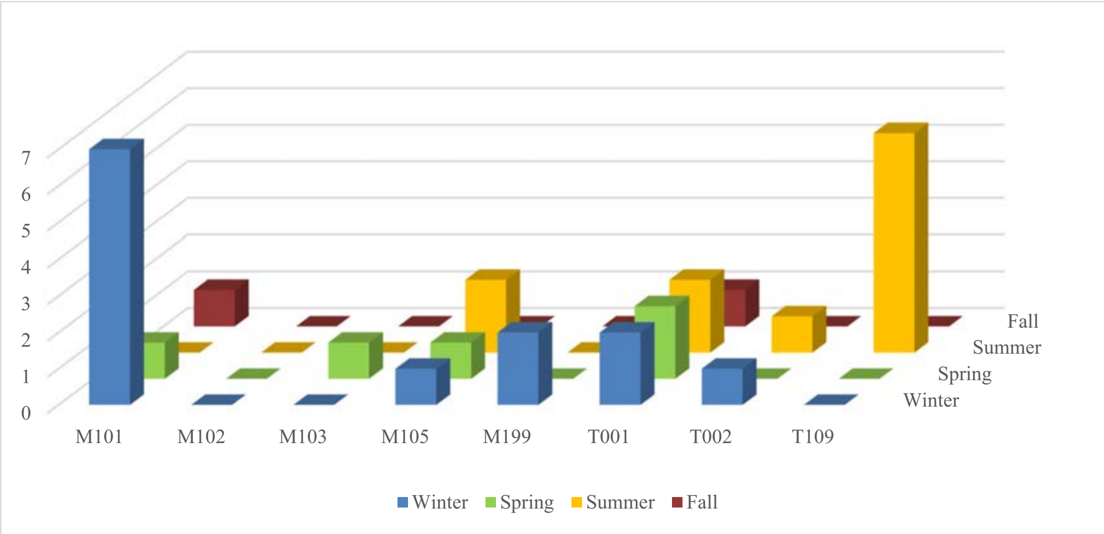

Figure 4. The number of derailment at turnouts by failure codes related to weather.

6. Analysing the Climate-Related Failures

Frequency of failure types is categorised in Table 2. Before calculating risk arising from identified in previous section, it should be known how big a catastrophic result is made by an accident cause. Table 3 helps us to understand their results in terms of cost. The values on the table stand for cost of average each case of failures.

Table 2. The likelihood of failure categorised by weather events.

Frequency of Failure	Low Temperature (<5 C^0)	High Temperature (20C^0<)
Certain	M101, T314	T109, T319
Likely	T308	T399
Unlikely	M199, T002, T307	T002
Improbable	T109	M102

Table 3. Average of Cost of a Derailment by Accident Cause Codes.

Codes	Average Cost ($)	Codes	Average Cost ($)
M101	37,896	T307	32,000
M102	396,013	T308	9,160
M199	501,105	T314	20,907
T002	883,797	T319	33,039
T109	378,700	T399	12,016

Therefore, risks of the accident codes can be rated considering their probabilities by Table 1 and impacts by Table 2. The riskiest accident code seems to be T109 followed by M101, T314 and T319. Considering huge impacts of M102, M199 and T002, these has been included in the analysis. However, their likelihood of happening is quite rare or improbable. As a result, both M199 and T002 induces medium risk on derailment, which might move forward into the risk management process. However, M102 is determined to fall into negligible category. The rest remain in the watch list in risk management process.

7. Conclusions

The paper investigates and analysis risk arising from natural hazard risks on railway turnout systems. 169 of 2,321 derailment-related records are evaluated to reach a conclusion. It is highly likely to express there is a tough relation between natural hazards and potential risk at turnouts.

It is found out that turnout geometry is quite vulnerable to high temperature, which results in high cost demanding to fix issues. On the other hand, almost each mechanical element of a switch should be moved forward into the risk management process to minimize potential failures particularly in winter and summer seasons. Roadbed settlement, ice and snow on rail, extreme weather conditions such as flood and strong wind also call for immediate action or risk management strategies as well. Further research will take into consideration the other characteristics of turnouts such as age, type, traffic density as pointed out in section 2. This might result in better understanding of the relationship.

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