Estimating the First Hitting Time for Track Geometry Degradation

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Outline

1. Introduction
2. Track Geometry Degradation
3. Modeling Approach
4. Implementation
5. Discussion
6. References
Track Geometry Defects is One Major Cause of Derailments in the United States

Ten-year trend for accident reductions from FRA data
Track Geometry

1Figures sources: AAR (2016); Transportation Safety Board of Canada (2014)
Research Objective

To estimate the first hitting time (FHT) in track geometry degradation and to discuss the preliminary results for a case study using track inspection data.
Data Collection Platforms

Track Geometry Car

Visual Inspection

1http://www.harscorail.com/intelligent-solutions/inspection/track-geometry-inspection-vehicle.html
2http://www.railwayage.com/index.php/m_and_u/whats-the-diagnosis.html

Distance (ft)
Measurement (in)
Track Geometry Degradation

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## Selected References on Track Geometry Degradation Models

<table>
<thead>
<tr>
<th>Reference</th>
<th>Degradation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iyengar and Jaiswal (1995)</td>
<td>Random field</td>
</tr>
<tr>
<td>Meier-Hirmer et al. (2006)</td>
<td>Gamma process</td>
</tr>
<tr>
<td>Oyama and Miwa (2006)</td>
<td>Exponential smoothing</td>
</tr>
<tr>
<td>Chang et al. (2010)</td>
<td>Multi-stage linear regression</td>
</tr>
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<td>Berawi et al. (2010)</td>
<td>Linear regression</td>
</tr>
<tr>
<td>Sadeghi and Askarinejad (2010)</td>
<td>Polynomial regression</td>
</tr>
<tr>
<td>Xu et al. (2011)</td>
<td>Linear regression</td>
</tr>
<tr>
<td>Quiroga and Schnieder (2012)</td>
<td>Exponential function</td>
</tr>
<tr>
<td>Andrade and Teixeira (2012)</td>
<td>Linear regression</td>
</tr>
<tr>
<td>Andrade and Teixeira (2013)</td>
<td>Hierarchical Bayesian</td>
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<td>Vale and M. Lurdes (2013)</td>
<td>Dagum model</td>
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<tr>
<td>Audley and Andrews (2013)</td>
<td>Linear regression</td>
</tr>
<tr>
<td>Guler (2013)</td>
<td>Artificial neural networks</td>
</tr>
<tr>
<td>Yousefikia et al. (2014)</td>
<td>Markov chain</td>
</tr>
<tr>
<td>Soleimanmeigouni et al. (2016)</td>
<td>Wiener process</td>
</tr>
</tbody>
</table>
Degradation Process and First Hitting Time

- Degradation level
- Failure threshold
- Degradation path
- Failure time
- Time
- Failure time: $t_a$
Wiener Process and First Hitting Time in Railway Track Geometry Degradation

Wiener Process

\[ W(t) = \omega_0 + \mu t + \sigma B(t), \]

where:

- \( W(t) \): Degradation at time \( t \) (in)
- \( \omega_0 \): Initial degradation (in)
- \( \mu \): Degradation rate (drift parameter) (in)
- \( \sigma \): Diffusion coefficient (in)
- \( B(t) \): Standard Brownian motion

First Hitting Time

\[ T = \inf \{ t \mid W(t) \geq a \}, \]

where:

- \( T \): first hitting time
- \( a \): threshold level
Data Set Description

- 1 mile track
- Foot-by-foot measurements
- 150-foot sections
Illustration of Surface Data

Distance (ft) vs Measurement (in)
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

Jul-1
Aug-15
Nov-15
Dec-15

Distance (ft)

Measurement (in)
Track Geometry Degradation for Selected Parameters

The graph shows the standard deviation (in) of various track geometry parameters over time. The parameters include Crosslevel, Surface Right (62 ft), Surface Left (62 ft), Alignment Right (62 ft), Alignment Left (62 ft), and Warp (62 ft). The data is recorded from June 2013 to April 2016.

The standard deviation values for each parameter are plotted against the inspection dates. The Crosslevel parameter shows a general increase in standard deviation from June 2013 to April 2016. The Surface Right and Left (62 ft) parameters also exhibit an increasing trend. The Alignment Right and Left (62 ft) parameters show a more stable trend. The Warp (62 ft) parameter has a relatively constant standard deviation with slight variations over time.
Correlation Between Selected Track Geometry Parameters

- Gage
- Crosslevel
- Surface Right (62 ft)
- Surface Left (62 ft)
- Alignment Right (62 ft)
- Alignment Left (62 ft)
- Warp (62 ft)
# Point Estimates for the First Tamping Cycle for Surface Data

<table>
<thead>
<tr>
<th>Section</th>
<th>Mean $\mu$</th>
<th>Mean $\sigma$</th>
<th>Standard deviation $\mu$</th>
<th>Standard deviation $\sigma$</th>
<th>Mode $\mu$</th>
<th>Mode $\sigma$</th>
<th>Median $\mu$</th>
<th>Median $\sigma$</th>
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</tbody>
</table>

$^2$Wiener process parameters – $\mu$: Drift parameter; $\sigma$: Diffusion parameter
Simulated Sample Paths for Surface Data

The image shows a graph with simulated sample paths for surface data over time (in months) and standard deviation (in inches). The graph includes observed degradation points marked with red asterisks. The x-axis represents time in months, ranging from 0 to 6, and the y-axis represents standard deviation, ranging from -0.05 to 0.25 inches. The graph also includes a zoomed-in inset, which further illustrates the sample paths and observed degradation points.
PDF of the First Hitting Time for Surface Data

![Graph showing probability density function (PDF) for simulated and theoretical first hitting times. The x-axis represents time in months, ranging from -50 to 350, and the y-axis represents probability density function values. The graph includes two curves: one for simulated first hitting time and another for theoretical first hitting time.](image-url)
CDF of the First Hitting Time for Surface Data

Cumulative density function (CDF)

- Empirical
- Lower bound
- Upper bound
- Theoretical

Time (months)

0 50 100 150 200 250 300

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Cumulative density function (CDF)
There is no consensus in the literature about track geometry degradation models.

Exploratory data analysis shows high variability in track geometry parameters.

Potential to use Wiener process to model track geometry degradation.

The FHT would allow to identify dominant track geometry parameters.


H. Chang, R. Liu, and Q. Li. A Multi-Stage Linear Prediction Model for the Irregularity of the Longitudinal Level Over Unit Railway Sections, 2010. ISSN 17433509.


Thank you.