Optimized Train Control

David Thurston, FIRSE, P.E.
Introduction

Train Control has existed since the beginning of railways. Safety has always been of the first importance in Signal Design. Regardless of Train Control type, braking distance is a common element. Understanding Braking distance is a key element in Capacity.
Rail Capacity

As miles of road continue to shrink, the traffic applied to the remaining lines is increasing.

Class 1 Freight Railroads Traffic vs. Track Miles

- Revenue Ton-Miles
- Road Miles Operated

Gross Tons Hauled (in thousands)

Route Miles (in thousands)

Year
The same traffic trend applies to rail and transit.
Capacity Constraints

Safety is assured through adherence to the rules.

Terminal Station (end of line)  Over 1,500 feet

15th-16th Street Sta.  Tracks  12th-13th Street Sta.

Station Platforms

Switches to Route trains
Capacity Constraints

There is a trade off between Capacity and Speed

Capacity for Various Speeds

![Graph showing the trade-off between capacity and speed.](image)
Contemporary Requirements

Designs are becoming more conservative. There is an increasing reliance on Enforcement.

Available (and soon to be available) technology offers value added features:

- Heath Monitoring
- Predictive Maintenance
- TSR’s
- RWP protection

An ACSES ADU
Train Control

- Manual Block (Time Table and Train Order)
- Track Warrant Control (TWC or Form “D”)
- Automatic Block Signals (including ABS, APB, and CTC)
- Trip Stop
- Inductor based Automatic Train Stop
- Cab Signals (With and without enforcement)
- Profile Based Systems
- Communications Based Train Control (CBTC and PTC)
The Role of Train Control

- Traffic Flow
- Remote Control
- Movement Authority
- Operational Safety
  - Highway crossings
  - Interlocking (Routing)
  - Train Separation
Train Separation

- Train Separation is directly related to Capacity

Minimum Headway is the Time Separation of Two Trains at their Closest Safe Braking Distance
Signal Spacing

Safety is assured through adherence to the rules.

Direction of Travel
A Common Factor in Train Control

The capacity of different advanced train control systems such as Profile based Cab Signals or Communications Based Train Control is negligible (as shown in the example below).

The key factor throughout is the calculation of Safe Braking Distance.

<table>
<thead>
<tr>
<th>Train Control Type</th>
<th>Headway (in Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2:30</td>
</tr>
<tr>
<td>Trip Stop</td>
<td>13.2</td>
</tr>
<tr>
<td>AF Cab Signals</td>
<td>12.9</td>
</tr>
<tr>
<td>CBTC</td>
<td>12.95</td>
</tr>
</tbody>
</table>
Conservative design generate lost capacity by stopping trains well short of required occupied blocks
Safe Braking Distance Model

- A mathematical expression of stopping distance
- Little uniformity in use or application
- IEEE Working Group 25 within the Standards Association was assigned the task of creating guidelines for SBD to address these issues
### Safe Braking Distance Model

**Current Progress:**
- Draft Guideline is complete
- Initial Ballot complete with comments
- Response complete and all comments addressed
- Formal response or re-ballot in progress
IEEE SBD Model (Draft)

TOTAL SBD

A
Overspeed

B
Entry Point

C
Free Running

D
Runaway Acceleration

E
Propulsion Removal

F
Dead Time

G
Brake Build up

H + I
Minimum Braking Rate and Braking Rate Factors

J
Overhang

DISTANCE

TOTAL SBD
Conventional Model Example

A – Maximum Entry Speed: 50 mph plus 3 mph

B – Entry Point: (Initial measurement point)

C – Distance Traveled During Reaction Time:

\[ D_C = V_A \times 1.466 \times t_R \]

Where:
- \( D_C \) = Reaction Distance component of SBD,
- \( V_A \) = Maximum Entry Speed, and
- \( t_R \) = Reaction Time.
Conventional Model Example

D – Runaway Acceleration: 2.0 mphps

Therefore, the speed at the end of the Runaway Acceleration period is 55 mph, and integrating over the one second period yields a distance traveled of

\[ D_D = 79.2 \text{ ft.} \]

E – Propulsion Removal: For this model we assume Linear deceleration to zero over one second providing a distance of

\[ D_E = 81.4 \text{ ft} \]
Conventional Model Example

**F – Dead Time:** Coasting after propulsion removal for one second

\[ D_F = 82.1 \text{ ft}, \]

**G – Brake Build Up:** 50% of full braking rate for one second.

\[ D_G = 81.8 \text{ ft}. \]

**H+I – Brake Rate:**

\[ D_{I+H} = V_{I+H}^2 \times 0.8333 \]

Where: \( D_{I+H} = \) Brake rate component of SBD,
\( V_{I+H} = \) Velocity at the beginning of the braking period

\[ D_{H+I} = 2,567 \text{ ft}. \]

**J - Overhang:** \( D_J = 15 \text{ ft}. \)
IEEE SBD Model Example Values

**IEEE SBD Model Example Values**

- **SPEED**
  - **A** Overspeed 50 + 3 mph
  - **B** Entry Point

- **DISTANCE**
  - **C** Free Running 8 sec. at 53 mph = 622 ft.
  - **D** Runaway Acceleration 2 mphps For 1 sec. = 80 ft.
  - **E** Propulsion Removal For 1 sec. = 82 ft.
  - **F** Dead Time For 1 sec. = 82 ft.
  - **G** Brake Build up For 1 sec. = 82 ft.
  - **H + I** Minimum Braking Rate and Braking Rate Factors @ 0.88 mphps = 2567 ft.
  - **J** Overhang = 15 ft.

**SBD = 3530 ft.**
Stochastic Approach

Origins of approach can be found in previous attempts to address capacity issues with the traditional methodologies

Traditional is Worst Case, but we don’t know “how safe” it is. Is there excess distance in traditional calculations?

The introduction of probability can help answer these questions.
Stochastic Approach

What is safe?

We *can* determine a minimum SBD thru the use of probability as the mean time between hazardous events.

One such metric was contained in a report to Congress in 1976 that stated the minimum acceptable rate of occurrence of fatalities on a transit property utilizing Automatic Train Protection was one in two billion passengers.
Stochastic Approach

By estimating the train density, train carrying capacity, and number of brake applications required for operations for a given system, the probability for an overrun of the SBD that would cause a hazard for this level of safety can be determined.

Utilize the same IEEE Model to ensure uniformity of results
Stochastic Approach

For Example:

LRT trains running 19 hours per day, Headway is 15 minutes
For a 15 mile system, lets say there are 10 stations protected by signals
End to end run time is approximately 30 minutes, forcing a brake application every 3 minutes
76 trains x 19 hours x 60 minutes/hour / 3 minutes between braking = 10.5 M brake applications/year
therefore the probability of stopping outside the provided distance is:

\[
\frac{1}{10.5M \cdot P(\text{Stopping Distance} > \text{SBD})}
\]
Stochastic Approach

But what is safe?

Using the report to Congress, the mean time to fatal accident is:

\[
\frac{(20B \times \text{Fatalities per accident})}{\text{passengers per year}}
\]

# of passengers is: 76 trains x 150 people, 365 days = 4.2M

With a single fatality each year, the mean time to hazard is:

\[
\frac{(20 \times 10^{10} \times 1)}{4.2M} = 4762 \text{ years}
\]
Stochastic Approach

To compare this to the Probability of exceeding the provided distance,

\[ P(D > SBD) = \frac{1}{(\text{stops or reductions for per year})(\text{Mean time between to hazard})} \]

\[ = \frac{1}{(10.5\text{M})(4762)} = 2 \times 10^{-11} \]

By calculating the Probability of the IEEE SBD model, for all available scenarios, the optimum SBD can be determined.
Stochastic Approach

Each part of the model is assumed to be independent, therefore distance contributed by each event is added while the probability of a hazardous event is multiplied.

By plotting all possible combinations of results (probability of overrunning vs. braking distance), we can see if the traditional case is overly conservative.
Stochastic Approach

Each portion of the model can be represented as a Probability Distribution Function (PDF of CDF)

For Example, Overspeed can be represented thru empirical data as:

\[ F_x(x) = P = (X(\xi) \leq x) = \begin{cases} 
1 & x \geq 2 \\
0.9 & 1 \leq x < 2 \\
0.8 & -1 \leq x < 1 \\
0.3 & -2 \leq x < -1 \\
0.1 & -3 \leq x < -2 \\
0 & x < -3 
\end{cases} \]
Stochastic Approach

Similar analysis can be performed for each model part where each portion of the PDF represents the probability of that portion of the SBD model exceeding the appropriate parameter.

Every possible combination of every event is combined to provide a family of SBD and total probability.
### Stochastic Approach

By creating either a table or plot of the probabilities of exceeding the provided distance vs. the calculated distances, we can interpolate which of the solutions provides the minimum distance that provides the level of safety desired.
Stochastic Approach

Anticipated decrease in distance from the traditional to the stochastic method of calculating SBD is 10 to 20%.

This corresponds to an increase in system capacity.

Further study is required to maximize a closed loop approach where by the actual brake rate (Part I and H of the IEEE model) is measured and is used to dynamically change the on board calculation of SBD for all trains running within the system.
Thank you