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Optimized Train Control

David Thurston, FIRSE, P.E.

Grainger Engineering Library - 2nd Floor - Commons Room 233
University of Illinois at Urbana-Champaign

Introduction

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- 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

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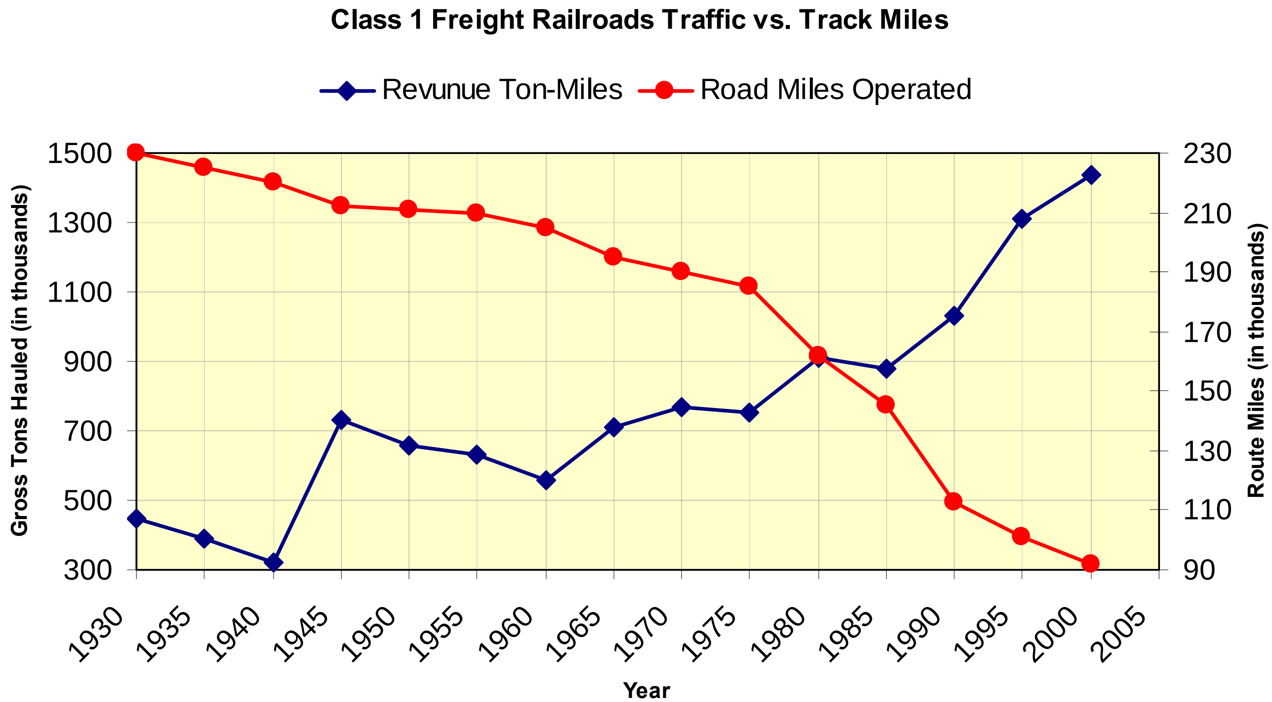
As miles of road continue to shrink, the traffic applied to the remaining lines is increasing.



Rail Capacity

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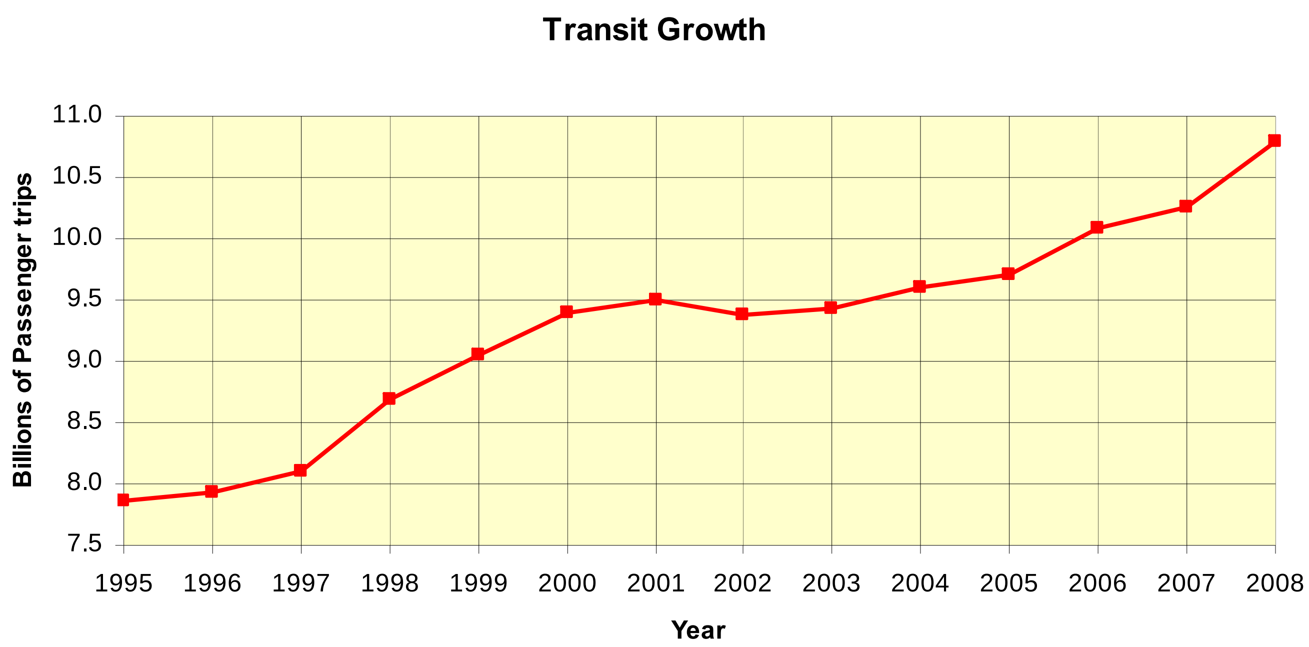
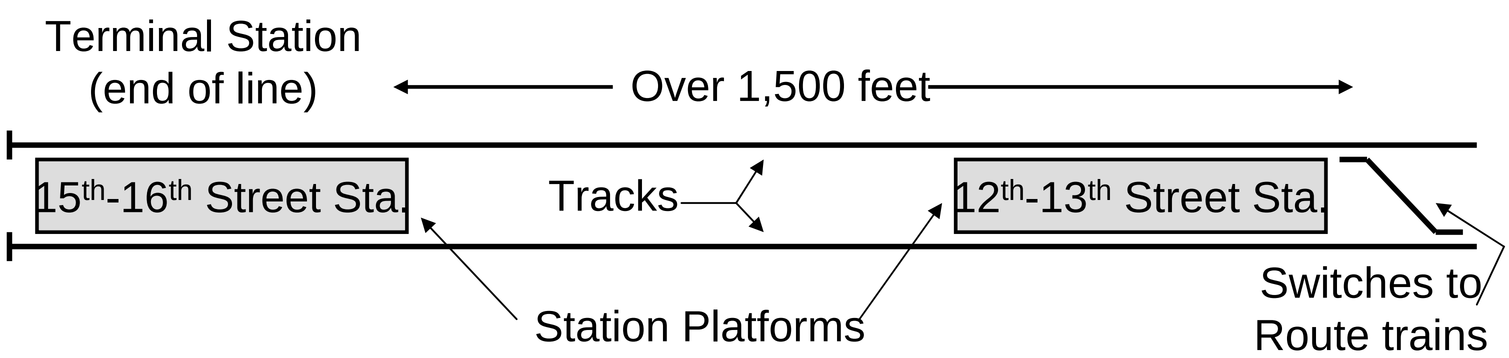
The same traffic trend applies to rail and transit.



Capacity Constraints

Safety is assured through adherence to the rules.



Capacity Constraints

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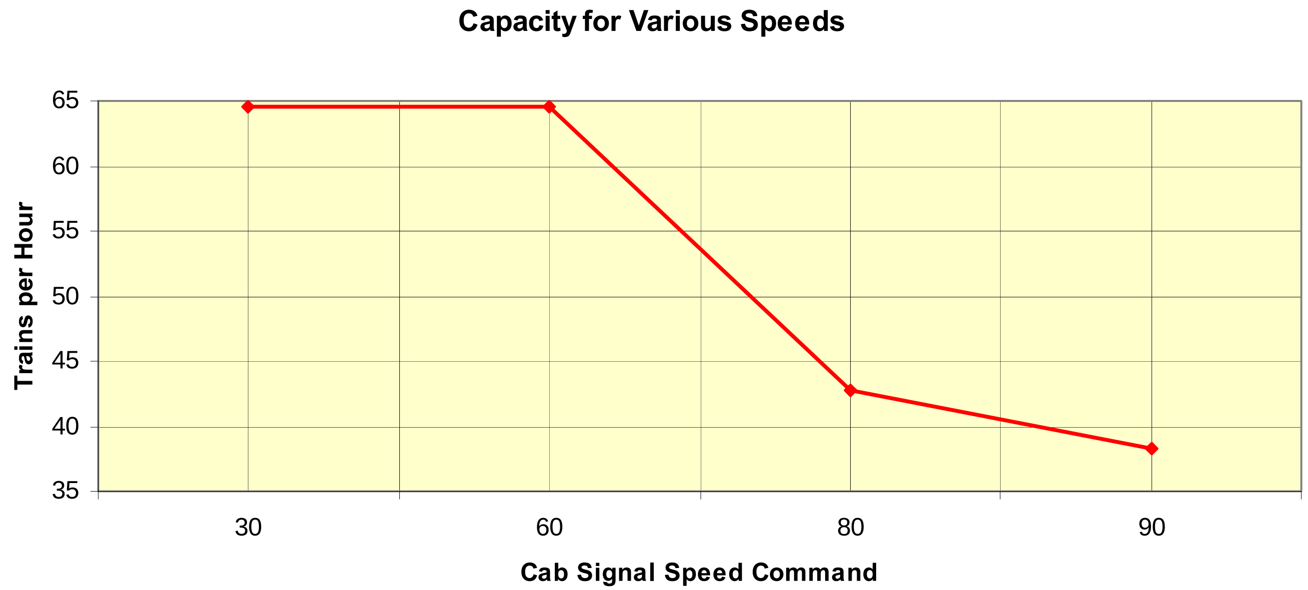
There is a trade off between Capacity and Speed



Contemporary Requirements

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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

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Train Control

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- 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

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

Train Separation

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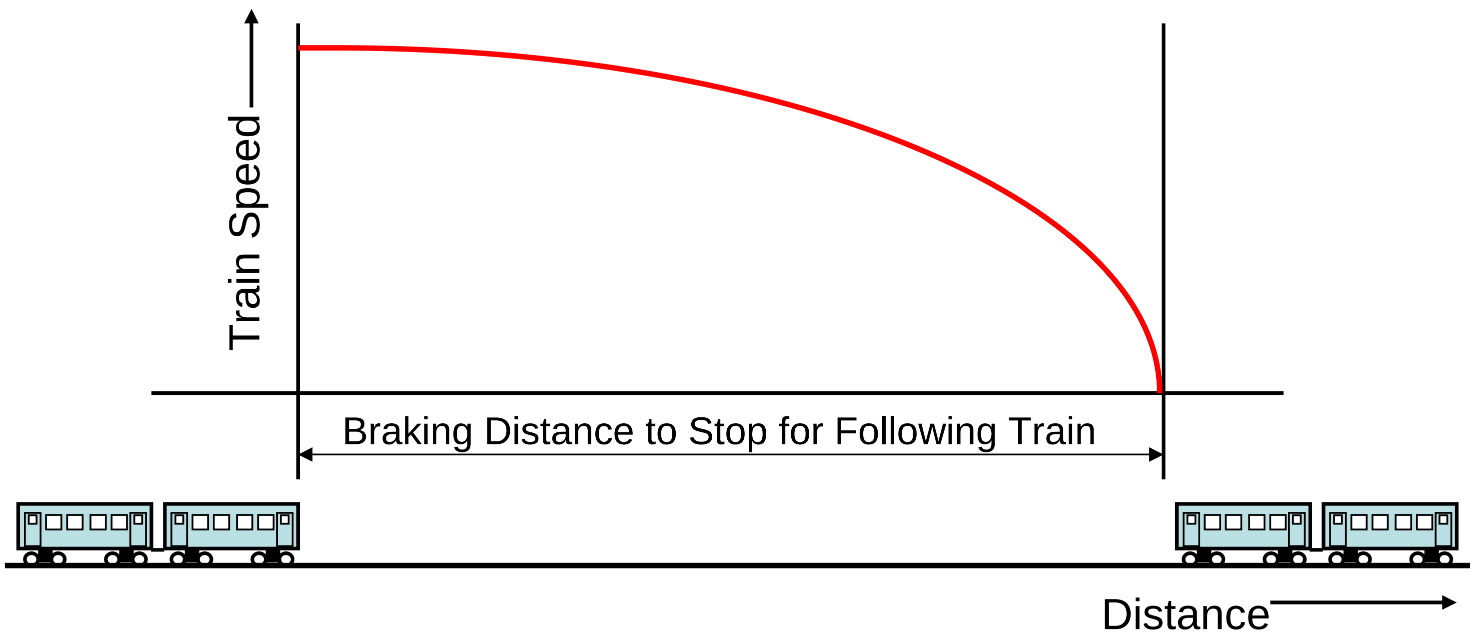
- Train Separation is directly related to Capacity



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

Signal Spacing

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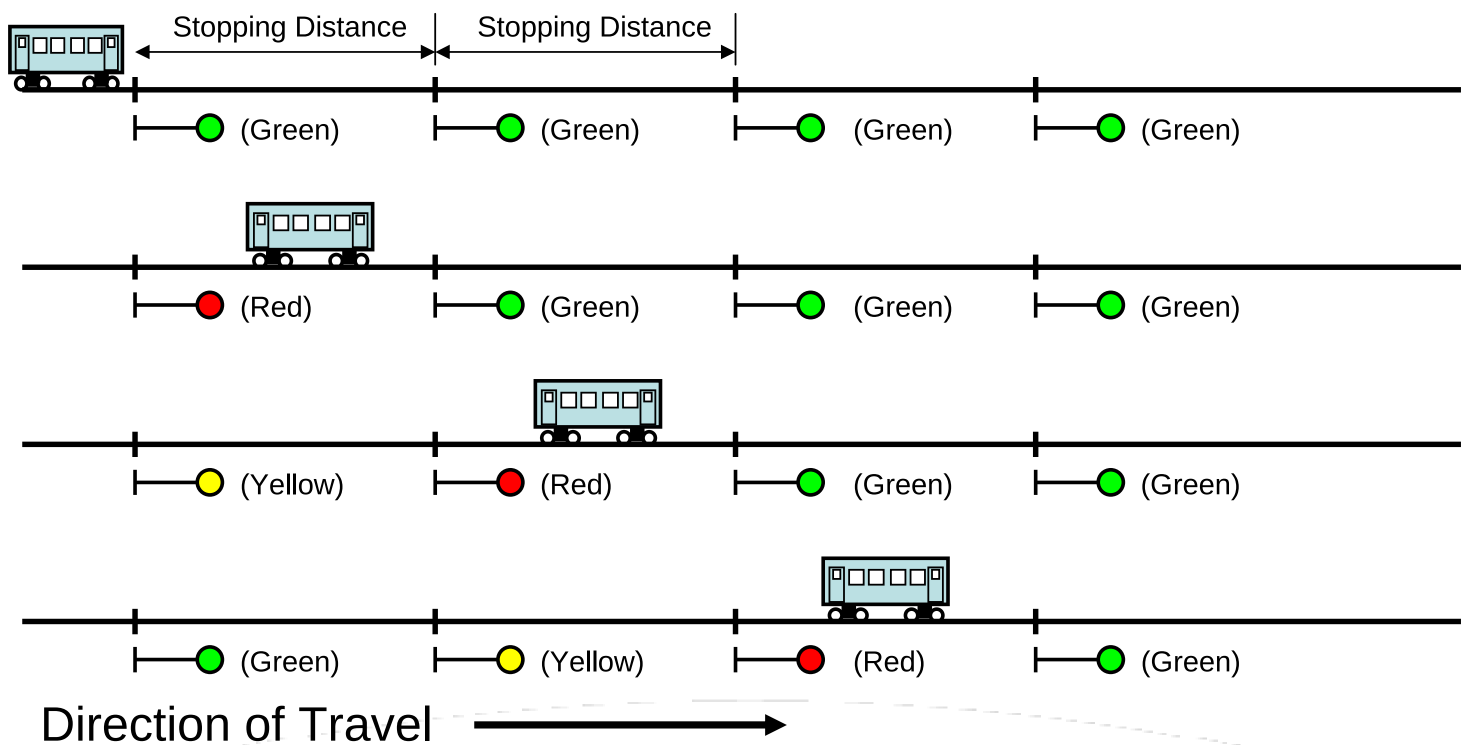
Safety is assured through adherence to the rules.



A Common Factor in Train Control

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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.

Average Trip Time for Three Train Control Types with Deceasing Headway							
Train Control Type	Headway (in Minutes)						
	2:30	2:22	2:15	2:07	2:00	1:52	1:45
Trip Stop	13.2	13	13.8	13.7	19.2	impractical	impractical
AF Cab Signals	12.9	12.7	12.6	13.5	13.2	14.2	18.8
CBTC	12.95	13.8	13.6	13	13.1	12.4	15.1

Resultant Capacity Gap

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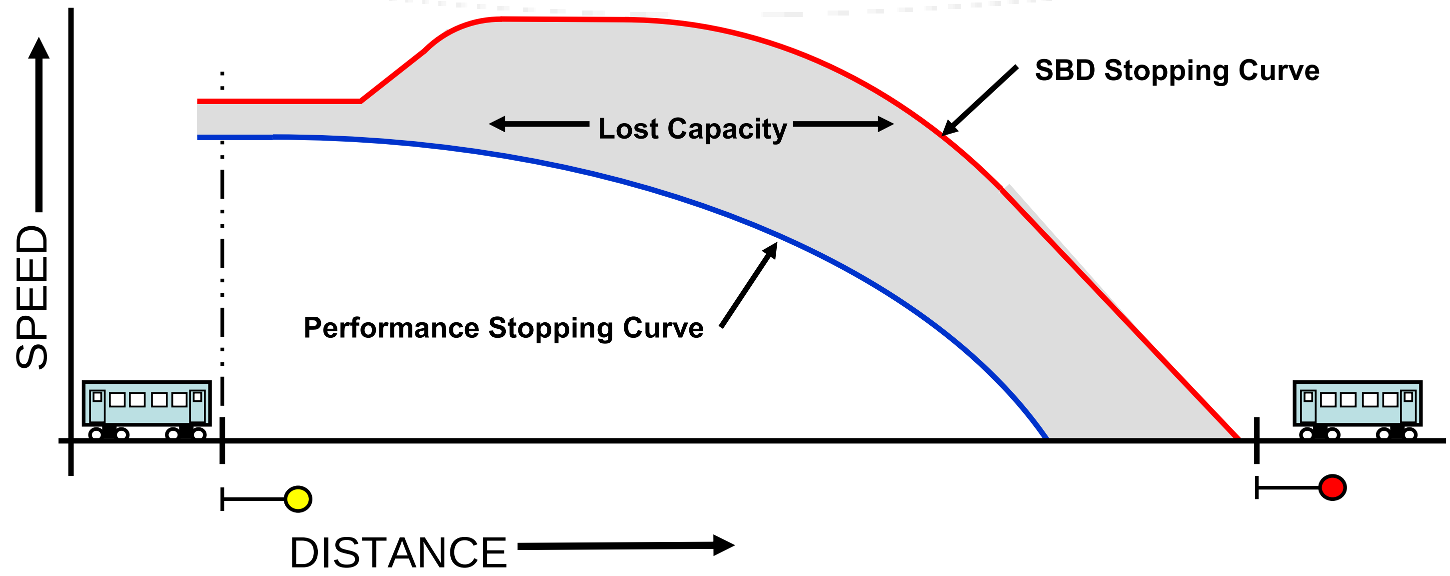

Conservative design generate lost capacity by stopping trains well short of required occupied blocks

Safe Braking Distance Model

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- 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

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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)

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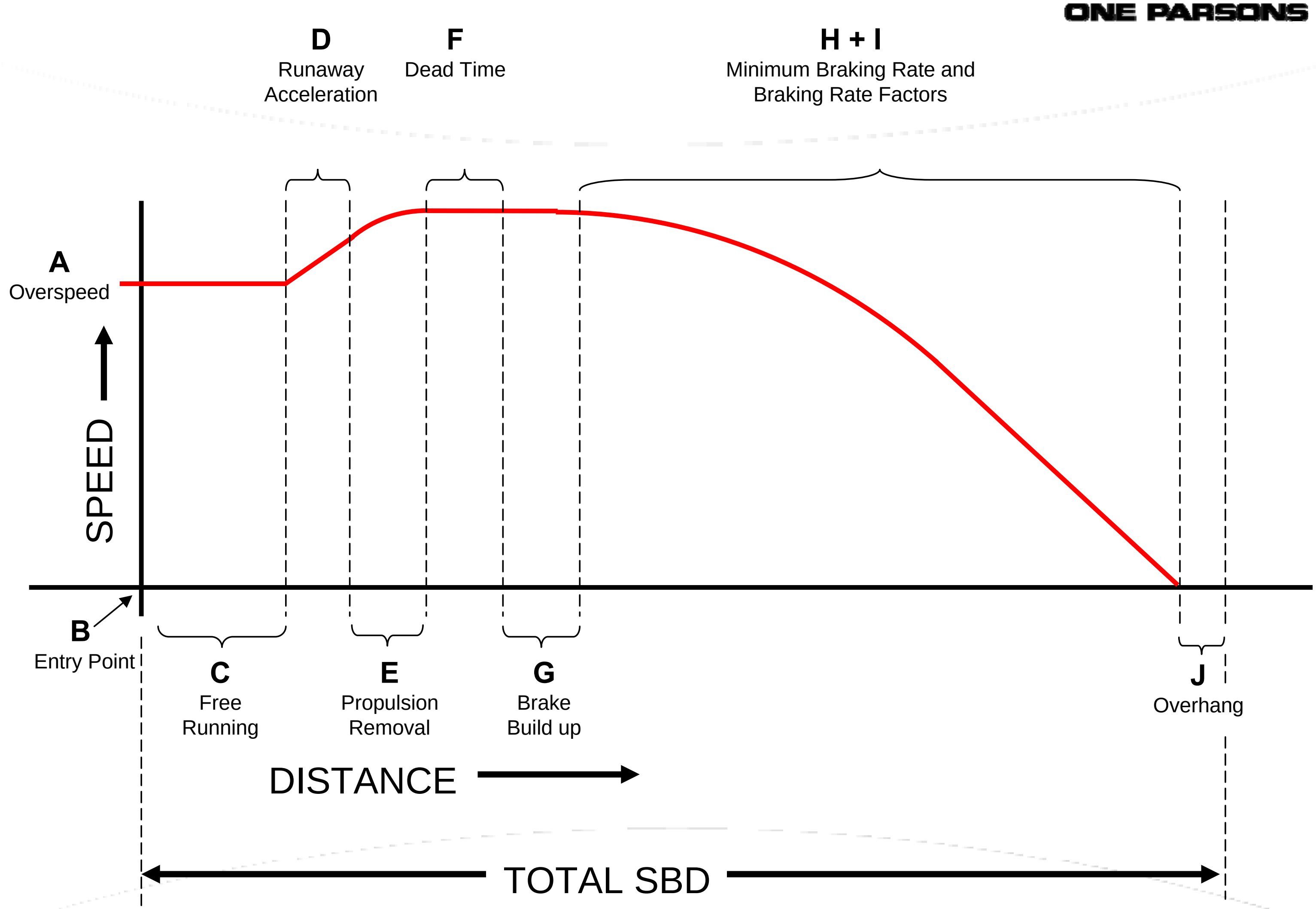

Conventional Model Example

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A – Maximum Entry Speed: 50 mph plus 3 mph

B – Entry Point: (Initial measurement point)

C – Distance Traveled During Reaction Time:

$$D_C = V_A * 1.466 * t_R$$

Where:

- **D_C = Reaction Distance component of SBD,**
- **V_A = Maximum Entry Speed, and**
- **t_R = Reaction Time.**

Conventional Model Example

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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

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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: $D_{I+H} = V_{I+H}^2 * 0.8333$

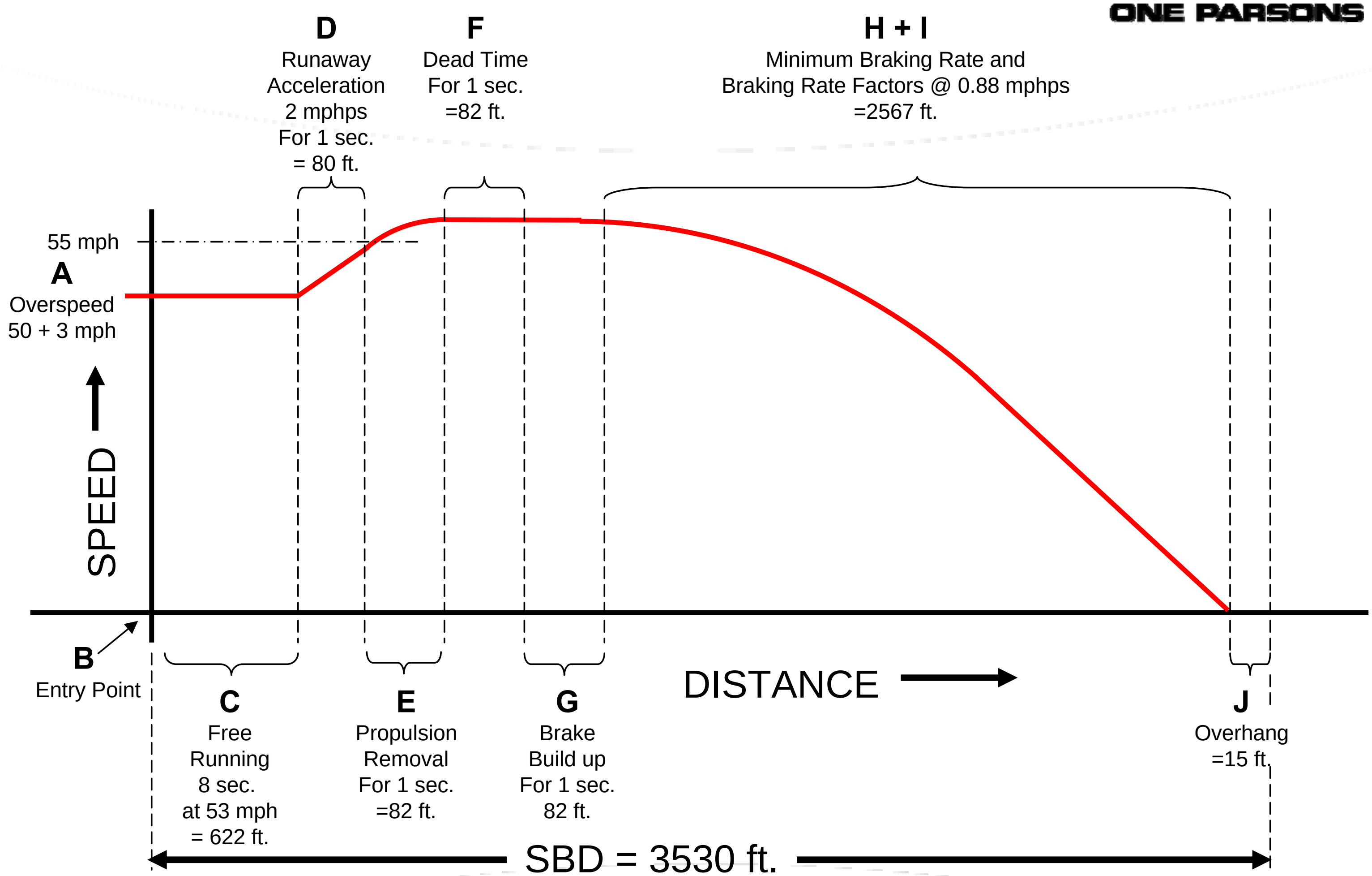
Where: D_{I+H} **= Brake rate component of SBD,**

V_{I+H} **= Velocity at the beginning of the braking period**

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

J - Overhang: $D_J = 15$ **ft.**

IEEE SBD Model Example Values



Stochastic Approach

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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

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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

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- 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

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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:

1/(10.5M*P(Stopping Distance>SBD)

Stochastic Approach

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But what is safe?

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

(20B x Fatalities per accident)/passengers per year

 # 0f passengers is: 76 trains x 150 people, 365 days = 4.2M

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

$(20 \times 10^{10} \times 1)/ 4.2M) = 4762$ years

Stochastic Approach

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

P(D>SBD) = 1/(stops or reductions for per year)(Mean time between to hazard)

$$= 1/(10.5M)(4762) = 2 \times 10^{-11}$$

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

Stochastic Approach

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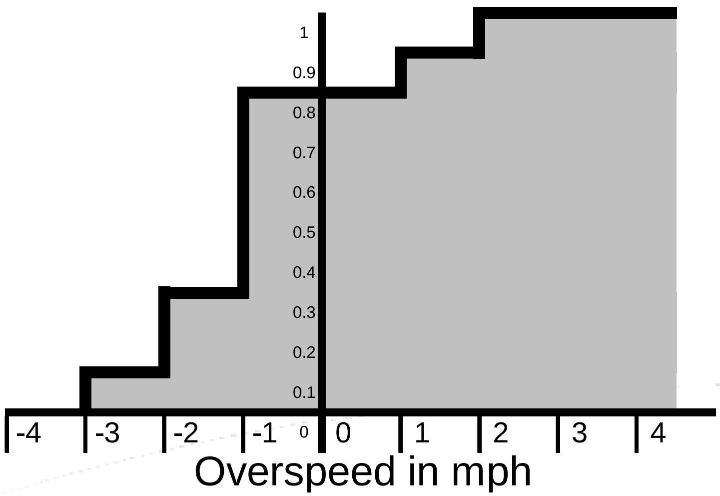
- Each part of the model is assumed to be independent, therefore distance contributed by each event is added while the probability of a hazardous event is multiplied
- By plotting all possible combinations of results (probability of overrunning vs. braking distance), we can see if the traditional case 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

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- 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

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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

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- 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

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Thank you