ONE PARSONS

The William W. Hay Railroad Engineering Seminar Series

April 3, 2009

ONE PARSONS

Optimized Train Control

David Thurston, FIRSE, P.E.

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

Introduction

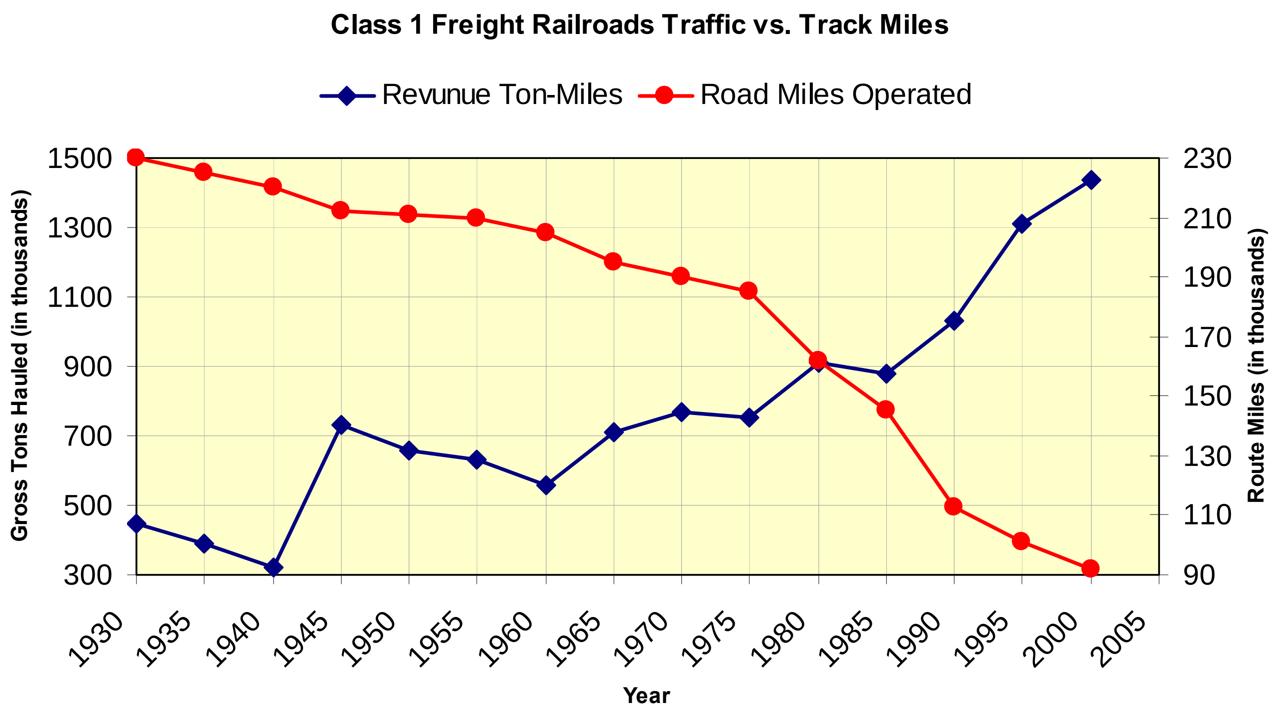
ONE PARSONS

- 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

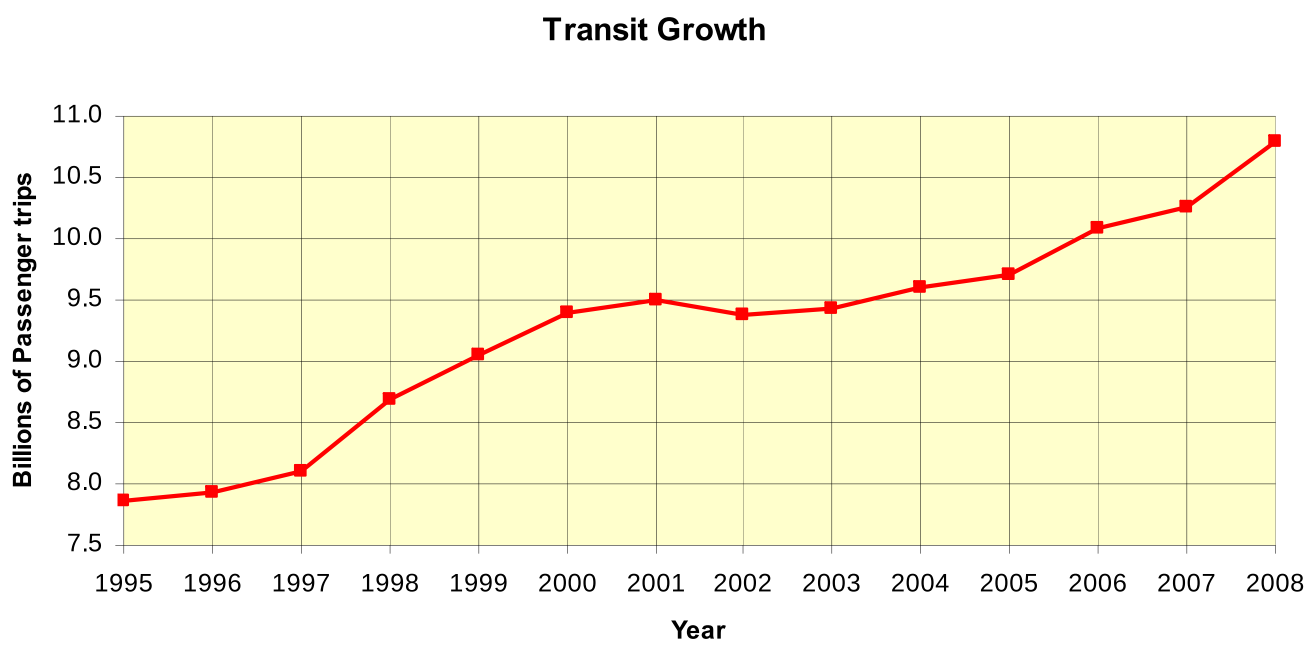
ONE PARSONS

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



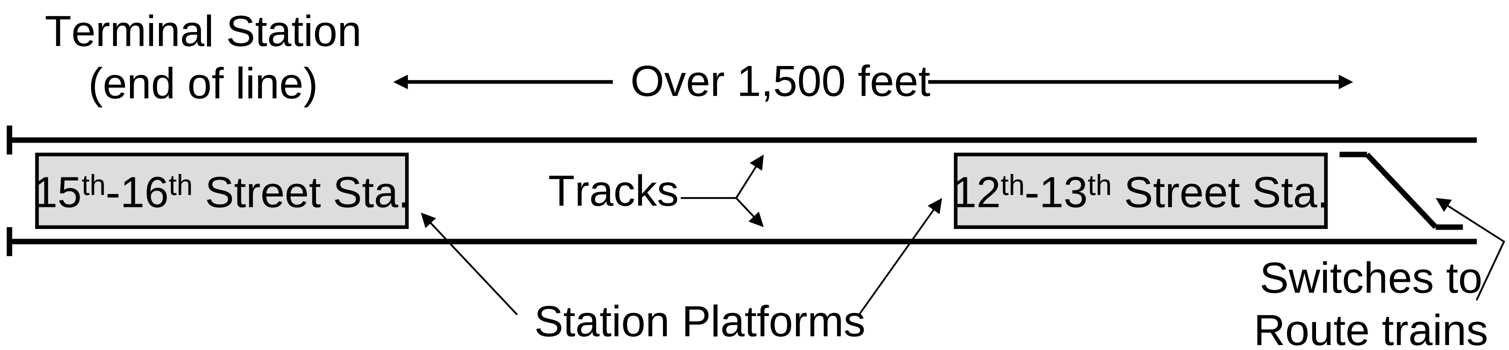
Rail Capacity

The same traffic trend applies to rail and transit.



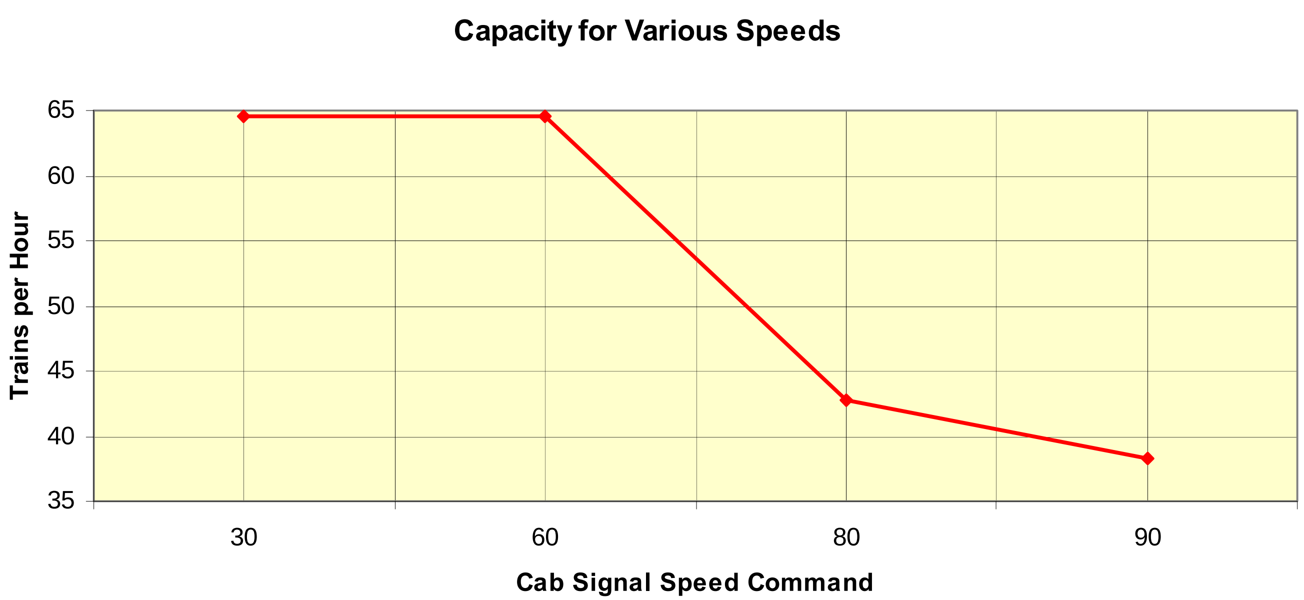
Capacity Constraints

Safety is assured through adherence to the rules.



Capacity Constraints

There is a trade off between Capacity and Speed



Contemporary Requirements

ONE PARSONS

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

ONE PARSONS

- 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

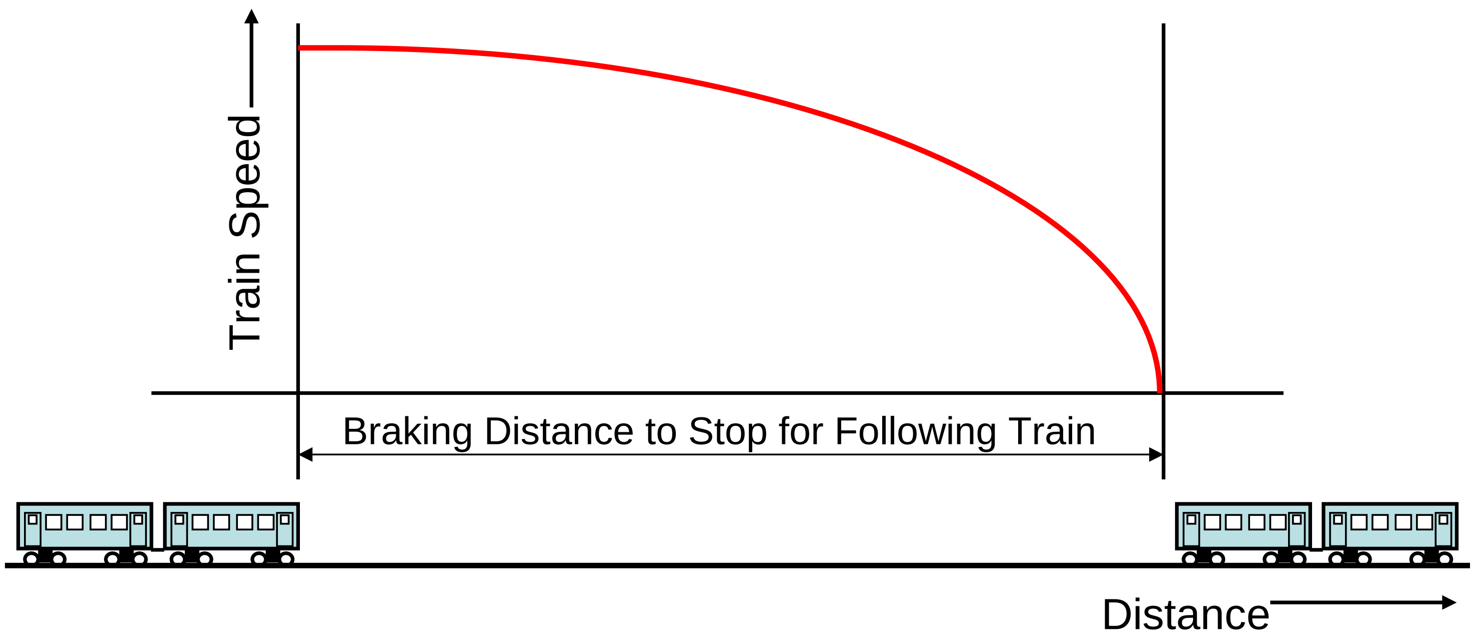
ONE PARSONS

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

Train Separation

ONE PARSONS

- Train Separation is directly related to Capacity

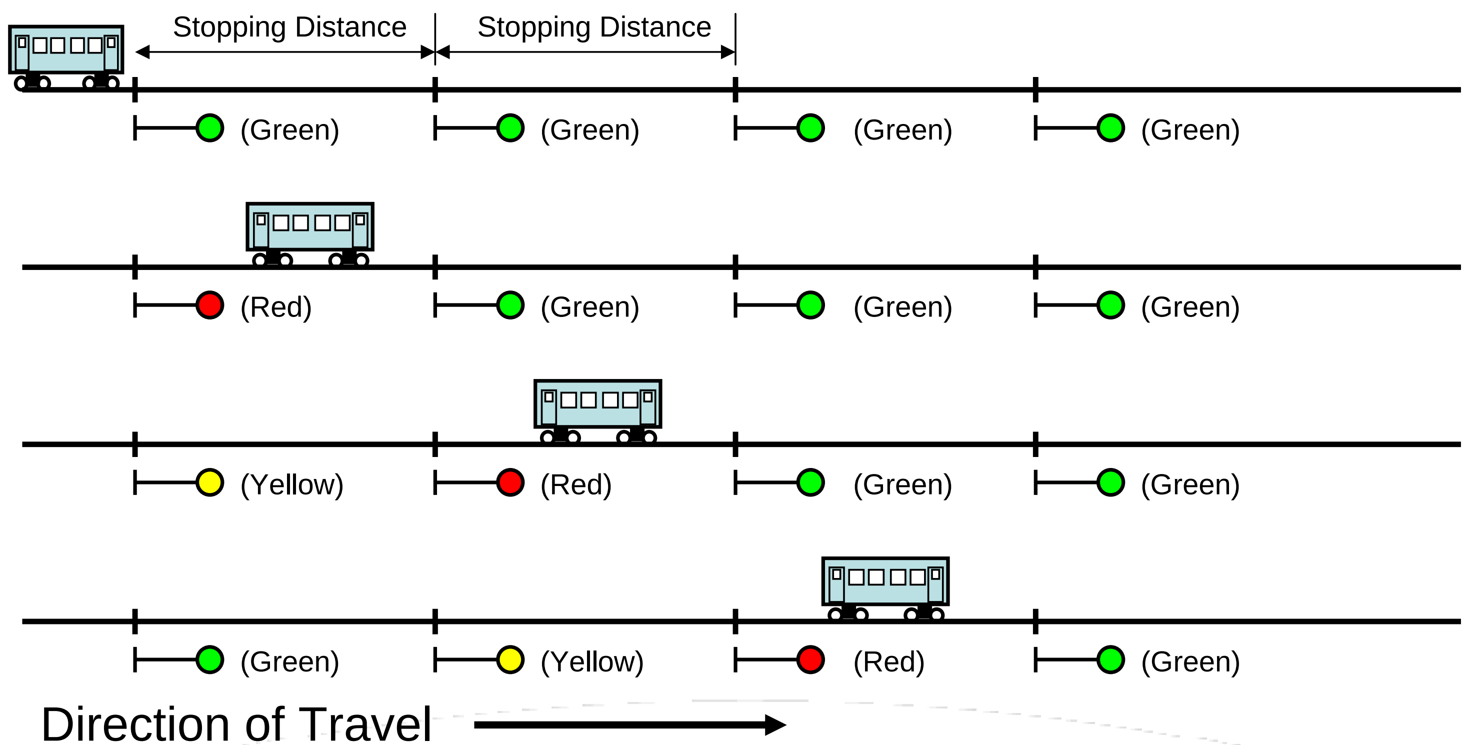


Minimum Headway is the Time Separation of Two Trains at their Closest Safe Braking Distance

Signal Spacing

ONE PARSONS

Safety is assured through adherence to the rules.



A Common Factor in Train Control

ONE PARSONS

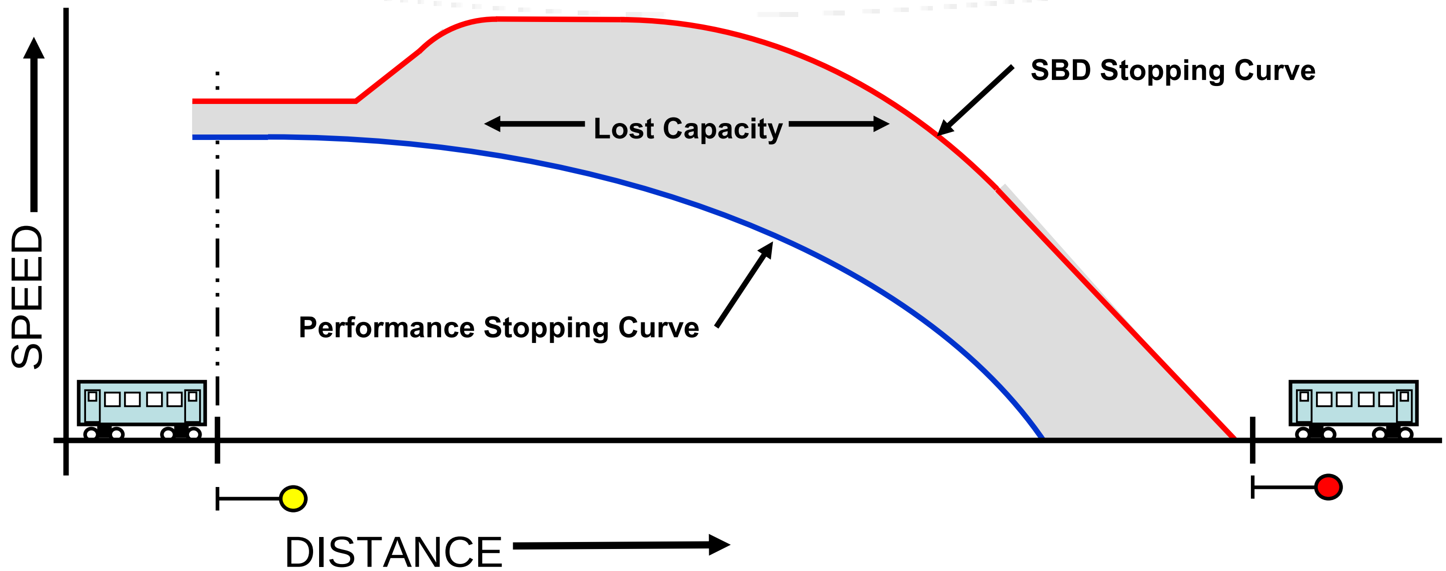
- The capacity of different *advanced* train control systems such as Profile based Cab Signals or Communications Based Train Control is negligible (as shown in the example below).
- The key factor throughout is the calculation of Safe Braking Distance.

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

ONE PARSONS



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

Safe Braking Distance Model

ONE PARSONS

- 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

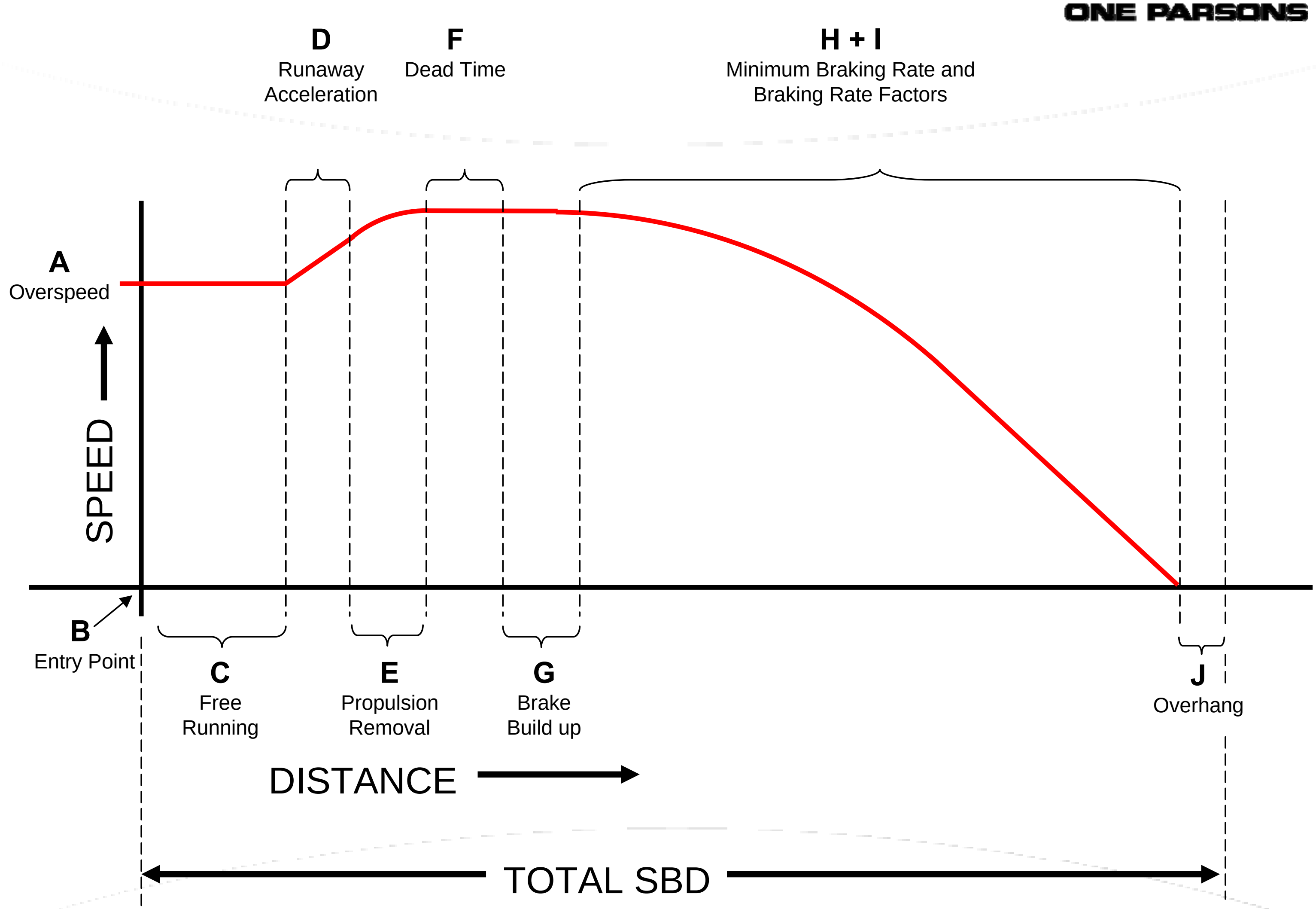
ONE PARSONS

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)

ONE PARSONS



Conventional Model Example

ONE PARSONS

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

ONE PARSONS

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

ONE PARSONS

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,

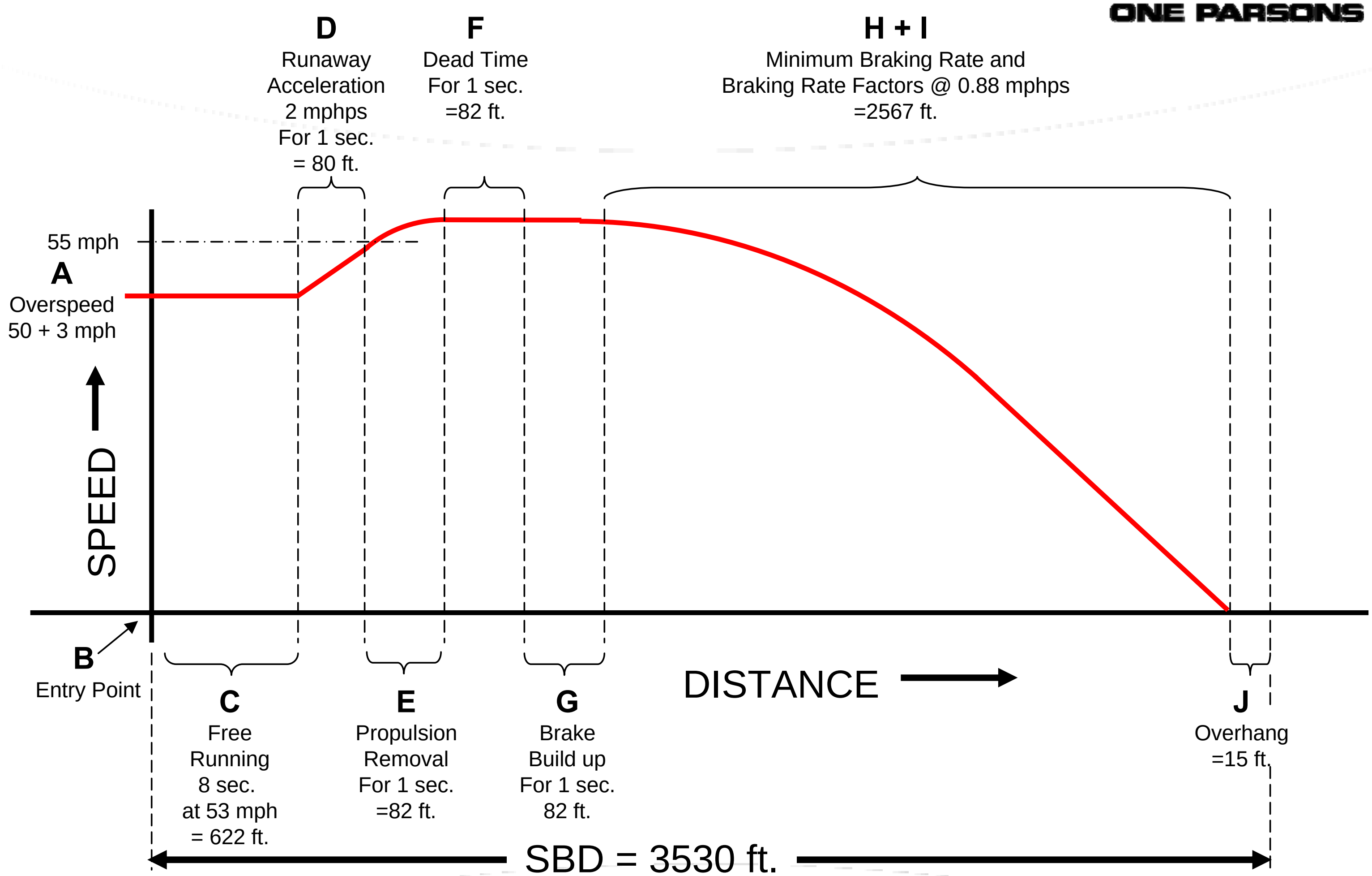
V_{I+H} = Velocity at the beginning of the braking period

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

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

IEEE SBD Model Example Values

ONE PARSONS



Stochastic Approach

ONE PARSONS

- 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

ONE PARSONS

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

ONE PARSONS

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

ONE PARSONS

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

ONE PARSONS

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

ONE PARSONS

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

ONE PARSONS

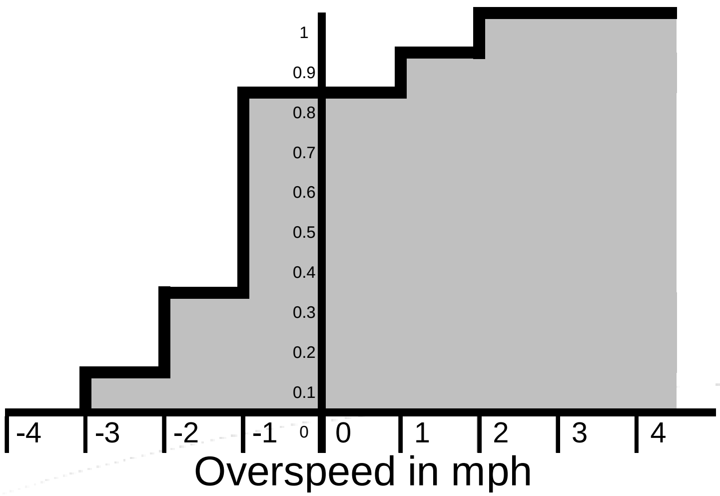
- Each part of the model is assumed to be independent, therefore distance contributed by each event is added while the probability of a hazardous event is multiplied
- By plotting all possible combinations of results (probability of overrunning vs. braking distance), we can see if the traditional case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

Stochastic Approach

ONE PARSONS

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

ONE PARSONS

- 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

ONE PARSONS

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

ONE PARSONS

- 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

ONE PARSONS

Thank you