

# The Speed That Passes the Most Trains Does Not Depend on the Time Taken to React to Signals

— with spacing as train length plus margin, distance run while reacting, and braking distance, the best speed is set by length, margin and braking alone, and reaction time only lowers the maximum number of trains —the separator is whether a part of the spacing grows in proportion to speed or to its square — [Paper 978]

Yuuki YAMAGISHI (山岸 勇輝)

Yamagishi Complexity Torus Lab, Japan

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## Abstract

Adding signal aspects cannot bring trains closer than the braking distance plus the train length (Paper 893). The time for a driver to see and react to a signal and the margin at the stopping point were not included there. Taking the deceleration of  $0.8 \text{ m/s}^2$  and train length of 200 m of Paper 893, this paper adds a stopping margin and reaction time to the spacing between trains, and counts the speed that passes the most trains per hour and that number. No new theorem or law is claimed. First, the speed that passes the most trains does not depend on reaction time: with no margin, varying reaction time as 0, 5 and 10 s left the best speed at 17.8887 m/s (**64.399** km/h) in every case, within  $10^{-3} \text{ m/s}$  of the formula's 17.8885 m/s (Section 2). Second, the best speed rises with the margin: with margins of 0, 50 and 100 m, the best speed was **64.399**, **72.000** and **78.871** km/h (Section 2). Third, reaction time only lowers the maximum number of trains: with no margin, the maximum was **160.9969**, **131.5757** and **111.2461** trains per hour for reaction times of 0, 5 and 10 s (Section 3). Fourth, running at 130 km/h passes fewer trains than the maximum: the number at 130 km/h was 128.0778 per hour with no margin and no reaction time (**0.795530** of the maximum), and 0.914598 of the maximum with a 100 m margin and 10 s reaction time (Section 3). Fifth, the separator is whether a part of the spacing grows in proportion to speed or to its square: the number of trains is speed over spacing and peaks where the zeroth-order part (length and margin) balances the second-order part (braking distance). The first-order part (distance run while reacting) did not move the peak and only lowered its height (Section 4). **Keywords:** train headway, line capacity, braking distance, reaction time, railway signalling, traffic flow.

Scope of this paper (scope note): No new theorem or law is claimed: that in a stream of trains or vehicles the number passed is speed over spacing, that braking distance grows with the square of speed so that some speed passes the most, and that this speed is set by length and braking, are all known in traffic flow and railway signalling. These are set values: the deceleration of  $0.8 \text{ m/s}^2$  and train length of 200 m are the model values of Paper 893, and stopping margins of 0, 50 and 100 m and reaction times of 0, 5 and 10 s are set here. They correspond to no line. Running is simplified: station stops, time spent accelerating and decelerating, the number of signal blocks, and spacing measured from the train ahead (Paper 893) are not included; spacing is set by one formula. The benefit of speed is not counted: shorter journey times from running fast, energy and passenger numbers are not treated. Only the number of trains is counted. Relation to earlier papers: Paper 893, in its scope note, did not include margins, leaving out the distance at which drivers see signals, the margin at the stopping point, station stops and time for acceleration and deceleration; this paper sits in the seats of signal reaction time and stopping margin (no earlier occupant). Paper 893 showed that adding signal aspects cannot bring trains closer than the braking distance plus the train length. Here a margin and reaction time are added to that spacing, and the speed passing the most trains is counted. What is added: finding the best speed and number for nine combinations of margin and reaction time, confirming that the best speed does not depend on reaction time, checking the maximum against a closed form, comparing with the number at 130 km/h, and placing the separator on “in proportion to speed, or to its square”.

## 1. Notation and the Question

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Setting: as in Paper 893, deceleration  $b = 0.8 \text{ m/s}^2$  and train length  $L = 200 \text{ m}$ , with a stopping margin  $m$  and a signal reaction time  $t_r$ . For trains running at speed  $v$ , spacing and number per hour are

$$g(v) = L + m + v t_r + \frac{v^2}{2b}, \quad q(v) = \frac{3600 v}{g(v)}$$

Setting the derivative of  $q$  with respect to  $v$  to zero gives  $v^2 = 2b(L + m)$ , from which  $t_r$  disappears. The maximum was also searched directly over 200001 speeds from 0.1 to 100 m/s.

Question: what sets the speed passing the most trains, and how does reaction time change it?

## 2. The Best Speed

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Computation 2.1: nine combinations of margin and reaction time.

| margin | reaction | searched best (m/s) | formula (m/s) | best (km/h)   | maximum (trains per hour) |
|--------|----------|---------------------|---------------|---------------|---------------------------|
| 0 m    | 0 s      | 17.8887             | 17.8885       | <b>64.399</b> | <b>160.9969</b>           |
| 0 m    | 5 s      | 17.8887             | 17.8885       | 64.399        | 131.5757                  |
| 0 m    | 10 s     | 17.8887             | 17.8885       | 64.399        | 111.2461                  |
| 50 m   | 0 s      | 20.0001             | 20.0000       | 72.000        | 144.0000                  |
| 50 m   | 5 s      | 20.0001             | 20.0000       | 72.000        | 120.0000                  |
| 50 m   | 10 s     | 20.0001             | 20.0000       | 72.000        | 102.8571                  |
| 100 m  | 0 s      | 21.9087             | 21.9089       | 78.871        | 131.4534                  |
| 100 m  | 5 s      | 21.9087             | 21.9089       | 78.871        | 111.1587                  |
| 100 m  | 10 s     | 21.9087             | 21.9089       | 78.871        | 96.2924                   |

In all nine combinations, the searched best speed was within  $10^{-3}$  m/s of  $\sqrt{2b(L+m)}$ , and the maximum matched the number at the formula's speed. With no margin and no reaction time the maximum agreed with  $3600/\sqrt{2L/b}$  within  $10^{-9}$ .

### Observation 2.2

the best speed is set by length, margin and braking, and not by reaction time. For the same margin, the best speed was the same for all three reaction times: raising the margin from 0 to 100 m raised the best speed from 64.399 to 78.871 km/h.

## 3. Reaction Time and 130 km/h

Computation 3.1: number at 130 km/h and its ratio to the maximum.

| margin | reaction | trains per hour at 130 km/h | ratio to maximum |
|--------|----------|-----------------------------|------------------|
| 0 m    | 0 s      | 128.0778                    | <b>0.795530</b>  |
| 0 m    | 5 s      | 108.7354                    | 0.826409         |
| 0 m    | 10 s     | 94.4686                     | 0.849185         |
| 50 m   | 0 s      | 122.0648                    | 0.847673         |
| 50 m   | 5 s      | 104.3705                    | 0.869754         |
| 50 m   | 10 s     | 91.1565                     | 0.886244         |
| 100 m  | 0 s      | 116.5911                    | 0.886939         |
| 100 m  | 5 s      | 100.3425                    | 0.902695         |
| 100 m  | 10 s     | 88.0688                     | 0.914598         |

### Observation 3.2

reaction time lowers the maximum and narrows the gap to 130 km/h. For each of the three margins, longer reaction time lowered the maximum: the ratio of the number at 130 km/h to the maximum came closer to 1 with larger margin and reaction time, from 0.795530 to 0.914598.

## 4. The Separator

### Observation 4.1

the separator is whether a part of the spacing grows in proportion to speed or to its square. The reciprocal of  $q = 3600v/g$  is  $(L + m)/v + t_r + v/(2b)$ , in which reaction time  $t_r$  is added as a constant independent of speed: the best speed is where the zeroth-order part  $(L + m)/v$  equals the part  $v/(2b)$  from the second-order term, and  $t_r$  did not move the peak but only lowered its height (from 160.9969 to 111.2461 trains per hour with no margin).

## Observation 4.2

what is not said. Station stops, time for acceleration and deceleration, the number of signal blocks, numbers on real lines, the benefit of running fast, and what speed to run at are not treated. What is shown is that with spacing set by one formula, the speed passing the most trains does not depend on reaction time.

## 5. Roll Call and Closing

1. spacing and number formulas (Section 1): reaction time drops out on differentiation.
2. best speed **64.399** km/h (no margin) (Computation 2.1): independent of reaction time.
3. **64.399, 72.000, 78.871** km/h for margins **0, 50, 100** m (Computation 2.1): rises with margin.
4. maximum from **160.9969** to **111.2461** trains per hour (Computation 2.1): reaction time lowers the height.
5. **0.795530** to **0.914598** of the maximum at **130** km/h (Computation 3.1): fewer trains.
6. proportional to speed, or to its square (Observation 4.1): the separator; the scope note of Paper 893.

Closing: The speed that passes the most trains does not depend on the time taken to react to signals. With the deceleration and train length of Paper 893 and a margin and reaction time added to spacing, the speed passing the most trains was **64.399, 72.000** and **78.871** km/h for margins of **0, 50** and **100** m, unchanged when reaction time was varied as **0, 5** and **10** s: reaction time only lowered the maximum, from **160.9969** to **111.2461** trains per hour with no margin. At **130** km/h the number was **0.795530** to **0.914598** of the maximum. The separator is whether a part of the spacing grows in proportion to speed or to its square. Placed among the earlier papers: to the spacing Paper 893 counted from braking distance and train length, the reaction time and stopping margin that Paper 893 did not include were added. To be honest. This is one formula without stops or acceleration, counting only the number of trains. At what speed the number peaks and how reaction time changes it, and no further.

## References

1. Yamagishi, Y. (2026). *Adding Signal Aspects Cannot Bring Trains Closer Than the Braking Distance Plus the Train Length* [Paper 893]. YOI: <https://www.yamagishiyuuki.com/yoi/893>

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