

# Widening the Exit Speeds Evacuation Only When There Are Many People; With Few, the Walking Distance Sets the Time

— widening the exit from 1 m to 2 m changes evacuation time by **0.986489** times for 10 people and **0.500029** times for 1000, walking time and exit time being equal at 50 people — the separator is whether one asks when the last person reaches the exit or when the queue in front of it clears — [Paper 895]

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## Abstract

It is easy to assume that widening an exit always speeds up evacuation. This paper counts, in a model where scattered people walk to an exit that passes people only at a fixed rate, how much exit width helps for each number of people. No new theorem or law is claimed. First, with few people, widening the exit hardly helps: widening from 1 m to 2 m gives **0.986489** times the time for 10 people and **0.978555** times for 30 (Section 2). Second, with many people, doubling the width nearly halves the time: **0.500297** times for 300 people and **0.500029** times for 1000 (Section 2). Third, and this is the core. What sets the time shifts with the number of people from walking distance to exit width: the walking time **38.461538** seconds equals the exit-only time (people divided by 1.3 per second) at **50** people, and width begins to help around there: **0.810663** times at 60 people and **0.528211** at 100 (Section 2). Fourth, near the boundary neither estimate suffices: the evacuation time divided by the larger of the two is **0.920068** at 10 people, **1.030965** at 60 and **1.000058** at 1000, largest at 60, near the boundary (Section 3). Fifth, widening the exit never makes it slower: in 240 runs changing only the width for the same arrangement of people, widening made evacuation slower 0 times (Section 2). Sixth, the separator is whether one asks when the last person reaches the exit or when the queue in front of the exit clears: the first makes walking distance set the time, the second makes exit width set it, and the number of people decides which to ask (Section 4). **Keywords:** evacuation time, exit width, walking distance, queue at the exit, boundary number of people.

Scope of this paper (scope note): No new theorem or law is claimed: that evacuation time is estimated by splitting it into walking time and time to pass the exit, that an exit can pass only so many people, and that exit width sets the time when there are many people are all known in evacuation calculations. No real building is claimed: a walking speed of 1.3 m/s, an exit passing 1.3 people per second per metre of width, and people spread uniformly within 50 m are model values matching no building or standard. The two values of 1.3 are separate values with different units. Smoke and crowd behaviour are not entered: reduced visibility from smoke, pushing, choice of exit, and time before starting to walk are not included. Relation to earlier papers: Paper 728 showed that most of the smoke is not what burned but air the plume pulled in, so the ceiling height sets the volume of smoke, and its scope note left evacuation undiscussed. This paper sits in that seat (no one has sat there before). Smoke and visibility are still left out; the time is counted from walking distance and exit width alone. Paper 549 showed that the time inside can change almost sixfold while the product does not move. This paper stands beside it. There the relation between the number in a queue and the time was examined. Here the queue in front of the exit sets evacuation time only when there are many people. What is added is measuring the effect of exit width for six numbers of people, deriving the boundary of 50 people from walking time and exit time, measuring that near the boundary evacuation time exceeds the larger of the two estimates, and placing the separator on arrival time versus queue clearing time.

## 1. Notation and the Question

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Setting:  $N$  people are scattered uniformly at distances 0 to 50 m from an exit and walk to it at 1.3 m/s. The exit passes 1.3 people per second per metre of width  $w$ , taking  $1/(1.3w)$  seconds per person. People queue in order of arrival and pass once the person ahead has passed. Evacuation time is when the last person has passed.

$$t_{\text{walk}} = \frac{50}{1.3}, \quad t_{\text{exit}} = \frac{N}{1.3w}, \quad N^* = 1.3w \times \frac{50}{1.3}$$

For each number of people, 40 arrangements were drawn, and for each the time was computed with widths 1 m and 2 m and averaged.  $N^*$  is the number at which walking-only time equals exit-only time for a 1 m exit.

Question: does widening the exit always speed up evacuation?

## 2. Number of People and the Effect of Width

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Computation 2.1: evacuation time was computed with widths 1 m and 2 m for six numbers of people.

| people | width 1 m (s) | width 2 m (s) | effect of doubling width |
|--------|---------------|---------------|--------------------------|
| 10     | 35.387219     | 34.909111     | 0.986489                 |
| 30     | 38.727079     | 37.896591     | 0.978555                 |
| 60     | 47.583016     | 38.573779     | 0.810663                 |
| 100    | 77.437357     | 40.903280     | 0.528211                 |
| 300    | 230.890226    | 115.513651    | 0.500297                 |
| 1000   | 769.275417    | 384.660032    | 0.500029                 |

### Observation 2.2

this is the core. What sets the time shifts with the number of people from walking distance to exit width. Walking-only time is 38.461538 seconds, equal to exit-only time at 50 people: for 10 and 30 people, doubling the width gives 0.986489 and 0.978555 times, barely shorter. It begins to help at 60, and at 300 and 1000 people gives 0.500297 and 0.500029 times, nearly half. In 240 runs comparing the same arrangement, widening made evacuation slower 0 times.

## 3. Near the Boundary

Computation 3.1: the evacuation time with a 1 m exit was divided by the larger of walking-only and exit-only time.

| people | larger of the two (s) | ratio to evacuation time |
|--------|-----------------------|--------------------------|
| 10     | 38.461538             | 0.920068                 |
| 30     | 38.461538             | 1.006904                 |
| 60     | 46.153846             | 1.030965                 |
| 100    | 76.923077             | 1.006686                 |
| 300    | 230.769231            | 1.000524                 |
| 1000   | 769.230769            | 1.000058                 |

### Observation 3.2

near the boundary, neither estimate suffices. The ratio is largest, 1.030965, at 60 people, near the boundary of 50, and approaches the larger value, 1.000058, as numbers grow: with many people far from the boundary, the exit-only estimate nearly suffices. Near the boundary, evacuation time exceeded both estimates. Yet it is far shorter than their sum of 84.615385 seconds.

## 4. The Separator

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### Observation 4.1

the separator is whether one asks when the last person reaches the exit or when the queue in front of the exit clears. With few people, the time stays on the side of walking distance, and doubling the exit width barely changes it: with many people, the time approaches the exit-only estimate, and doubling the width nearly halves it. Which to ask depends on which side of the boundary of 50 people one is on.

### Observation 4.2

sitting in Paper 728's seat and placed beside Paper 549.728 showed that ceiling height sets the volume of smoke and left evacuation undiscussed. This paper counts that evacuation time from walking distance and exit width, without smoke. 549 examined the product relation between the number in a queue and time. Here the queue in front of the exit sets the time only when there are many people.

### Observation 4.3

what is not said. Real building or evacuation-standard values, visibility in smoke, pushing, choice of exit, and time before starting to walk are not treated. What is shown is that, in this model, widening the exit helps only when there are many people, and with few the walking distance sets the time.

## 5. Census and Closing

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1. walking time 38.461538 seconds and exit time  $N/(1.3w)$  (Section 1): two estimates.
2. 0.986489 times for 10 people (Computation 2.1): barely helps.

3. **0.978555 times for 30** (Computation 2.1): **still walking distance**.
4. **boundary at 50 people** (Observation 2.2): **the core**.
5. **0.810663 times for 60** (Computation 2.1): **begins to help**.
6. **0.500029 times for 1000** (Computation 2.1): **nearly half**.
7. **0 slower runs** (Observation 2.2): **out of 240**.
8. **ratio 1.030965 at 60** (Computation 3.1): **exceeds the larger near the boundary**.
9. **ratio 1.000058 at 1000** (Computation 3.1): **approaches the larger**.
10. **arrival, or queue clearing** (Observation 4.1): **the separator; Papers 728, 549**.

Closing: Widening the exit speeds evacuation only when there are many people; with few, the walking distance sets the time. With people within 50 m walking at 1.3 m/s and an exit passing 1.3 people per second per metre, doubling the width gave 0.986489 times the time for 10 people and 0.500029 times for 1000: around 50 people, where the walking-only time of 38.461538 seconds equals the exit-only time, what sets the time shifts from walking distance to exit width. Near that boundary, at 60 people, evacuation took 47.583016 seconds, 1.030965 times the larger of the two, so neither estimate sufficed. Yet it was far shorter than their sum of 84.615385 seconds, and with many people the larger one nearly suffices. Placed among the earlier papers: sitting in the evacuation seat that Paper 728 left undiscussed, and beside the queue of Paper 549, we placed an exit whose effect depends on the number of people. To be honest: walking speed and exit rate are model values, and smoke, pushing and choice of exit are not included.

## References

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