Field studies on the capacity of escalators

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Abstract

Nowadays urban development tends to high buildings, maximising the utility of limited space. In an effort to maintain comfort plenty of escalators connect levels in buildings. Of course there is much theoretical information about capacity of escalators, but do these model reality well? To figure out whether the assumed capacities specified in guidelines are reachable or not, we investigate the performance of escalators at railway stations and shopping centers in several field studies. The specific angle of slope amounts to 30°, the speed to 0.5 m/s.

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Peer-review under responsibility of PED2014.

Keywords: capacity; escalators; field study; performance; public transportation; railway stations; shopping centres

1. Introduction

During the last decades there has been a trend to maximize the utility of limited space. Therefore high buildings with plenty of levels connected with escalators, stairs and elevators are planned. In this paper we want to discuss the performance of escalators.

In the past different groups have thought about this topic and have made interesting statements. There are norms like DIN EN 115-1:2010-06 or BS 5656-2:2004 which group the practical handling capacity of escalators in dependence on the specific speed of the escalator. Other scientists not only see a connection between the capacity and the speed but also declare an importance of the density of persons on each stair, like Weidmann (1993) does. Schindler and OTIS, both established producers of escalators, equally indicate the practical handling capacity of their escalators in dependence on the speed and the density of persons. Every one of them sees the practical handling capacity lower than the theoretical capacity. However, the dependence of the practical handling capacity of the moving direction of the escalator or the art of building where the escalator is located has not been investigated yet. Depending on the art of building persons carry more or less package with them, a high appearance of large pieces of luggage surely reduce the capacity of an escalator because less persons are able to board.

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To have a better overview on the practical handling capacity of escalators empirical studies are missing, hence we have carried out field studies on this topic. In our study we reduced the observed escalators to such at shopping centres and railway stations. In general there is a difference regarding traffic at these two locations. At railway stations more persons seem to be in a rush than persons at shopping centers. Is therefore the capacity of escalators at railway stations higher than at shopping centers? And, is there a difference between the capacities of escalators with different moving directions?

In this work we discuss the first results of our field study.

2. Capacity according to theory and literature

The theoretical capacity of an escalator is composed of speed \( v \) in m/s, stair depth \( y_1 \) in mm, the number of stairs per meter (calculated from \( y_1 \)) and the density \( p \) in persons/stair. For example:

\[
\frac{0.5 \text{ m/s}}{s} \cdot \frac{2.5 \text{ stairs}}{m} \cdot \frac{2 \text{ persons}}{\text{stair}} \cdot \frac{60\text{ s}}{\text{min}} = 150\frac{\text{persons}}{\text{min}}
\]

Table 1. Theoretical capacity of escalators. All values have been calculated with \( y_1 = 400 \text{ mm} \). Depending on density \( p \) and on the specific speed there are theoretical capacities on the right.

| stair width [mm] | \( v = 0.50 \text{ m/s} \) | \( v = 0.65 \text{ m/s} \) | \( v = 0.75 \text{ m/s} \) |
|------------------|--------------------------|--------------------------|--------------------------|
| 600 \( \sim p = 1.0 \) | 75.00                     | 97.50                     | 112.50                    |
| 800 \( \sim p = 1.5 \) | 112.50                    | 146.30                    | 168.80                    |
| 1000 \( \sim p = 2.0 \) | 150.00                    | 195.00                    | 225.00                    |

The highest practical handling capacity at a specific speed of 0.5 m/s and with a stair width of 1000 mm is stated by OTIS with 105 persons/min (table 2), what fits to Westphal (1971). In his field study he averages the practical handling capacity of downstairs and upstairs escalators. This flow is only 70% of theoretical capacity, the lowest practical capacity is denoted by British Standard and Weidmann (1993) with 75 persons/min, what amounts only 50% of theory and at least seems reachable in reality over a longer time interval. Another value is denoted by Oeding (1963), he discovers 70 to 80 persons/min as maximal flow.

Table 2. Practical handling capacity of escalators according to literature and industry (depending on stair width, speed and density; under crowded condition).

| source | \( v = 0.50 \text{ m/s} \) | \( v = 0.65 \text{ m/s} \) | \( v = 0.75 \text{ m/s} \) |
|--------|--------------------------|--------------------------|--------------------------|
| DIN EN 115-1:2010-06 | 100.00                   | 121.67                   | 136.67                   |
| BS 5656-2:2004, Weidmann | 7.50                     | 146.30                   | 112.50                   |
| Schindler | 100.00                   | 121.70                   | -                        |
| OTIS | 105.00                   | 126.75                   | 135.00                   |

3. Field studies

During our field studies we have made 62 measurements at escalators with a specific speed of 0.5 m/s. The following tables (Table 3 and 4) show an extract of our results. The maximal capacity varies with the observed time interval. Therefore the smaller the time interval is set, the higher the maximal capacity.
To structure the measurements we split the data into two main sections with two sub-sections each. The main sections are the locations (railway stations/shopping centers), the sub-section is the moving direction (upstairs/downstairs). As an effort to get a moderate overview of the influence of the intervals size, we analyzed the flow of each measurement with four different intervals, in fact 10 seconds, 30 seconds, 60 seconds, 90 seconds and 120 seconds.

Table 3. Measurements at railway stations, N(t) data. An overlook at the results of our measurements at railway stations, divided into upstairs and downstairs moving direction, also depending on time interval $\Delta t$. Each measurement has an independent identification.

| railway station ID | capacity of observed escalator [persons/min] depending on time interval $\Delta t$ [s] | mean $\Delta t = 10$ s | $\Delta t = 30$ s | $\Delta t = 60$ s | $\Delta t = 90$ s | $\Delta t = 120$ s |
|--------------------|---------------------------------|------------------|------------------|------------------|------------------|------------------|
| up                 |                                 | 30.33            | 80.67            | 51.08            | 38.53            | 31.80            |
| 34                 |                                 | 23.45            | 86.00            | 58.85            | 51.66            | 42.69            |
| 40                 |                                 | 25.49            | 48.66            | 40.47            | 31.54            | 28.89            |
| 41                 |                                 | 18.36            | 66.60            | 50.02            | 41.33            | 35.01            |
| 45                 |                                 | 23.53            | 84.42            | 51.13            | 42.96            | 42.96            |
| 47                 |                                 | 22.13            | 72.63            | 60.13            | 51.68            | 51.68            |
| 49                 |                                 | 42.20            | 103.77           | 70.14            | 58.19            | 51.86            |
| 50                 |                                 | 37.49            | 93.98            | 70.80            | 63.36            | 54.89            |
| down               |                                 | 71.18            | 107.72           | 88.21            | 85.30            | 83.45            |
| 3                  |                                 | 77.77            | 102.09           | 88.40            | 87.09            | 84.97            |
| 7                  |                                 | 53.81            | 93.76            | 74.15            | 68.05            | 65.43            |
| 11                 |                                 | 44.25            | 87.36            | 64.14            | 54.31            | 50.77            |
| 13                 |                                 | 21.91            | 75.85            | 54.66            | 43.10            | 38.93            |
| 19                 |                                 | 21.10            | 82.61            | 60.21            | 46.04            | 38.23            |

The highest capacity at railway stations of 103.77 persons/min upstairs and 107.72 persons/min downstairs (IDs 50 and 3) occur at an interval of only 10 seconds. In comparison maximal measured capacity of escalators at shopping centers is merely 91.50 persons/min (IDs 57 and 27), in both moving directions. However, these values are exclusive peak values and not observable over longer periods. Hence peak values are not authoritative for dimensioning escalators because they would be oversized. In this case the escalators capacity approximates to a lower flow as expected, which is improvident. Values belonging to an interval of 120 seconds or even the mean flow are more suitable. Still there is a disadvantage of the mean flow. The mean flow seems in comparison to the peak values way too low. This denotes in peak times an escalator dimensioned with mean flows does not guarantee a smooth process.

Obviously the capacity depends extremely on the contemplated time interval $t$. Analyzing the data of each time interval in comparison to the values given by literature it gets conspicuous that at $t = 10$ seconds the appending values almost equates to the practical handling capacity of British Standard. With a larger $t$ the observed capacity is located in an area below the practical handling capacity of literature.

The average maximal flow according to the time interval $t = 10$ seconds is different at the two locations. Making no difference in moving directions, the average maximal flow in shopping centers results to 72.24 persons/min, at railway stations to 81.05.

Again Fig. 1a punctuates the dependence on $t$, representing a N(t) chart with maximal flow under specific time intervals. Fig. 1b shows in red how many persons at a specific time point boarded the escalator.

In contrast to Fig. 1, Fig. 2 illustrates the development of the maximal flow depending on time interval $t$. The boundary values of $t$ are set to 10 seconds at the minimum- and 120 seconds at the maximum-side. The result of this dependence is an exponential function, which approximates to a horizontal line by growing $t$. In respect to standard deviation of the mean flow error bars are installed. All curves have a similar progress. Subsequent we compare measurements under two main criteria. Criterion one is the location where the measurement has been taken, criterion two is the moving direction of the escalator.

Fig. 2a illustrates the comparison of downstairs escalators at railway stations and shopping centers. Here the flow at railway stations is about 10 to 20 persons/min higher than the flow at shopping centers.

In difference to Fig. 2a, Fig. 2b shows the opposition between upstairs escalators at railway stations and shopping centers. The two curves take a closer course to each other as in Fig. 2a. At railway stations the flow is merely 5 to 10 persons/min higher. Additionally the graph according to railway stations features salti.
Fig. 1. (a) Example for N(t) analysis (table 4, ID 26) with different time intervals. The observed escalator with moving direction downstairs is located at a shopping centre. Time intervals are set to find the maximal flow of passengers; (b) Example for N(t) analysis with derivation (Table 4, ID 26).

Table 4. Measurements at shopping centres, N(t) data, with same structure as Table 3.

| shopping center ID | capacity of observed escalator [persons/min] depending on time interval Δt [s] |
|--------------------|----------------------------------------------------------------------------------|
|                    | mean | Δt = 10 s | Δt = 30 s | Δt = 60 s | Δt = 90 s | Δt = 120 s |
| up                 |      |           |           |           |           |            |
| 51                 | 37.41| 50.30     | 78.46     | 74.89     | 52.11     | 52.11      | 64.57     | 52.11     | 44.84     | 45.64     |
| 52                 | 21.54| 27.54     | 62.70     | 41.80     | 36.12     | 30.83      | 41.80     | 36.12     | 30.83     | 28.61     |
| 53                 | 46.38| 44.90     | 78.78     | 70.13     | 63.66     | 59.67      | 63.66     | 59.67     | 53.08     |
| 54                 | 18.27| 12.47     | 58.60     | 36.47     | 29.36     | 26.68      | 36.47     | 29.36     | 26.68     | 23.58     |
| 57                 | 23.05| 23.46     | 91.50     | 60.34     | 48.12     | 43.23      | 60.34     | 48.12     | 43.23     | 36.45     |
| 60                 | 31.47| 31.47     | 72.99     | 52.94     | 46.35     | 43.42      | 52.94     | 46.35     | 43.42     | 43.15     |
| 61                 | 49.86| 49.86     | 88.31     | 71.42     | 64.98     | 57.36      | 71.42     | 64.98     | 57.36     | 56.55     |
| down               |      |           |           |           |           |            |
| 21                 | 50.30| 50.30     | 84.99     | 74.85     | 65.59     | 58.17      | 74.85     | 65.59     | 58.17     | 54.62     |
| 22                 | 27.54| 27.54     | 69.28     | 49.22     | 45.61     | 43.69      | 49.22     | 45.61     | 43.69     | 40.06     |
| 23                 | 44.90| 44.90     | 79.10     | 60.22     | 54.28     | 52.22      | 60.22     | 54.28     | 52.22     | 51.66     |
| 24                 | 31.08| 31.08     | 72.36     | 53.48     | 44.70     | 37.07      | 53.48     | 44.70     | 37.07     | 36.12     |
| 25                 | 12.47| 12.47     | 50.66     | 23.61     | 18.51     | 15.04      | 23.61     | 18.51     | 15.04     | 15.04     |
| 26                 | 23.46| 23.46     | 91.03     | 70.55     | 44.88     | 40.62      | 70.55     | 44.88     | 40.62     | 36.99     |
| 27                 | 25.71| 25.71     | 69.80     | 43.82     | 39.13     | 34.26      | 43.82     | 39.13     | 34.26     | 31.57     |
| 28                 | 54.08| 54.08     | 91.09     | 82.35     | 70.32     | 66.30      | 82.35     | 70.32     | 66.30     | 62.61     |
| 29                 | 55.54| 55.54     | 91.43     | 72.29     | 67.52     | 64.94      | 72.29     | 67.52     | 64.94     | 62.61     |
| 30                 | 35.70| 35.70     | 84.32     | 61.40     | 55.04     | 50.09      | 61.40     | 55.04     | 50.09     | 45.46     |
| 31                 | 32.90| 32.90     | 69.29     | 59.01     | 43.05     | 40.05      | 59.01     | 43.05     | 40.05     | 38.68     |
| 32                 | 41.12| 41.12     | 68.49     | 58.21     | 49.34     | 45.18      | 58.21     | 49.34     | 45.18     | 43.52     |
| 33                 | 19.57| 19.57     | 80.39     | 42.50     | 27.02     | 26.93      | 42.50     | 27.02     | 26.93     | 26.64     |

The comparison of different moving directions at the same location is illustrated in Fig. 2c for shopping centers and in Fig. 2d for railway stations.

Independent of the location both diagrams indicate, that downstairs escalators have a higher flow than upstairs escalators. The reason for this phenomenon could be the subjective feeling of nearness by each individual. To get a maximal flow the persons need to step right behind each other, but a lot of persons feel uncomfortable with a back right in front of his or her face. Hence at upstairs escalators boarding persons leave more space to the persons in front of them. On the other hand the persons view maintain open at downstairs escalators on these grounds boarding persons leave less space to the person in front. That could be the reason for higher flows on downstairs escalators than on upstairs escalators.
Fig. 2. (a) development of the flow under specific time intervals comparing downstairs escalators at railway stations and shopping centres with error bars to visualise standard deviation of the mean flow. (b) same structure as (a). Comparison of upstairs-escalators. (c) same structure as (a). Comparison of escalators at shopping centres with different moving directions. This might answer the question whether there is a dependence of the flow on the moving direction. (d) same structure as (c). Comparison of escalators at railway stations with different moving directions.

A dislike of persons to stand very close to each other on escalators at shopping centers could be observed by Rogsch (2013) in his study about the usage of escalators under normal conditions at shopping centers as well. He denotes an acceptance of little personal space under rush conditions, but distinguishes the preference of people to get as much personal space as possible, at least at shopping centers. This fits our observations.

Fig. 2d shows diverging graphs with growing time interval. The difference between upstairs and downstairs rises from about 10 persons/min at the minimal time interval to about 20 persons/min at the maximal analyzed time interval. On the opposite the graphs in Fig. 2c process almost parallel.

4. Conclusion

We discussed the results of our measurements under different perspectives. There is a link between the flow and the type of use of the building where the escalator is located as well as between the flow and the moving direction of the escalator. We want to underline that the flow values provided depend significantly on the time interval used for the calculation of the mean flow. To enable an evaluation which interval is the best to represent the capacity of escalators
further field studies are necessary. Other locations as railway stations and shopping centers should be included. For example airports would be an interesting location with a benefit on different type of occupants.

For a time interval of 10 seconds we found the highest capacity at railway stations of 103.77 persons/min upstairs and 107.72 persons/min downstairs. In shopping centres the maximum amounts 91.50 persons/min in both moving directions. We have to note that these values are exclusive peak values and not observable over longer periods. This cast doubts to specifications in guidelines and handbooks where capacities of 100 persons/min are given without any limitation regarding the time periods for which such high flow values could be maintained. So at least a few questions of our introduction possibly are answered, but other questions appeared which we need to answer in the future for a better appraisal of the capacity of escalators.

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