# High Density Measurements from Ramadan at Makkah, 2025

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**Abstract** We provide an extensive set of measurement data from Ramadan 2025 at Makkah, KSA. A great number of cameras has been installed in critical locations in and around the Holy Mosque, so that not only the areas in the immediate vicinity of the Kaaba are evaluated, but also entrances, passages and other walkways. We regard this as a unique opportunity to compile data for crowd movement in the high density, multi-cultural, multi-age, multi-fitness regime, data that is needed to further understand the movement and behaviour of high density crowds in order to guarantee safety and comfort.

**Keywords** High Density Crowds, Fundamental Diagram, Maximum Capacity, Pedestrian Safety

## Fundamental Diagrams

Two of the key criteria when designing places for safe pedestrian motion is the maximum throughput and the density at which this maximum occurs. The reason is obvious: a channel or passage can only handle a certain maximum throughput; if the incoming flux of pedestrians exceeds this capacity, people will accumulate, driving the density to dangerous levels (asphyxia, crowd crushes). As can be seen from the data compiled by Holl[1], Löhner et al.[2], and Helbing et al.[3] shown in Figures 1,2, there is a wide discrepancy of so-called fundamental diagrams.

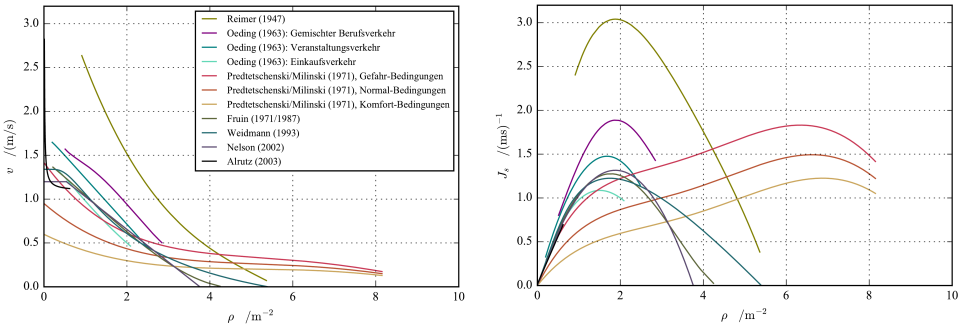


Figure 1: Compilation of Fundamental Diagrams: Velocity (left) and Flux (right) (from [1])

The most immediate differences one can discern are:
a) A series of measurements where the maximum flux peaks at 1.8-2.0 p/sqm, and others where the peak is at 6-7 p/sqm;
b) A series of measurements where the pedestrian motion stops completely at 3.8-5.4 p/sqm, and others where the motion never stops, even for densities greater than 8.0 p/sqm;
c) The large variation in maximum densities measured: which range from 2.0 p/sqm to greater than 8.0 p/sqm.
There are a number of possible reasons for this discrepancy; the two most obvious being:
a) Some of the authors were actually never able to measure situations with such high densities, and simply extrapolated curves;

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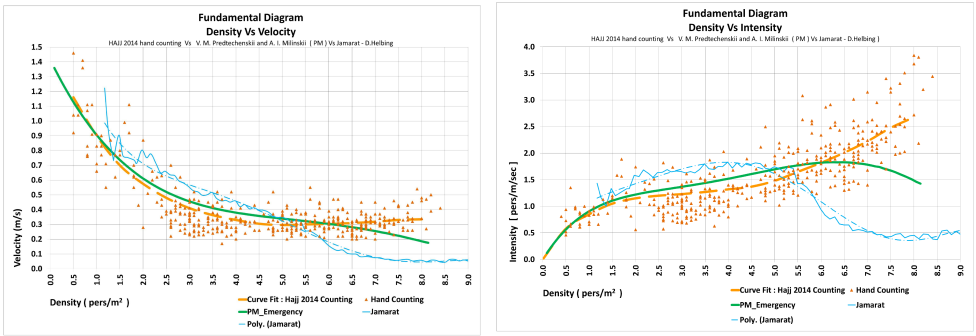


Figure 2: Fundamental Diagrams Sites in Makkah, KSA: Velocity (left) and Flux (right) (from [2])

b) Some of the authors report controlled experiments and not field data; this implies that the individuals being measured had no need to reach a certain place at a certain time and had the option of simply stopping if they so desired.

In order to increase our knowledge and understanding of high density flows, and the possible differences between them, an experimental campaign is being prepared for the upcoming Ramadan season. A great number of cameras has been installed in critical locations in and around the Holy Mosque, so that not only the areas in the immediate vicinity of the Kaaba are evaluated (as in [2]), but also entrances, passages and other walkways. We regard this as a unique opportunity to compile data for crowd movement in the high density, multi-cultural, multi-age, multi-fitness regime, data that is urgently needed not only for static analysis but also for network and micro/agent models.

The final paper will provide an extensive compilation of the measurements, elaborate on the observations, and thus expand on previous empirical studies in Makkah by the authors, such as [2] and [3].

## Bibliography

[1] Holl, S., *Methoden für die Bemessung der Leistungsfähigkeit Multidirektional Genutzter Fußverkehrsanlagen*; Schriften des Forschungszentrums Jülich, IAS Series Band/ Volume **32**, ISBN 978-3-95806-191-0 (2016).

[2] Löhner, R., Muhamad, B., Dambalmath, P. and Haug, E., *Fundamental Diagrams for Specific Very High Density Crowds*; Collective Dynamics **2**, 2018. doi: http://dx.doi.org/10.17815/CD.2017.13

[3] Helbing, D., Johansson, A. and Al-Abideen, H.Z., *Dynamics of Crowd Disasters: An Empirical Study*; Physical Review E **75**, 046109 (2007).