**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte

**Band:** 71 (1994)

**Artikel:** Crowd modelling

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**DOI:** https://doi.org/10.5169/seals-54154

# Crowd Modelling
## Modélisation des masses humaines
## Modellierung von Menschenmassen

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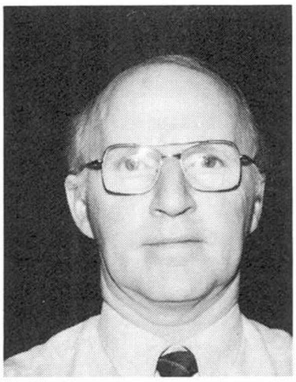

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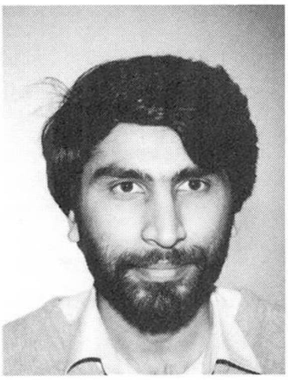

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**SUMMARY**
This study develops a computational model that enables the analysis of the flow of a crowd to be examined. The placement of individuals that comprise the crowd may be random within a bounded space and the crowd density may be varied. The walking speed of the individuals is described using a Normal Distribution, the mean and standard deviation may be independently varied. The speeds of given individuals may also be specified independently of the distribution; this enables the influence of moving individuals to be examined.

**RÉSUMÉ**
Les auteurs ont développé un modèle assisté par ordinateur qui permet de calculer les flux de foule, compte tenu de la répartition aléatoire des individus dans un espace limité et de la variation de la densité humaine. La vitesse de déplacement est définie par une répartition normale avec variation autonome de la valeur moyenne et de l'écart type. L'attribution d'une vitesse indépendante de la variation permet d'examiner l'effet d'une masse humaine à déplacement lent et rapide.

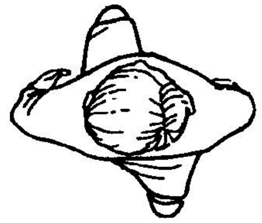
**ZUSAMMENFASSUNG**
Für die Berechnung von Menschenflüssen wurde ein Computermodell aufgestellt, in dem die Personen innerhalb eines abgegrenzten Raumes zufällig verteilt sind und die Massendichte variiert werden kann. Die Gehgeschwindigkeit wird durch eine Normalverteilung mit unabhängig wählbarem Mittelwert und Standardabweichung beschrieben. Durch Vorgabe einzelner Geschwindigkeiten unabhängig von der Verteilung kann der Einfluss sich bewegender Personen untersucht werden.

## 1. INTRODUCTION.

The movement of pedestrians in and about crowded public areas is the concern of a number of professions. Shinjyuki station in Japan will handle 1362000 passengers daily; 70000 spectators wish to leave Wembley stadium,London, almost simultaneously; the World Trade Centre, a high rise building in New York City, has 50000 employees and an estimated 80000 daily visitors. In each of these situations the problems posed in planning for normal egress have to be integrated with emergency requirements. Central to the problem is that the physical environment of any structure or space needs to safely accommodate large flows of people. Current design procedures, embodied in codes, have evolved from empirical evidence obtained from observation. The work subsequently described presents a computer simulation that follows the progress of each individual in a uni-directional crowd moving towards a common objective. Slow moving individuals whether a large number of elderly or a single disabled individual or an individual encumbered with baggage or an individual in a hurry will all influence the flow of any body of people in which they move. The simulation allows variation of the movement characteristics of any individual or a group of individuals in a randomly spaced crowd flow. The movement characteristics of individuals within the crowd are described in a statistical manner that allows variation of mean and deviation.

## 2. PREVIOUS WORK.

Templer [15] describes the spatial requirements of a pedestrian and the manner in which the pedestrian systematically occupies and relinquishes space. The space required for pedestrian movement is dependent on four factors, the body ellipse, the pacing zone, the sensory zone and the buffer zone.The body ellipse represents the physical plan dimensions of the body, the pacing zone represents the space within which movement occurs. The sensory zone is the distance a person tries to maintain between the body and other parts of the environment so that there will always be enough time to perceive and evaluate and react to approaching hazards. The buffer zone is the space that people maintain between themselves and others for psychocultural reasons. In crowded spaces the sensory and buffer zones will merge and will not be present in densely crowded spaces. A conflict is any stopping or breaking of normal walking pace due to a too close confrontation with another pedestrian. A conflict does not mean actual impact; pedestrians can stop and turn with remarkable speed.



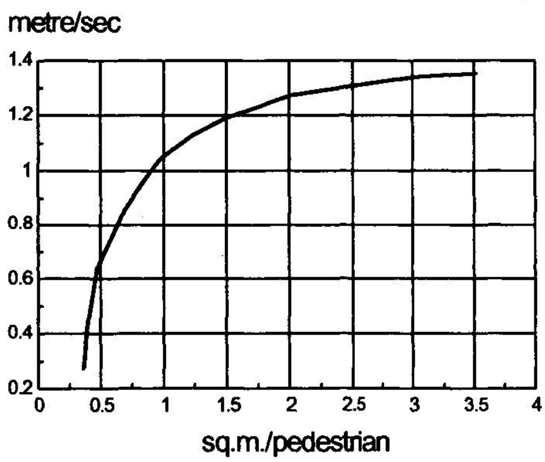



Fig.1. Pedestrian walking speeds. (Taken from Fruin.)

The work of Fruin [4] provides many of the benchmarks for pedestrian movement. The simplest of starting points is the free flow walking speed which Fruin obtained from surveys of 1000 non baggage carrying pedestrians, 1.37 m/sec for males and 1.29 m/sec for females. Tanaboriboon [14] obtained a mean value for Singaporean men of 1.32 m/sec and for women 1.15m/sec. These differences in such a basic parameter are an indication of the difficulty in examining the characterisitics of crowd flow from a general viewpoint. Cunningham and Cullen [3] in work relating to London Underground point to the volume of work that the measurement of pedestrian characteristics has produced and the associated difficulties. Crowd density influences the velocity of the individual within the crowd and numerous authors have examined the relationship. Fig.1 taken from Fruin [4] illustrates an observed relationship between density and velocity, experimental scatter exceeded ±10%. The primary interest concerns the flow rate of the mass as opposed to the velocity of an individual and this is illustrated in Fig.2. Also shown in Fig.2 are results presented by Ando [1]. The shift in Fig.2 emphasises the particular nature of any empirical study. The mean walking speed of Singaporeans is 74 ped/m/min., relatively slower than that of his American counterpart. Nevertheless the Singaporean maximum flow rate is 89 ped/m/min which is higher than the 81 ped/m/min and 78 ped/m/min obtained in the U.S. and Britain respectively.

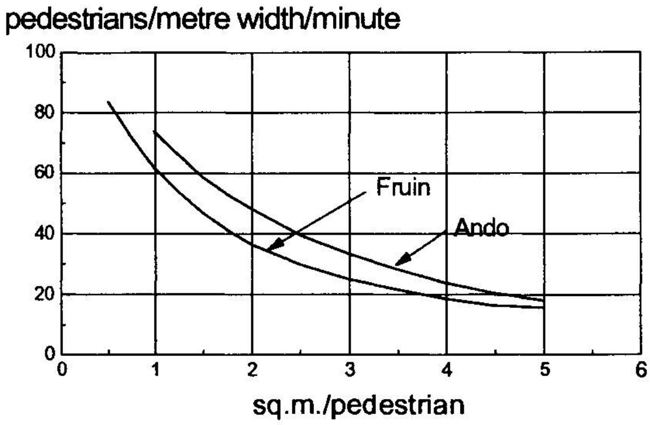



Fig.2. Pedestrian flow rates.

Considerable variations in these measured values occur without crossing international boundaries; Hoel [5] measured pedestrian walking speeds in the U.S. at 88 ped/m/min. A 15 second surge into a civil defense shelter was measured as equivalent to 146 /m/min., with a 5 minute interval reaching 105/m/min. Peak values for marching soldiers of 157 /m/min., have been obtained.

Pedestrian flow rates impact on the engineer,architect and emergency planner through design codes that specify allowable flow rates through varying exit widths. These in conjunction with evacuation times result in necessary component and aggregrate exit widths in any facility. The Guide to Safety at Sportsgrounds [7] gives maximum flow rates and assumes that the movement is through an exit width of at least 1.1 metres (a double unit width). From stands and all stairways a flowrate of 40 persons/minute per unit of exit width (550 mm) is required. From terraces and the ground generally a flow rate of 60 persons per unit of exit width should be used. The Guide to Fire Precautions in Existing Places of Entertainment and Like Premises [6] states that in crowded conditions a file of people moving through and opening will occupy a space of about 525 mm in width (unit of exit width). Furthermore people will move through that space at a rate of about 40 persons per minute per unit of exit width. It is questionable whether the concept of calculating exit widths in multiples of a given dimension can be considered valid above 2 units wide. Above this regular patterns of formation become blurred. It is against this background that there has been a development in recent years of a system based on increments of unit width rather than whole units. It is recommended that in places of entertainment the lowest incremental width to be used should be 75 mm which would allow for up to 15 persons where the maximum caluculated evacuation time is 2.5 minutes; each exit dealt with seperately. BS 5588, Fire precautions in the Design, Construction and Use of Buildings [2] gives allowable capacities in terms of exit widths varying from 800 mm up to 1800 mm. Above 1100 mm the capacity:width relationship is linear. A 1500 mm exit width is required for 300 people. If a flow rate of 80 persons/m/min., is assumed the evacuation time would be 2.5 minutes. An exit width of 5mm/person gives an exit time of 2.5 min. This is also the value given in NFPA 101 [9].

## 3. MODELLING OF CROWD FLOW.

Kendik [8] classifies current models evolving from people movement:

1. Flow models based on the carrying capacity of independent egress-way components or the unit exit-width concept.
2. Flow models based on empirical studies of crowd movement.
3. Network optimization models.
4. Computer simulation models.

The first of these reduces the problem to a simple aggregation. The second approach has been adopted by a number of authors. Polus [10] uses both one- and three-regime linear models to fit relationships between pedestrian speed and density. The third approach was used by Selem and Al-Rabeh [12] who present a model concerning a site at Mecca that accommodates 750000 pilgrims. The pilgrims cross a bridge and stop on three occasions, each time in the vicinity of a pillar in order to perform a religious rite. The bridge is in essence a corridor with three obstructions where the pilgrims halt. The area was broken down into activity zones the geometry of these was established using aerial photography. Predetermined safe crowd densities were set for each zone and an optimisation procedure was adopted to establish a safe flow onto the bridge. The demand interval spanned 5 hours; the model indicated that in order to avoid congestion that would exceed safety limits an 8 hour interval was necessary. Different examples of the fourth category are to be found in the Engineering for Crowd Safety conference proceedings [13].

## 4. PRESENT WORK.

Savage [11] clearly demonstrates the practicality of computer simulation in examining a number of problems relating to continua that are aptly described using hard particle models. In his granular flows, knowing the positions and velocities of all the particles, one searches through the particle list to determine the next particle pair that will collide; knowing the law that descibes the collision the collision is implemented to determine the post collisional velocities and directions of the colliding particle pair and so on. The driving forces included gravity, wind and ocean currents.

In the problem to be considered here each pedestrian provides the driving force; the avoidance of collisions in combination with available spaces determines the pattern of movements. In this application the model describes a two-dimensional unidirectional flow of a variable density crowd randomly distributed in an Observation Area which is a rectangle of length L and width W. The crowd flow is parallel to the length L, simulating a corridor situation. The number of people in the Observation Area determines the density. This number of people will always be present in the Observation Area since it is bounded by periodic boundaries; as an individual passes through the upstream boundary reentry occurs at the same location on the downstream boundary with the same speed. For the work presented here the length L, the separation between periodic boundaries, was set to 12.19 m (40 ft) while the width and densities were varied from 1.22 - 3.05 m (4 - 10 feet) and 5 - 55% respectively. However, the length can be varied as required. An individual's Resident Area is represented by an octagon enclosing a circle of diameter 610 mm. The Observation Area has a mesh 30.5 mm square, only one individual's Resident Area may occupy a node in the mesh. In addition all individuals have a Movement Area that is defined by an octagon enclosing a circle of 1220 mm diameter. The simulation is initiated by the random placement of individuals within the Observation Area. The velocity assigned to individuals follows a Normal Distribution with the user defined mean and standard deviation. The assigned speed is the maximum speed with which that individual can move. However, it is possible to model a disabled or an energetic individual by assigning individuals a very low or very high speed respectively.

The Movement Area enables each individual to move forward with a stride length of 610 mm. The preferred direction is straight forward, but if this is not possible then the individual randomly chooses to move either left or right. Lateral movement left or right is restricted to 305 mm. Motion forward is achieved by scanning for space that allows a full length stride with a corresponding space for the second stride. If space is available for two strides, the individual moves forward by one stride. If space is only available for the first stride, the individual still moves forward, the preferred direction being straight ahead. If movement by one stride is not possible, the whole sequence is repeated for reduced stride. The reduction being 30.5 mm each time (the nodal spacing) till either movement is possible or zero foot stride is reached which means no motion is possible. An individual will always

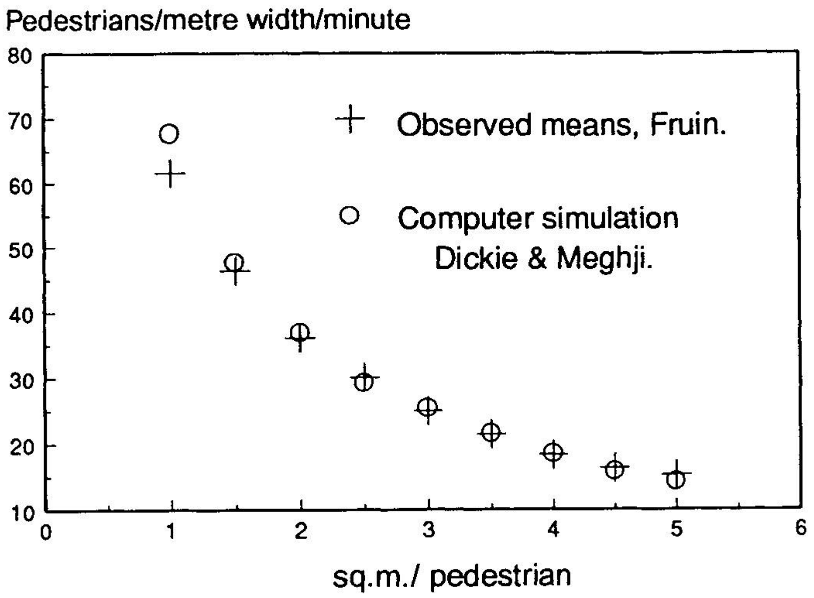



Fig.3. Comparison of observation with simulation.

advance as far forward as possible. The movement starts with the individual with the highest speed. The time for next normal stride is computed for each individual and is compared with the total simulation time to determine the next individual motion. All individuals in the Observation Area will try to move with their assigned maximum speed during the whole of simulation process. The simulation is run for about 500 seconds and the results are then averaged.

Fig.3 illustrates a comparison with the observed results of Fruin [4]. The results concern a crowd possessing a walking speed distribution that has a mean of 1.31 m/sec and a distribution of .152 m/sec. At higher flow rates (>90) the model will produce the same falling flow rate that is observed in practice.The correlation between the observed results and those obtained from the model is good. The ability of a pedestrian to alter his or her gait is recognised by the model. In addition variation of anthropometric data is possible.The model has been used to examine certain factors that will influence crowd flow. A summary of the results for crowd densities that give approximately one person/ $m^2$ is contained in Table 1.

| Case | No.of Ped. | Velocity m/sec | Deviation m/sec | Flow Ped/m/min | Corridor width (m) | Comment |
|---|---|---|---|---|---|---|
| 1 | 40 | 1.31 | 0.061 | 81 | 3.05 | |
| 2 | 40 | 1.40 | 0.061 | 87 | 3.05 | |
| 3 | 40 | 1.31 | 0.152 | 77 | 3.05 | |
| 4 | 40 | 1.40 | 0.152 | 87 | 3.05 | |
| 5 | 39 | 1.31 | 0.061 | 82 | 3.05 | +1 at 1.83 m/sec |
| 6 | 39 | 1.31 | 0.061 | 79 | 3.05 | +1 at 0.61 m/sec |
| 7 | 35 | 1.31 | 0.061 | 70 | 3.05 | +5 at 0.61 m/sec |
| 8 | 16 | 1.31 | 0.061 | 81 | 1.22 | |
| 9 | 20 | 1.31 | 0.061 | 81 | 1.52 | |
| 10 | 24 | 1.31 | 0.061 | 81 | 1.83 | |
| 11 | 15 | 1.31 | 0.061 | 43 | 1.22 | +1 at 0.61 m/sec |
| 12 | 19 | 1.31 | 0.061 | 71 | 1.52 | +1 at 0.61 m/sec |
| 13 | 23 | 1.31 | 0.061 | 76 | 1.83 | +1 at 0.61 m/sec |

Table 1.

Case 1 serves as a reference value and concerns a flow level of 81 pedestrians/ metre width /minute, similar to the values adopted by all design codes. It should be borne in mind that the velocity given in column 3 is not the mean velocity of the crowd, it is the mean of each individual's velocity potential Due to lateral movements and interferences in stride patterns the mean velocity of the flow is the character of an audience to be taken into account. A crowd leaving a football match will be predominantly composed of young men who will walk with speeds that are higher and lie in a narrow band than an audience leaving a theatre. The influence of a slow individual, Case 6, is not significant in the larger crowd. One person in forty is 2.5%, if the level is increased to 12.5%,Case 7, the decrease in flow is more marked. Two unit of exit widths referred to in numerous codes are equivalent to 1.1 m. Case 12 relates to an exit width of 1.22 m and clearly a slow individual will significantly impede the flow. The reduction for an exit width of 1.52 also represents a significant departure from code values. In flows of this density and over a length of 10 m a pedestrian might expect to change his line of forward movement possibly once. Case 5 concerns an individual who wishes to move at a rapid walk. The model shows that the speed of this individual's walk requires that he or she will be making lateral adjustments at a rate of one per metre, increasing the possibility of collisions.

## 5. CONCLUSION.

A computational model is presented that enables crowd flow to be examined and the model is shown to agree well with field data. The density of the crowd and the characteristics of individuals who make up the crowd can be varied. The impact of slowly and rapidly moving individuals is considered and the results have implications with regard to exit widths assumed in commonly used codes.

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