Deducing the Impact of Excluding Social Groups when Modelling Pedestrian Flow

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For practical applications, it is often necessary to make broad assumptions when modelling pedestrian movement. Depending on the purpose of the model, certain factors may be simplified or excluded. These assumptions may be required to represent the scenario or focus on specific user objectives for technical or technological reasons. However, it is critical for those using people-movement models to understand the impact of underlying assumptions. This is important for any kind of pedestrian flow model: Whether it is mathematical, regulatory, experimental or computational, it is a simplification and requires leaving out real-world factors [1]. These omissions and simplifications must be identified and justified, and the impact of their exclusion assessed.

This is challenging. Often, a factor is excluded or simplified because its impact is deemed negligible and/or undesirable. However, it is dangerous to underestimate the impact of a specific factor without close scrutiny, especially as the real-world scenario becomes more complex or dynamic, and the impact less intuitive.

This article presents a simple deductive approach to understanding the implications of excluding a particular factor: the presence of social groups in flow. This approach could be a useful tool to help explore the significance of other behavioural factors when designing models. Ideally, such deduction is already applied informally when developing models and scenarios, but the more-formal application might produce more-transparent documentation of modelling decisions.

Example Hypothesis

This article addresses the exclusion of social groups (formed from existing or emerging social ties) when modelling large-scale pedestrian flows, assuming that this effect is dominated by physical factors. Here we *deduce* the impact of social groups on pedestrian flow from stated premises [2–9] by comparing a population of individuals and one of social groups.

There has been research on the impact of social groups on people movement [10–14] (e.g., on group longevity in emergency and influence on movement), but fewer attempts to explicitly model social groups [4, 15–22]. There has been significantly more modelling of the impact of physical factors on crowd flow [18–19, 23–27].

We have drawn conclusions from a set of accepted premises to demonstrate the reasonable application of this logic. The purpose of this analysis is to decide whether this is a factor that should be excluded from a model.

Premises

[P1] Individuals have different speeds (**v**) based on their physical attributes [23, 28]. Given that movement is not constrained by the surrounding population or physical conditions, individual speeds vary between \mathbf{v}_{min} and \mathbf{v}_{max} , producing a range of speeds, $\mathbf{R}_{I} = \mathbf{v}_{max} - \mathbf{v}_{min}$, assuming $\mathbf{v}_{min} > 0$ (i.e., that there is movement).



Individuals and Groups. Orange outlines indicate group membership.

[P2] Social groups exist in pedestrian flows[1–22]. These groups may be of different sizes, demographics and configuration. Group members try to ensure the group remains intact by moderating their speed; i.e. traveling at the speed of the slowest group member (given [P1]).

[P3] Each group moves at the speed of its slowest group member (given [P2]). The range of group speeds within a population consisting only of social groups (or a sub-population within a flow), R_G = [max{G1_{min},...Gn_{min}} – min {G1_{min}-Gn_{min}}], where G1_{min} is the minimum travel speed of a member of G1, etc.

 $R_l > R_G$ unless: (1) population density dictates movement so the population can reach a velocity (v_ρ) where $v_\rho < min(v_{min})$ (i.e., achievable speed is less than the minimum individual speed); (2) every individual has the same speed (contradicting [P1]). [P3] implies that speed varies more in a flow of individuals (F_l) than in a flow of groups (F_G).



Social grouping through speed modification. Purple arrows indicate possible speeds; red arrows, selected speeds.

[P4] If F_l and F_g start in the same initial configuration, then F_l will have more potential to spread out over time while continuing to move towards the same target (all other things being equal) than F_g given [P3]; i.e. $R_l > R_g$. This is true until the population density completely dictates the individual's ability to select a travel speed; i.e., when $v_p < min(v_{min})$. This also suggests that in mixed populations (individuals and groups), there is more opportunity for individuals to move away from slower-moving groups, assuming that their range of individual speeds is typically greater than that of groups. Therefore, it is possible that sub-populations of predominantly groups or predominantly individuals might develop within a larger flow. [P5] F_I will be formed from a lower-density (more distributed) population (D_I) unless physically constrained (given [P4]). D_I will enable continued higher speeds given that (1) individuals are not constrained by the slowest group member and (2) the population is more distributed, reducing the effective population density [9, 23, 27]. F_G will be formed from a higher density (less distributed) population (D_G). D_G will enable continued lower speeds given (1) that individuals are constrained by the slowest group member and (2) that the population is subject to a higher population density. Therefore, v_I (the velocity produced during D_I) should be greater than v_G (the velocity produced during D_G), all other things being equal.

[P6] Flow is a function of velocity, population density and effective width [23, 27]. The implication of [P1–P5] is that until population densities dictate movement (i.e., when $v_{\rho} < min(v_{min})$):

 $F_l = v_l^* D_l^* w$

 $F_G = v_G^* D_G^* w$

where v_l is the velocity of the flow of individuals and v_G is the velocity of the flow of groups. From above [P5]:

v_l > v_G D_l<D_G

Implications

This implies that (1) if a flow is formed only from groups (F_G), then it will move more slowly than flows formed only of individuals (F_I): $v_I > v_G$; and (2) F_G moves at higher densities ($D_I < D_G$) given that they move within a smaller range of velocities ($R_I > R_G$) that are less-distributed. F_I will travel more quickly (as $v_I > v_G$), but at lower population densities ($D_I < D_G$). Conversely, F_G will travel more slowly at higher densities, possibly producing similar flow levels. (F_G) is more likely to experience higher congestion for longer periods, potentially leading to elevated levels of discomfort and physical interaction.

Although F_i and F_g produce different underlying conditions, they may result in similar aggregate conditions – notably, similar flow rates (on average, or at a point in time), where $F_i \approx F_g$. This may lead underlying differences to be obscured.

This means that flow in a population consisting primarily of groups and flow in a population consisting primarily of individuals may appear similar (by measure), but the underlying conditions experienced may be very different.



Similar emerging conditions masking underlying dynamics (comparing flow, f, against population density, ρ).

This analysis is true until densities dictate movement entirely (i.e., $v_{\rho} < min(v_{min})$). This analysis excludes numerous other factors that might contribute to the impact of social groups; e.g., passing through pinch-points, individual actions (people holding hands, people assisting others, group members attempting to form/reform a group, etc.). It is therefore possible that social groups have an even greater impact than that derived here.

Summary

This brief discussion outlines a simple deductive approach to exploring the impact of a modelling assumption — the differences in flows of individuals and flows of groups, based on speed moderation for group maintenance. Different underlying conditions in the population are deduced although these conditions may occasionally produce similar high-level flow outcomes.

A reader's first response might be that this is speculative. It is. However, this speculation is intended to use broadly defensible initial premises to pose questions about the underlying assumptions when designing a model. These are questions that have to be addressed by modellers when documenting and justifying their assumptions.

We have examined extreme examples to demonstrate the point that flows purely of individuals and of groups produce different conditions. In reality, flows are likely to include individuals *and* groups. The derived impact cannot be deduced to be uniform or static across time, scenarios or a population. It may be reasonable in some scenarios for modellers *not* to represent the impact of social groups; e.g., when population density determines the individual's travel speed or when the number of groups in the population is sufficiently low.

There may be a threshold number or proportion of group numbers/types below which their impact is negligible. However, for large pedestrian flows, it is challenging to know this before analysis has been conducted and whether such conditions will be maintained uniformly throughout the population. For instance, sub-populations of groups might appear within a larger flow beyond this 'threshold' temporarily, even though it is reached globally.

In any case, our example shows that a high-level measure of flow may not sufficiently describe the conditions on a route if groups are present. When collecting data on the movement of large crowds, densities and group behaviours should also be considered. Afterward, a decision can be made about representing groups and other factors based upon an assessment of the expected impact.

For the practical use of people movement models, practitioners must understand the real-world factors that influence pedestrian performance. The factors that are included in their assessment should be reported and justified, along with those excluded. It is suggested that deductive approaches might help achieve this. It is argued here that the scale of the flow alone is not a robust justification for the exclusion of social group factors from modelling efforts. When considering this, and numerous other modelling decisions, similar deductive analysis can aid the modeller in assessing, documenting and explaining their assumptions and the scenarios examined.

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