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A Hybridized approach to validation: The role of sociological research methods in pedestrian modeling

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Abstract

Pedestrian and crowd-movement models are difficult to validate using traditional empirical methods because of data-related issues such as generalizability, collection ethics, and costs. Commonly used validation methods make strong assumptions about emergence and the importance of crowd structure, leaving a gap in validation literature. The paper reviews the most common methods of validating pedestrian models and proposes a hybridized qualitative approach to validating models that covers more complex group dynamics and possible situations of panic.

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1. Introduction

Validation in modeling and simulation is an ongoing challenge, particularly for agent-based modelers. Engineers, mathematicians, and economists have proposed a number of possible solutions, none of which yet predominate the field of pedestrian modeling. Empirical validation is particularly challenging for agent-based modelers due to the high degrees of freedom, emergence, non-linearity, and path-dependent natures of the models (Fagiolo et al. (2006), Ligtenberg et al. (2010), Klugl (2008), Gilbert and Troitzsch (2005)). Considering that pedestrian models are inherently sociological and psychological—given that they attempt to model human behavior from a variety of angles—it is important to acknowledge that some purist researchers "…are critical of the suggestion that meaningful empirical validation is possible" or that it is reasonable "…to represent the social context as vectors of quantitative variables with stable dimensions" (Windrum et al. (2007)). For critics of empirical methods, however, it is not

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enough to conclude that quantifying social behaviors is nearly impossible. If pedestrian modeling is to achieve greater credibility in the wider modeling community, progress must be made in developing methods to analyze the validity of existing models. In this study, the researchers propose a hybridized method of model validation by incorporating sociological research through survey collection. This research is presented as a pilot study to determine the feasibility of using survey data in model development and validation, and is not proposed as a final solution, but rather a compliment to the existing methods of observational video and laboratory data.

This paper first reviews existing attempts to validate pedestrian models. It proceeds by explaining the methodology of the researchers' proposed survey approach to understanding pedestrian egress behaviors by asking individuals to predict what they would do in certain situations. The findings of the pilot study are discussed and contextualized as a first step in more extensive future research. In conducting this pedestrian behavioral survey, the researchers intend to challenge the notion that individuals act in predictable ways, even in non-panicked venue egress, and that the mobility of group members plays a substantial role in the behavior of others in that group.

2. Validation of Pedestrian Models

Two major themes emerge in validation research of pedestrian models: comparison to existing related studies and video observation. One way that modelers address the problem of validation is to compare their model results and capabilities with the work of others (Banerjee et al. (2009), Murphy et al. (2013)). This is often presented as a last note before the conclusion of the paper to demonstrate that the model is at least as good as other published research in the same field. (Klugl (2008)) call this type of validation "model alignment" in which previously established models considered valid by others are used as a benchmark for the validity of newer models. Some scholars caution against relying entirely on this type of validation stating, "It should be kept in mind that just because two models produce similar results doesn't necessarily mean that either model is valid, since both could contain a similar error" (Law (2007)). In specific scenarios, such as modeling pedestrian movement around well-known landmarks, researchers can provide some validation by comparing their model to the observation and work of other, even sociological or anthropological, researchers (Curtis et al. (2011)). While this presents an interesting opportunity to validate a model against real-world data from multiple sources and disciplines, it is a unique situation when a pedestrian model reflects a data-rich context or environment and cannot be applied to more generalizable scenarios. Models seeking to describe evacuations from parks or other public areas where repetitive events are uncommon will not have the same rich base of available data with which to compare results for validation.

An increasingly common way to validate pedestrian models is by comparing videos of real-world or laboratory-based crowds and comparing this qualitative data to simulation results (Kretz et al. (2006), Seyfried et al. (2009), Zhang et al. (2012), Berrou et al. (2007), Lerner et al. (2009), Lerner et al. (2007)). Use of video in both laboratory and real-world settings provides a wealth of data with which to validate pedestrian models. Some researchers have even addressed the generalizability of this data by collecting video input globally (Berrou et al. (2007)). For most researchers, this video data provides validation of the ways in which crowds move in their models, namely related to crowd density, flow rates, bottlenecks, and individual velocity. Some researchers use this video data to identify subjective qualitative data, such as identifying age, mobility challenges, and gender (Berrou et al. (2007)). This type of qualitative analysis relies on major assumptions about the visual detection of age and mobility as well as socially constructed concepts of gender (Martin (2004)). It introduces unintentional researcher bias as study investigators attempt to identify demographic markers in video footage based on predetermined values about what those qualities should resemble.

Panic, in particular, is a difficult behavior to validate in pedestrian models given the ethical limitations of observing humans in real-world panic environments or subjecting individuals to mock-emergency situations. Helbing et al. (2000) conducted a study of "escape panic" based on nine movements and behaviors identified in socio-psychological literature and media. These generalized behaviors were then approximated using particle systems theory, calibrated based on real pedestrian flow data, and tested using sensitivity analysis on parameter values. The authors assert that the model visually replicates observed panic behavior, and furthermore the simplicity of the model makes it generalizable to a variety of scenarios. Even with this wealth of socio-psychological data, Helbing et al. still proposed the need for more data with which to validate the model. To address the lack of data available to evaluate pedestrian evacuation dynamics, Shiwakoti et al. (2011) proposed an approach in which experiments with Argentine ants are conducted to approximate human panic behavior. While these studies contribute greatly to the generation of new research methods designed to improve the validity of pedestrian models, they overgeneralize the role that group dynamics play in human egress situations. Specifically, altruistic behaviors for mobility-challenged group members fall outside the scope of current validation data collection efforts.

3. Exploring Other Data-Collection Avenues

As discussed above, there are critical areas of development needed in the field of modeling pedestrian and crowd movement. Research relying on video footage for calibration and validation data incorporates what one could consider macro-level sociological data. Crowd flows and basic human movement are readily observed in such footage, but ultimately many pedestrian situations are not comprised of an entire collection of singly traveling individuals. Some research must also delve into the ways in which groups negotiate pedestrian environments by adjusting movement strategies such as trajectory and preferred speed based on other group members' needs. While some can rely on comparison with other research observations, even in the field of sociology and psychology, the extent of these applications is limited to very specific scenarios and cannot likely be extrapolated to other situations. Laboratory experiments suffer from their own drawbacks, primarily by assuming that role players make decisions about movement and their environment in a controlled setting in the same way they would in real-world situations. Among the biggest challenges for this type of data collection remains the ethical consideration for those being observed on the footage or in laboratory settings, particularly in studies involving panic and management of mobility-challenged travel companions, and the ability to apply these particular observations to a wider variety of settings.

Other researchers have noted the conflict between capturing sociological and psychological processes in modeling and the available validation techniques. One researcher noted, "A more fundamental obstacle to the validation of socio-spatial systems, especially those systems involving intensive negotiation and decision making, is their heavy dependence on unaccountable knowledge, such as emotions and trust" (Ligtenberg et al. (2010)). Some researchers have suggested that when empirical data is lacking, a viable method of model validation is through consultation with experts in that particular field (Klugl (2008), Ligtenberg et al. (2010)). One proposed solution to this problem involves a two-step process in which a model is both "microvalidated" and "macrovalidated" (Moss and Edmonds (2005)). This validation procedure suggests validating agents with individuals' behavior, ensuring that at the individual level the model replicates sociological data. According to the research of (Moss and Edmonds (2005)), microlevel behavior is representative of sociological behavior and best validated through qualitative methods. Macrovalidation, on the other hand, ensures that the aggregate data and higher level processes are operating in an expected way. This level of validation most often represents more quantitative data. The researchers propose, "When such microlevel phenomena can be demonstrated to describe aspects of observed social behavior and interaction, and, at the same time, to generate the macrolevel phenomena sharing the statistical signature of real social data, then we shall say that the model has been cross-validated" (Moss and Edmonds (2005)).

Using this framework as the basis for adaptation of pedestrian modeling techniques, we propose a cross-validation approach to validation. The first phase of this, addressing the microlevel phenomena, would be to ask individuals how they expect they would behave in certain pedestrian egress scenarios. We acknowledge that there is much debate about the effect of response bias, where respondents report answers based on perceived social norms that dictate "right" answers over "wrong." We accept some level of response bias and agree with those researchers who have demonstrated that individual bias has little overall effect on the relationship between factors in the study (Gove and Geerken (1977)). As this study is mainly concerned with group dynamics, our questions focus on changes in trajectory and adjustment of group spacing based on crowd density and the presence of mobility-challenged individuals within one's group. The proposed pilot study produces a dataset with which to conceptually validate the current prototype pedestrian model. Macrolevel validation techniques, particularly the use of video footage and laboratory experiments to extract the pedestrian velocity, flow, and trajectory, are not explored in this paper as a wealth of information currently exists about these types of validation attempts.

4. Methodology

This study serves as a pilot for future inquiry into the possible use of qualitative data to augment more commonplace validation methods as described above. To assess the viability of a survey-based qualitative data source to calibrate and validate a pedestrian ABM, the researchers designed five questions to capture aspects of choice and human behavior that are difficult to observe in video observations or laboratory settings. Each question described a short scenario followed by a question about how the respondent would react. Sub-questions challenged the respondents to think about how mobility-challenged travel companions might alter their decision choices. There were five sub-questions resulting in a total of 10 multiple choice and free-form short answer questions. A list of these questions is provided in Appendix A.

The survey was administered through an online platform allowing for anonymity. No one was required to answer a question before moving on to the next to allow voluntary withdrawal from the study at any point. Seventy-one responses were recorded for the survey overall, though response rate varies by question. None of the questions specifically addressed panic-induced or influenced evacuations to avoid the bias introduced by those who do not know how they would act in an emergency situation, or who might resist answering to avoid exposure of unconventional or unethical behaviors. The survey does not collect respondents' personally identifiable information, including IP address, or ask for information that could be considered unethical or criminally implicating.

5. Findings

Interpretation of the questions about mobility-challenged group members led to respondent bias about the meaning of this term in practice. In the question, researchers suggested this term encompassed small children, elderly, and physically handicapped people. The majority of free-form answers in the survey referred to physically handicapped individuals when describing how trajectories, strategies, and group distances would change. Some of the physically handicapped persons referred to in responses were elderly equipped with wheel chairs or canes, but very few respondents directly named children as a reason for changing their exit strategies. Future versions of the survey will attempt to better distinguish between types of mobility, accounting both for those with slower walking speeds as well as those with physical disabilities or necessary equipment to aid mobility.

5.1. Changing Trajectory

As mentioned above, the questions in this pilot survey did not specifically address panic situations. Approximately 55% of respondents reported that, in general, they would walk past the closest exit to their current location in order to leave the venue near their transportation. Only 28% answered that they were unlikely to pass the closest exit and 16% were neutral. Of the 71 respondents, 52 (73%) would change their strategy if they were with mobility-challenged group members (children, elderly, and/or physically challenged). The majority of reasons cited for this strategy change related to congestion levels and either waiting for the crowd to dissipate or finding alternative "less traveled" routes. For some this meant leaving through the closest possible exit, while for others this meant traveling to the exit closest to their car/transportation. Though the sample size for this study is relatively small, the overwhelming consensus that crowd congestion dictates exit strategy provides evidence that a valid pedestrian model must account for the dependency of strategy choice on the mobility of certain group members.

Likewise, the majority (87%) stated that they would change to another exit if their preferred exit was too crowded. Again, when asked to consider how accompanying a mobility-challenged person might affect this decision, the majority pointed directly to issues of congestion. While only 50% felt they would likely change their exit strategy, a widely cited reason for the exit preference choice was based on understandings of congestion and seeking out the most convenient solution for the mobility-challenged person. Several respondents specifically named safety as a concern, despite the fact that the situation was based on a non-panicked scenario, which overrode the individual's preference for waiting at a crowded exit or not.

Table 1. Response summary for trajectory change-related questions.

		Change Strategy for Mobility Challenged Group Member		
	Pass Closest Exit	Yes	No	No Response
Likely	39 (54.9%)	33 (84.6%)	3 (7.8%)	3 (7.8%)
Neutral	12 (16.9%)	10 (83.3%)	2 (16.7%)	0 (0 %)
Unlikely	20 (28.2%)	9 (45%)	8 (40%)	3 (15%)
No response	0	-	-	-
	Change Exit	Yes	No	No Response
Likely	62 (87.3%)	31 (43.7%)	28 (45.2%)	3 (4.8%)
Neutral	4 (5.6%)	2 (50%)	2 (50%)	0 (0%)
Unlikely	5 (7.0%)	1 (20%)	3 (60%)	1 (20%)
No response	0	-	-	-

5.2. Adjusting Group Distance

Survey respondents were asked about the preferred spacing between group members while leaving a crowded venue. In general, 97% felt they would walk at arm's length or closer to the other members. Traveling with a mobility-challenged person, for the majority of respondents, would result in an adjustment of even tighter group spacing. A small percentage (15.5%, and 18.3% respectively) said that they would actually walk farther apart or make no changes at all to spacing when traveling with a person who has mobility issues. Future survey questions might delve into reasons why some respondents would walk farther from a group member with mobility challenges. Only two respondents out of 71 would keep a distance longer than arm's length, and both indicated they would walk closer if in the company of mobility-challenged persons. This finding demonstrates that, in general, groups move through crowded venues with relatively tight cohesion between members, particularly when accommodating someone with mobility challenges attempting to exit the venue.

Table 2. Response summary for group distance preferences.

		Mobility Challenged Group Member			Panic or Emergency			
	Group Distance	Closer	Farther	No Change	Closer	Farther	No Change	No Resp.
Shoulder-to-shoulder	8 (11.1%)	4 (50%)	3 (37.5%)	1 (12.5%)	6 (85.7%)	0 (0%)	1 (14.3%)	1
Within arm's length	61 (84.7%)	41 (67.2%)	8 (13.1%)	12 (19.7%)	51 (83.6%)	3 (4.9%)	7 (11.5%)	0
Around 5 feet apart	2 (2.8%)	2 (100%)	0 (0%)	0 (0%)	2 (100%)	0 (0%)	0 (0%)	0
No response	0	-	-	-	-	-	-	-

When asked about encountering a loud, rambunctious oncoming group, 54% of respondents felt they were likely to avoid the obstacle by changing directions or moving out of the way. Of those who would adjust their path to maintain a distance from the loud group, the majority (68%) felt this was also the best course of action if they were accompanying someone with mobility issues. Approximately 24% of all respondents would not change course to avoid the loud group. Even with a mobility-challenged person in their group, 70% would continue on the same trajectory toward the rambunctious group. Among those neutral in their decision to change course or not, nearly 44% felt they would not change directions when traveling with someone with restricted mobility. Among the reasons cited arose a theme of "standing one's ground" and tapping into a collective sympathy of those with mobility issues to the point of assuming the loud group would likely be the one to move around the mobility-challenged individual. Of those who felt changing course was the best option, the majority again cited safety concerns and the overall wellbeing of the person with limited mobility.

Table 3. Response summary for avoiding oncoming rambunctious group.

		Change Strategy for Mobility Challenged Group Member		
	Avoid Loud Group	Yes	No	No Response
Likely	38 (53.5%)	5 (13.2%)	26 (68.4%)	7 (18.4%)
Neutral	16 (22.5%)	9 (56.3%)	7 (43.8%)	0 (0%)
Unlikely	17 (23.9%)	4 (23.5%)	12 (70.6%)	1 (5.9%)
No response	0	-	-	-

5.3. Experimental disobedience

The final question of the survey asked respondents to recall an emergency drill in which they witnessed others behaving in a way that would be considered inappropriate if it were a real emergency event. The question was designed to begin to explore the ways in which experimentation cannot accurately capture realistic evacuation data. Respondents reported a number of common behaviors, of both themselves and their peers, which take place during emergency drills and would likely not happen during an actual emergency scenario. These ranged from slow response and exit times to individuals continuing to work through a drill or return for personal belongings. Some recounted that individuals verbally debated whether to leave the building at all. Several respondents noted that this behavior happened even when participants did not realize that it was just a drill. Particularly interesting responses from the survey include noting that during an actual emergency, respondents witnessed some people running toward the source rather than exiting. These people were attempting to help with the problem rather than safely egress. One respondent recalled a real earthquake in which people in line refused to move because they did not want to lose their place, demonstrating behavior that would be extremely difficult to capture in a pedestrian evacuation model. These findings substantiate the serious challenges of modelers, including ourselves, who intend to incorporate panic behavior into evacuation simulations. Ultimately, some combination of video footage of actual events, laboratory data in which individuals role play through an emergency situation, and survey data that asks respondents to anticipate how they might react in an actual emergency may be the only way to truly collect representative data to validate panic models.

6. Model application

The researchers of this study collected this pilot survey data to determine feasibility of using respondents' projected behaviors in particular scenarios to validate a pedestrian evacuation model. The final question of the survey was mainly exploratory, given the current model does not account for panic during egress. Answers from this question will be used to guide future model designs rather than validate the current version of the model. The current model is one of two prototype models being developed by this research team. One uses Repast Simphony to explore the mechanisms behind simulating group behavior through dynamic heading updating (Collins et al., 2014). The model incorporating the survey data for validation purposes was designed to investigate the interaction between individual and group dynamics. It was developed in NetLogo (Wilensky (1999)) and accommodates up to 5,000 agents per run. Agents egress from the venue in heterogeneous group sizes ranging from one to fifteen. Model users can vary the population size, average group size, and number of obstacles using the interface in NetLogo. Agents have varying walking speeds (slow, normal, and fast) to reflect different mobility levels. Additionally, agents have individual preferences for how far they will wander from the group.

Unlike the work of (Vizzari et al. (2013)), the model does not measure group cohesion from the center of the group, but rather on an artificially assigned "group leader" to whom members gravitate. This simplistic interpretation of group cohesion serves the purpose of allowing individuals to walk in varying degrees of independence from the group while providing a connection between them.

In Fig. 1, exits are represented in green, obstacles in yellow, and group leaders are represented as red flags. Other group members are shaped like blue people. Groups, including "groups" of one, progress through the model by navigating around obstacles to reach their preferred exit. Given that some individuals are comfortable at farther distances, a group will occasionally split to navigate around an obstacle and rejoin on the other side. Upon reaching an exit, a certain percentage of groups will determine that the exit is too crowded and reroute to find the next closest, less crowded option. These groups may change exits several times during a simulation depending on the crowd density.

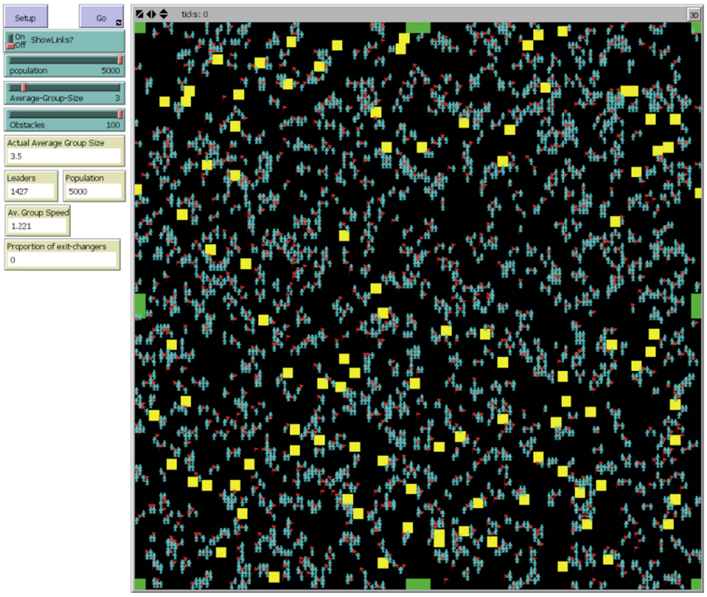

Fig. 1. NetLogo prototype evacuation model.

Given the early stages of this model development, the survey data provided conceptual validation for some of the behaviors coded into the model, including the ability of agents to move to another exit if they felt there was a less crowded option. (Klugl (2008)) emphasize the importance of conceptual validity by noting, "Without a model exhibiting a high conceptual validity that is implemented and verified, no subsequent step makes sense." Additionally, the unpredictability of respondents' answers to the survey questions about panic justifies the modelers' choice to remove this feature from the model until further research can be conducted.

The pilot survey results serve greater value as calibration mechanisms and will likely guide future versions. In particular, the survey revealed a number of behavioral responses to loud, rambunctious groups which will be incorporated in the next version. Additionally, the ways in which individual strategies change based on the presences of mobility-challenged group members became a major focus of the survey results. Some respondents claimed that they would drastically alter their own exit strategy when in the company of a less readily mobile person, while several others claimed that in certain circumstances this would be an asset that could help them more effectively exit. Since group dynamics are a critical interest in our pedestrian research, it is vitally important to understand the ways in which individuals adapt to having certain types of group members such as small children, elderly, and physically disabled people.

7. Conclusion

The pilot survey provided ample data with which to calibrate the current pedestrian evacuation model prototype and direct future development of subsequent versions. More data will be employed to validate a full version of the model following a larger sample sized survey. The main point the researchers were trying to make in this exercise was to demonstrate the usefulness of asking people how they would behave in certain scenarios, rather than making assumptions based on overhead video or unnatural laboratory experiments. As demonstrated in the survey responses, people do not role play evacuation very well as emergency drills have become such a common feature of certain venues. Additionally, the survey responses revealed that groups truly do matter during an evacuation, and that strategies change to accommodate less mobile individuals in the group. One cannot assume that all individuals will evacuate the model at some mathematical average speed and predetermined trajectory when certain members of the group dictate more than others the speed and direction of the group. In future versions of the prototype model, the researchers will incorporate more group dynamics features that account for the data revealed in the survey. To validate the model, another larger survey will be conducted in coordination with the use of video footage and possible laboratory experimentation to provide a well-rounded approach to validating the model. The final validation will include consultation with experts in the field of pedestrian evacuation, namely practitioners experienced in facilitating real-world venue egress and emergency evacuation. Evaluation from subject matter experts will assist in determining if the final model is closely representative of real-world systems, particularly of group dynamics during exiting scenarios.

Appendix A. Pilot survey questions

1. When leaving a very crowded event (e.g. stadium, concert venue, or festival), how likely are you to walk past other exits to get to the exit closest to your car/transportation? (1-unlikely, 2-neutral, 3-likely)
   - Would traveling with a mobility-challenged person (children, elderly, physically disabled) change your exit strategy? If so, how. (free form)
2. If your preferred exit is crowded, how likely are you to change to another exit? (1-unlikely, 2-neutral, 3-likely)
   - Would your decision change if you were with a mobility-challenged person (children, elderly, physically disabled)? If so, how. (free form)
3. You are walking with a group through a crowded place. How close do you tend to stay to other group members? (shoulder to shoulder, within arms' length, several steps apart, five feet apart or more)
   - Is this preferred spacing different if you are travelling with a mobility-challenged person (children, elderly, physically disabled)? (none, closer, farther)
   - How would a panic or emergency situation change this preferred spacing? (none, closer, farther)
4. A group of loud, rambunctious people are approaching you and your group. How likely are you to change directions or move to avoid them? (1-unlikely, 2-neutral, 3-likely)
   - Would your strategy be different if you were traveling with a mobility-challenged person (children, elderly, physically disabled)? If so, how.
5. Recall a fire, earthquake, or other emergency drill experience from your past. Some people will not exit promptly or refuse to exit at all. Other than these types of incidents, describe the actions of you or someone you observed who behaved in a way contrary to what would have been expected during an actual emergency. (free form)

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