Micro-Scale Spatial Modification and Pedestrian Behavior

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Abstract This study explores how subtle modifications to spatial design can significantly alter pedestrian behavior. Leveraging machine vision-based 3D tracking and existing security cameras to collect uncontrolled ecological data of shoppers in their natural environment (i.e. , retail stores), we created a framework for classifying pedestrian behavior throughout their trip. On this basis, we conducted an experiment which introduced a constriction in a retail aisle and measured the resulting behavioral shifts. Our findings indicate a marked rise in traversing and navigating behaviors at the expense of browsing or deliberating (thought-intensive periods of consideration) events—a demonstration that relatively small changes in spatial design can nudge shoppers in a significant way. These results not only provide a framework for analyzing changes in a retail environment, but also provide a framework for modeling the impact of changeable design elements on pedestrian behavior more broadly, with applications in planning public and private spaces where loitering, dwell time, or free flow of traffic are relevant design considerations.

Keywords Pedestrian Behavior, Spatial Design, Machine Vision, Behavior Classification

Introduction

The ability for the spatial design of an area to instill a sense of hostility or placidity, and doing so, shape pedestrian behavior, has drawn considerable public and scholarly attention over the last decades [1, 2, 3]. In a context with important ethical and practical ramifications, there remains a need for systematic methods to quantify and model how subtle alterations to an environment can shape pedestrian behavior. In the realm of pedestrian and evacuation dynamics, most established models emphasize large-scale crowd flow or emergency contexts. However, there is growing interest in the effects of smaller-scale interventions—such as aisle width or signage placement—on localized behavior [4]. In this analysis, we introduce a framework for measuring the behavioral response of pedestrians to changes in their physical environment at a micro-scale, based on fine-grained body pose detections, and provide an example of such an experiment.

Methodology

We conducted a six-week observational study in a specialty retailer using Standard AI's Vision ML platform. Finetuned 2D pose detection models, each run at 10 FPS on pre-existing overhead security cameras, are synthesized into three-dimensional poses based on triangulation of the 2D poses from the separate cameras, allowing for continual data collection in a manner which minimizes observational bias. Using the 3D pose of the individual shopper at every time step in their shopping trip, we clustered the individual's journey into distinct behavioral events composed of self-similar and externally dissimilar windows. We then performed unsupervised learning on embeddings extracted from segment-level trajectories, leading to the emergence of 25 distinct clusters of shopper behavior. Human labeling of these segments means that we have a precise understanding of the rates at which a variety of different attributes are displayed within these clusters, from the presence of confusion to whether pedestrians were looking at their phones.

Three weeks into the study, following the agreed-upon design, the retailer relocated promotional shelving to make space for additional units on the aisle's south side, which previously had no promotional material. This was done in accordance with their existing store design and promotional principles, and so was intended to introduce a situationally plausible but physically significant constriction. Doing so reduced the effective navigable width by approximately one-third, from 2.5 meters to 1.7 meters. The design goal was to nudge shoppers away from behaviors associated with shopping to those associated with movement by increasing the sense of constriction and decreasing the area available for comfortable

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browsing. Over the subsequent four weeks, we captured another large set of trajectories and classified them using the same behavioral segmentation schema. Then, by using a chi-square test, we determined how significant the change in behavioral patterns is after the change to the physical environment. No other layout changes were made in the aisle during this period. Although prices and packaging are continually in flux, the choice of a specialty retailer for the study minimizes the effects of seasonality, as shoppers are highly brand loyal and radical changes to the product paradigm are rare.

Results and Discussion

Chi-square analysis revealed a significant shift in pedestrian behavior ($p < 10^{-16}$). Traversal behaviors increased by 3.7%, while browsing and deliberating declined by 2-3%. The strong statistical significance indicates that subtle aisle modifications can measurably influence pedestrian activity. Although real-world confounding factors—such as daily variations in store traffic—are inevitable in a naturalistic setting, the large sample size and robust clustering approach lend confidence to our conclusion that a physically narrower channel prompted an immediate and quantifiable change in pedestrian activity. With a p value so functionally close to zero, future studies of behavioral changes could take place over shorter windows of time, reducing the chance for confounding factors like seasonality to impact the results.

Table 1: Behavioral shift after aisle modification.

Behavior	Pre-Modification (%)	Post-Modification (%)
Traversal	45.2	48.9
Browsing	25.1	22.3
Deliberation (Consideration)	18.7	16.0

These findings suggest that modest spatial modifications can exert an outsized influence on pedestrian dynamics—even at relatively low densities—and underscore the importance of analyzing micro-scale interactions for both retail and urban planning. Our framework can be extended to other contexts by equipping spaces with camera-based tracking, applying unsupervised behavior classification, and systematically varying layout features. In these contexts, potential applications include determining optimal bench placement in public squares, testing signage efficacy in transportation hubs, or gauging how to balance foot traffic flow with dwell time in museum galleries.

By combining high-resolution trajectory tracking, track segmentation, behavioral clustering, and controlled spatial interventions, this study offers a novel lens on how design choices aimed at nudging pedestrians toward or away from different behaviors can be measured and analyzed. Beyond retail, these insights and methodologies have the potential to enrich the field of pedestrian and evacuation dynamics by enabling fine-grained, data-driven tests of spatial design.

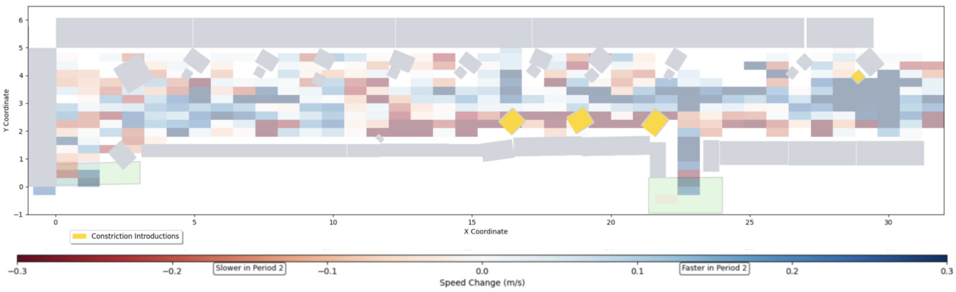

Figure 1: Change in speed throughout the aisle from the control to test phase.

Bibliography

[1] Garcimartín, A., Maza, D., Pastor, J. M., Parisi, D. R., Martín-Gómez, C., & Zuriguel, I., *Redefining the Role of Obstacles in Pedestrian Evacuation*, *New Journal of Physics*, **20**(12), 123025, 2018.

[2] Zhang, J., Seyfried, A., *Quantification of Bottleneck Effects for Different Types of Facilities*, *Transportation Research Procedia*, **2**, 51–59, 2014.

[3] Dubey, R. K., et al., *Cognitively Grounded Floorplan Optimization to Nudge Occupant Route Choices*, Available at SSRN, 2022. `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4003119`

[4] Feliciani, C., et al., *Nudging Crowds: When It Works, When It Doesn't, and Why*, *Traffic and Granular Flow'22*, **443**, 11, 2024.