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Analyzing a Shopper's Visual Experience in a Retail Store in 3D

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Abstract

What a shopper visually encounters on a trip to a retail store directly influences both their personal shopping experience, as well as the productivity of the store. Specifically, the layout design of the store plays an important role in determining this visual experience. To evaluate such designs, we develop an analytical approach to estimate the rack faces that may be exposed to the shopper traveling along a straight pathway. We explicitly model the dynamics of a shopper's 3D field of vision (accounting for easy head and eye movements) with the static faces of a system of curved racks. Our preliminary findings suggest that low-to-medium rack curvatures offer the most exposure when placed between 30° and 60° from the travel path. Highly curved racks should be placed more orthogonal or even obtuse to achieve the highest exposure. We believe our findings would better inform store managers and retail executives insights into how a certain layout would perform visually, as well as the ability to know what parts of racks would be seen more often than others, allowing them to better allocate shelf space.

Keywords
Facility layout; retail store; human vision; exposure

1. Introduction

Retail design refers to how retailers present themselves to potential customers. There are many facets of retail design including visual communications, merchandising, store design, and store planning, all of which contribute to the overall perception by customers, and therefore the success of the company (Dunne et. al., 1995). Store planning more specifically refers to the decisions concerning the physical store space. These consist of space allocation, circulation, and layout decisions. Layout decisions can be further broken down into those involving departments, rack fixtures, product groups, and even individual products.

Although there are many different measures to evaluate a store layout, one that has been recently emerging in literature is exposure. Essentially, this measure quantifies how well a layout presents its products to customers. Increasing a shopper's exposure to products, as well as knowing exposure levels of specific fixture locations in a layout, can be beneficial to both shoppers and store managers. Shoppers would potentially experience less time searching for already planned purchases, as well as make more unplanned purchases, thus boosting their shopping experience. Managers meanwhile would benefit by strategically placing their products, while being better equipped to negotiate rack space with manufacturers. While this information has not gone unrecognized in the retail industry, it has been proven difficult to harness.

Previous research has indeed revealed a strong relationship between exposure and sales (Applebaum, 1951; Cairns, 1962; Dreze et al., 1994; Dunne et. al., 1995). However, Sorensen (2009) found that on the average shopping trip, people will only see around 11% - 41% of products. The need for improved product exposure to shoppers has drawn interest from the IE/OR research community, with a few recent studies focusing on optimizing the store layout using various approximations of exposure (Peters et al., 2004; Li, 2010; Yapicioglu and Smith, 2012). Recently, Parikh and Mowrey (2014) and Mowrey et al. (2016) suggested that optimizing layouts for exposure must account for the shopper's field of vision. They estimate exposure of a layout with racks placed at varying angles considering a shopper walking along a main aisle in a 2D setting. While their findings set the foundation for analyzing retail layouts considering exposure, there are two key limitations; first, they rely on a 2D approximation of a 3D environment and second, their focus is limited to rectangular racks.

Our interest in increasing product exposure primarily stems from our personal visits to local retail stores, as well as discovery of up-and-coming retail layouts online. Consider a Wal-Mart store in the Midwest US (see Figure 1). Upon entering the store, there is a section of racks (carrying beauty products) that are oriented at a 45° angle; all other racks in the rest of the store are at the typical 90°. The 45° racks give a very unique look and feel at the entrance; the shopper can see much deeper into the aisles and be exposed to far more products. Further, many retailers have begun using *curved* racks in certain areas of their stores (see Figure 2).

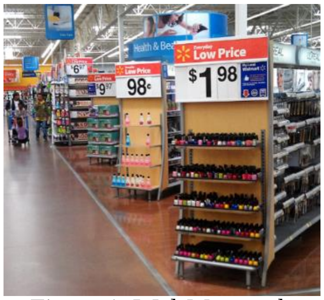

Figure 1. Wal-Mart racks oriented at 45°.


Figure 2. Curved racks at a gas station.

So is the 45° a better angle than 90°, or are there other orientations that can help increase exposure? Can such increases be quantified? Would the curvature on a rack increase or degree exposure? We wish to address these questions in a 3D setting. We believe our contribution will provide a more realistic and comprehensive understanding of the relationship between rack layout and exposure.

2. An Exposure Model for 3D Curved Racks

2.1 Modeling the 3D Human Field of Regard

We model human vision in 3D by considering the angular limits of vision in both horizontal and vertical directions, along with the depth of view (*DOV*). The combined effect of eye and head movement result in the field of regard (FoR) – angular size of the viewing area -- that can be modeled as an elliptical sector of a sphere; see Figure 3. Both our illustration (Figure 3) and parameters (Figure 4) are based on those presented by Parker and West (1972).

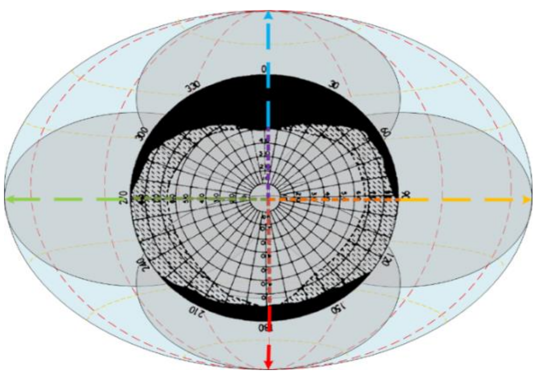
Figure 3. Model of 3D human field of regard.

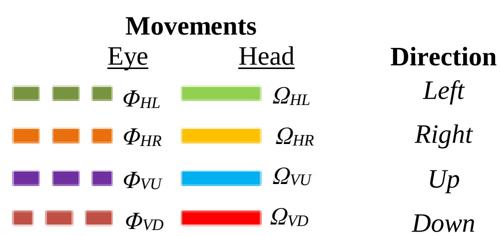

Figure 4. Parameters for angular limits of vision.

2.2 Modeling Curved Racks in 3D

Curved racks have been introduced recently in retail stores. Although there are many variations of curved racks, we model a generic curved rack and its location in a rack layout in 3D as a combination of angle of curvature (α), chord length (c), width (w), height (H), and orientation (θ); see Figure 5. The minimum distance between racks is designated as a_c and the shopper distance to the nearest part of the racks is a_m. Accordingly, the radius of curvature (r) can be found by $\frac{c}{2\,sin\left(\frac{\alpha}{2}\right)}$, and the inside ($L_I$), outside ($L_O$), and endcap ($L_E$) arc lengths can be given by the following: $\frac{2\alpha\pi}{360}\left(r-\frac{w}{2}\right)$, $\frac{2\alpha\pi}{360}\left(r+\frac{w}{2}\right)$, and $\frac{2\alpha\pi}{360}\left(\frac{w}{2}\right)$, respectively. We further classify curved racks as either concave (curving inward towards the shopper) or convex (curving outward away from the shopper). We refer to each of the four rack faces (f) as A-D (see Figure 5), and each rack is designated as $n \in N$, where N is the number of racks in the layout and n = [1, N]. Note that the traditional rectangular rack is a special case of a curved rack with α = 0° (which results in $r \rightarrow \infty$).

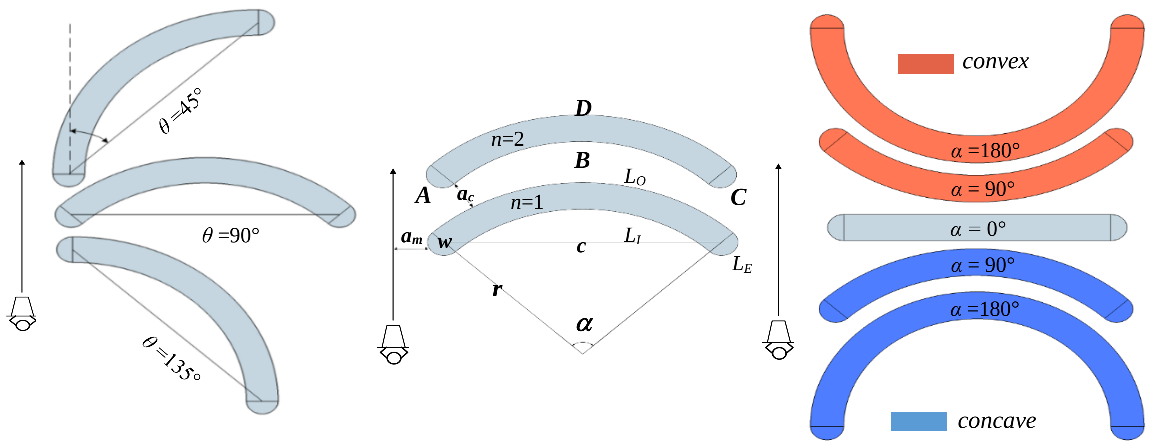

Figure 5. Modeling 3D curved racks.

2.3 Estimating Exposure of 3D Curved Racks

Our proposed approach estimates exposure in 3D considering a shopper walking along a path through a layout of racks. We first decompose the 3D problem of estimating exposure into a set of 2D problems (see Figure 6). For each 2D problem, we analytically derive exposure at a shopper's step (y) along the pathway and at a height (h), beginning with the shopper's eye height (S_E). We then repeat this 2D algorithm to estimate exposure (E_{yh}) for m_u levels above and m_d levels below the eye height, where each level corresponds to a unique height above the floor (h=0). Both m_u and m_d, are derived using the vertical limits of the shopper's spherical FoR, which includes a combination of eye and head vertical angular limits (e.g., Φ_{VU} + Ω_{VU}), DOV, and step-size of k ft, where $m_u = \frac{DOV*\sin(\Phi_{VU}+\Omega_{VU})}{k}$ and $m_d = \frac{DOV*\sin(\Phi_{VD}+\Omega_{VD})}{k}$. Each 2D exposure E_{yh} is aggregated across all levels (m_d through m_u; each at its specific height h) that fall within the rack range $[0,H]$ to estimate the exposure in 3D at a step (y). This process then repeats for all steps along a shopper's path through the layout of racks. We now summarize a few aspects of approach, but not the analytical expressions due to space limitations.

To calculate exposure in 2D at height h, we first find possible candidate points – points used to designate the exposed arc(s) on a curved rack – for each of the 4 rack faces (A-D) separately. These points are then evaluated for feasibility through analytical or computational checks; the candidate point must be within the shopper FoR and unobstructed. Since the DOV of a shopper's eye extends as a radius in a spherical form, the effective depth of vision will change based on the height at each height h. We define this effective depth of vision as DOV_h, which can be calculated analytically considering DOV, h, and S_E. Further, the effective horizontal angular limit (Φ_{HR} + Ω_{HR} + Φ_{HL} + Ω_{HL}) will also change with respect to h. In other words, the maximum angular limits (left and right) for a human's eye occurs at eye-height; these limits will shrink when looking up and down. To determine the effective horizontal angular limit at a given h, we first determine the vertical angle associated with the level and then utilize the equation of an ellipse (associated with the 3D FoR) considering the horizontal and vertical angular limits.

When aggregating 2D exposure over all h values, we must consider additional candidate points and feasibility checks. Most notably, we check if candidate points fall within the "dead zone of vision" that exists due to the vertical angular limits (see grey area in Figure 7). Points must lie beyond this zone to be considered feasible. We also identify numerically the intersection point(s) between the dead zone and the FoR at each height h, which are used as potential candidate points to determine exposure E_{yh}.

Besides calculating the exposure of racks, we also determine the intensity (time of exposure) of each *exposed* interval (t), considering its height (h), face (f) and rack (n), where an interval is defined by two points. At each shopper step (y) our algorithm updates intensity I_{nfht} by checking if the exposed arc(s) overlap(s) *any* part of the interval (defined by two points). Following the completion of a shopper's path (i.e., $\forall y$), the *maximum exposure* $MaxE_{nfh}$ is approximated considering all rack intervals that were exposed at *any* step on the shopper's path. We approximate the total exposed area $MaxE_{nf}$ of each rack and face along the entire pathway by aggregating $MaxE_{nfh}$ at each height h using the trapezoidal rule; $MaxE_{nf} = \frac{k}{2}[MaxE_{nfa} + 2MaxE_{nf(a+k)} + 2MaxE_{nf(a+2k)} + \ldots + MaxE_{nfb}]$, where a and b

represent the min and max heights of the rack, respectively (see Figure 8). Finally, we determine the maximum exposure of the layout by $MaxE = \sum MaxE_{nf}\ \forall\ n,f$.

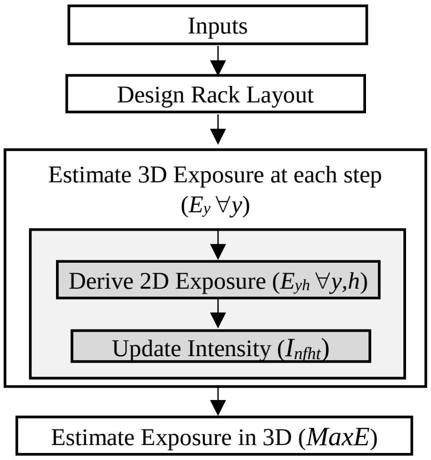

Figure 6. 3D exposure algorithm.

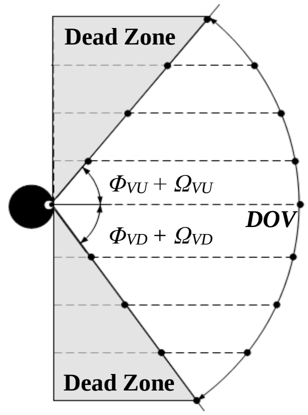

Figure 7. Illustration of dead zone.

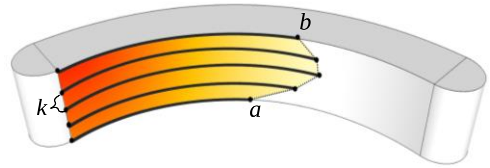

Figure 8. Trapezoidal rule to approximate 3D exposure.

3. Preliminary Results

To demonstrate the use of our approach to estimate exposure (ft^2) and intensity of a given rack layout, we evaluate 6 rack layouts considering 2 angles of curvature (α**;** concave only) and 3 angles of orientation (θ). Table 1 summarizes the system parameters. Unidirectional shopper travel is considered. We discretize the travel path in steps of 0.25 ft) and a rack location as 1ft x 1ft. Shopper FoR parameters are based on easy eye (horizontal and vertical) and head (horizontal) movements.

Table 1. Parameters values for experimentation.

Notation	**Definition**	**Value**
N	Number of full length racks (right side only)	3
a_c	Width of cross aisle	8 ft
a_m	Shopper distance to racks	5 ft
c,w,H	Chord length, width, height of rack	50, 5, 7 ft
DOV	Depth of focused vision	50 ft
S_E	Shopper Eye Height	6 ft

Field of Regard Parameter Values

Φ_{HL}	Φ_{HR}	Φ_{VU}	Φ_{VD}	Ω_{HL}	Ω_{HR}	Ω_{VU}	Ω_{VD}
15°	15°	15°	15°	30°	30°	0°	0°

Figure 9 shows the intensity profiles (red = longest exposed and yellow = shortest exposed; white = not exposed) for each of the 6 rack layouts. Based these preliminary results, we observe the following:

i. *Subsequent-obstruction* (i.e., degree of rack area that lies within FoR, but is blocked by parts of the *previous* rack) is *less prevalent* in racks with *higher* degrees of curvature; e.g., compare illustrations (a) and (i). Notice the substantial difference in exposure between Rack 1 (unobstructed) and Rack 2 obstructed by Rack 1 (and Rack 3 obstructed by Rack 2) in each layout. Now consider illustrations (c) and (k) and notice how Racks 2 and 3 have an increased amount of exposure compared to illustrations (a) and (i), respectively. We attribute this to the ability of the human eye to see more around the curved (α = 90°) face D of preceeding racks, leading to increased exposure of face B on succeeding racks compared to when α = 0°.
ii. *Self-obstruction* (i.e., degree of rack area that lies within FoR, but is blocked by other parts of the *same* rack) is *more prevalent* in racks with higher degrees of curvature. For instance, compare the exposure on each face B in illustrations (e) and (g). As can be seen, when curving the rack at this orientation, there is no longer exposure on face B due to obstruction from face A (endcap).

We further determine the exposure of rack layouts with 5 different curvatures across varying orientations ranging from 0° to 180° in steps of 10° (see Figure 10). We observe that the curvature (α) of racks that maximizes the total layout exposure is dependent on the orientation (θ) of the racks. That is, maximum expsoure may occur when low-to-medium curved racks are placed at acute angles (e.g., racks with α = 0°, 45°, 90° placed at $\theta \in$[30°, 60°]), while highly curved racks would need to be placed more orthogonal or obtuse to the travel path (e.g., racks with α=135° and 180° placed at θ >70°). To further understand this, consider Figure 11. When θ=40°, exposure on face B decreases to 0, while exposure on face D first decreases and then increases. When θ=90°, however, there is a drastic change in these relationships as *both* B and D faces experience general increasing trends. In other words, dependent on the orientation, curving the rack to a certain degree provides the possibility to expose a favorable amount of rack area on both B and D faces to shoppers.

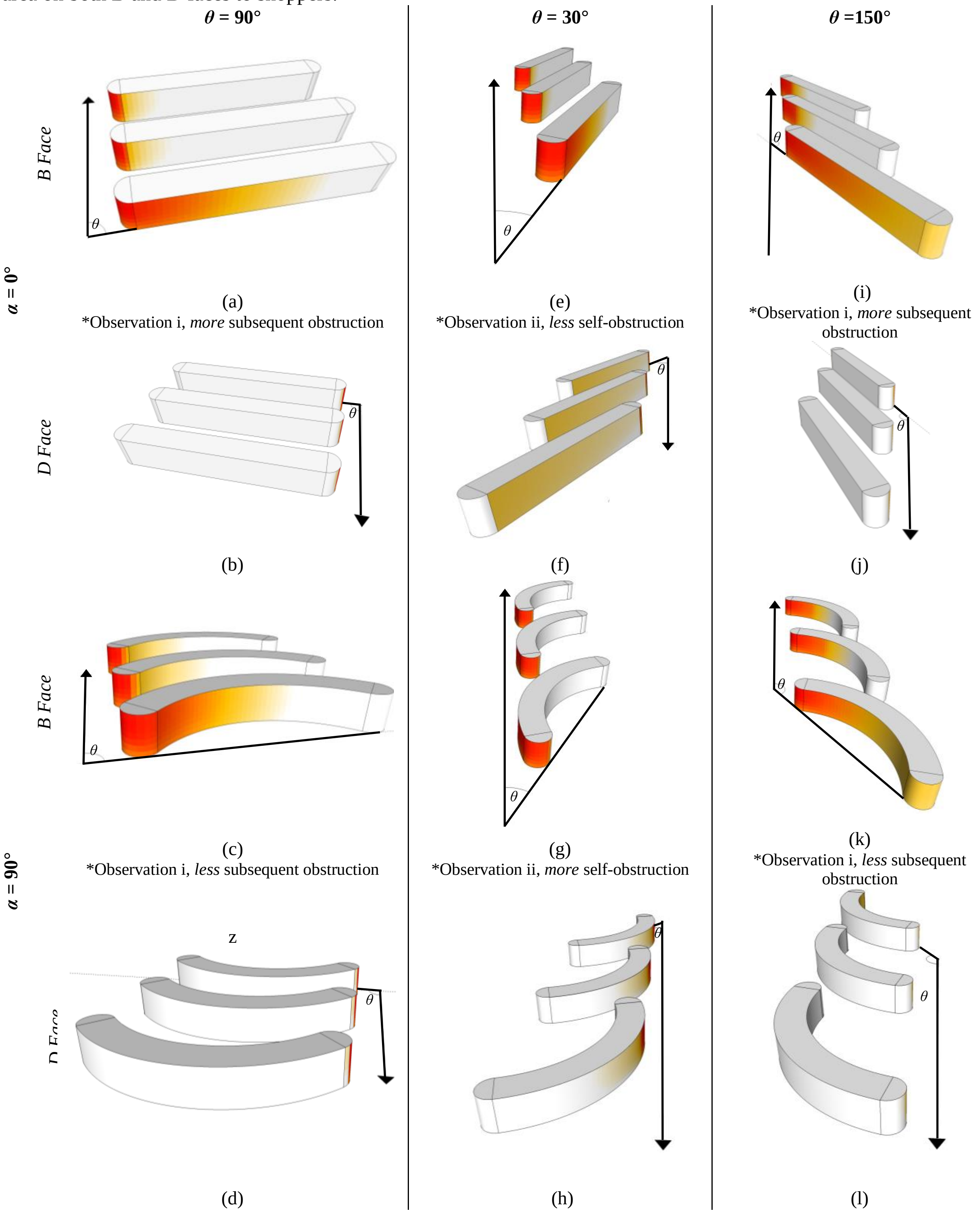

Figure 9. Intensity profiles of all 4 exposed faces of a 3-rack system for curvatures of α=0° and 90° and rack angles θ=30°, 90°, and 150° for given FoR parameters (see Table 1).

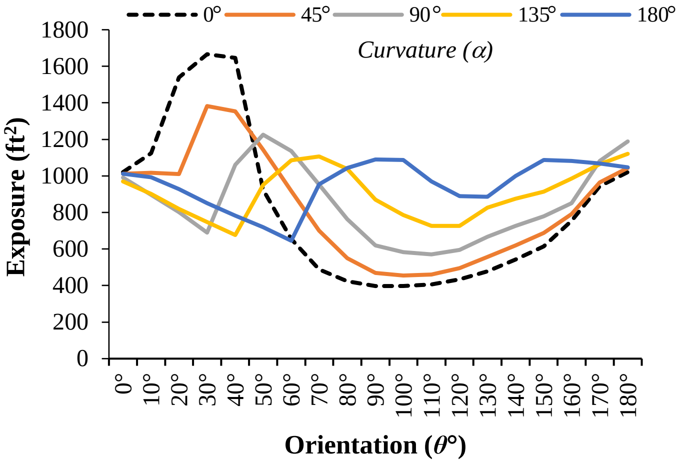

Figure 10. Exposure of rack layouts with varying curvature.

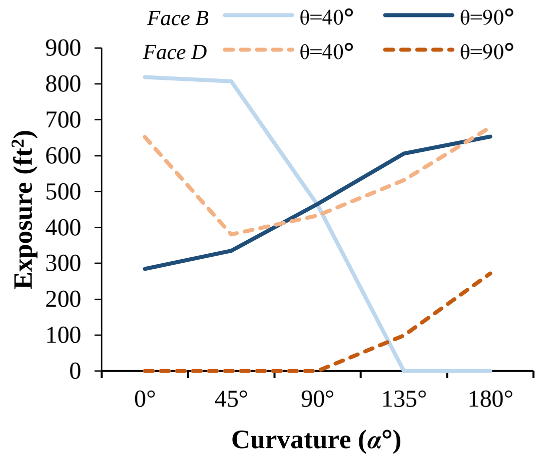

Figure 11. Exposure of Faces B and D for two orientations.

5. Conclusions

Exposure has been recognized as a key metric in designing retail layouts, but very few quantitative models exists that effectively capture the shopper's 3D FoR. Our main contribution was to consider a traveling shopper's 3D FoR into an analytical approach to estimate the exposure of a system of racks placed along a straight pathway. We introduced curved racks and provided a mathematical approach to model them as part of the rack layout. Preliminary findings from our experiments with 5 different rack curvatures, each of which could potentially be placed between 0°-180°, suggested that the rack curvature (α) of rack and its orientation (θ) jointly determine the points of maximum exposure. We believe this was likely due the dynamics of the 3D FoR and curved rack faces inducing varying levels of visual obstructions. Our next steps are to validate these findings for other shopper FoR values and system parameters. We strongly believe our research will provide store managers and executives insights into how a certain layout would perform visually, as well as the ability to know what parts of racks would be seen more often than others, allowing them to better allocate shelf space.

Acknowledgement

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References

1. Applebaum, W. (1951). Studying Customer Behavior in Retail Stores. *Journal of Marketing*, *16*(2), 172-178.
2. Cairns, J. P. (1962). Suppliers, Retailers, and Shelf Space. *The Journal of Marketing*, *26*(3), 34-36.
3. Dreze, X., Hoch, S. J., and Purk, M. E. (1994). Shelf Management and Space Elasticity. *Journal of Retailing*, *70*(4), 301-326.
4. Dunne, P. M., Lusch, R. F., and Gable, M. (1995). *Retailing* (2nd ed.). South-Western College Pub, OH.
5. Li, C. (2010). *A Facility Layout Design Methodology for Retail Environments*. PhD dissertation. Swanson School of Engineering. University of Pittsburgh.
6. Mowrey, C., Parikh, P. J., Gue, K. R. (2016). Impact of Rack Layout on Visual Experience in a Retail Store. In review.
7. Parikh, P. J. and Mowrey, C. (2014). Designing Retail Facilities to Maximize Product Exposure. *Progress in Material Handling Research: 2014*, Material Handling Institute, Charlotte, NC.
8. Parker Jr, J. F., & West, V. R. (1972). *Bioastronautics Data Book*. Biotechnology Inc. Falls Church, VA.
9. Peters, B. A., Klutke, G.-A., and Botsali, A. R. (2004). Research Issues in Retail Facility Layout Design. In R. D. Meller, M. K. Ogle, B. A. Peters, G. D. Taylor and J. S. Usher (Eds.), *Progress in Material Handling Research: 2004* (pp. 399-414).
10. Sorensen, H. (2009). *Inside the Mind of the Shopper: The Science of Retailing*. Upper Saddle River, N.J.: Wharton School Pub.
11. Yapicioglu, H., and Smith, A. E. (2012). Retail Space Design Considering Revenue and Adjacencies Using a Racetrack Aisle Network. *IIE Transactions, 44*(6), 446-458.