Agent-Based Modeling of Anchor Spillover and Complementary Store Effects in Complex Shopping Malls

Bona Kim (24691469) · Seonjeong Jeong (24732339)

1. Background

In modern shopping malls, anchor stores play a central role in shaping how customers move and where they make purchases. Anchors usually have a large size and strong reputation, which makes them a main attraction point. Because of this, they not only draw visitors directly but also affect nearby stores. Some of those surrounding stores benefit from the anchor's high traffic while others may lose customers because of competition.

The purpose of this project is to study how two key factors influence customer movement and sales distribution inside a mall network: 1) the quality of the anchor store, and 2) the category composition of its surrounding stores.

To analyze this, we built an agent-based simulation (ABM) that models customers as independent agents who move through a network of stores following realistic behavioral rules. Each customer is assumed to make decisions based on a combination of attraction, avoidance, and goal-seeking tendencies. Specifically, customers are drawn to busy areas (cohesion), avoid overly crowded areas (separation), and sometimes move toward stores that offer complementary products (love rule).

Previous studies have explored related ideas. Shanmugam (2013) discussed how anchor quality is related to mall performance, showing an inverted U-shape between quality and overall traffic. Mizuta (2017) developed a large-scale ABM for mall environments, combining pedestrian and purchasing behaviors. Our project extends these works by connecting the Boid model of crowd motion to a shopping mall network, making it possible to visualize and quantify customer diffusion and sales concentration patterns.

2. Model Explanation

2.1 Core Assumptions

In our model, all customers (agents) start their shopping journey at the anchor store, which is represented as node 0 in the network. Each agent continues shopping for a fixed period — ten steps in simulation time, roughly equal to 2.5 hours of stay — and then exits the mall.

The anchor quality parameter controls how strong the initial attraction is. When the anchor is of high quality, almost every customer stays around it, resulting in strong concentration but weak diffusion. A low-quality anchor does not attract many agents, so the traffic becomes random and evenly spread. The medium-quality anchor provides a balance between attraction and exploration, allowing us to clearly see both crowding and diffusion effects.

Purchases occur mainly at the anchor and at complementary stores, reflecting real-world co-shopping behaviors, such as customers visiting electronics stores and then moving to phone-accessory stores nearby. Agents also react to local crowd dynamics. They are attracted to dense areas (cohesion), tend to follow the flow of others (alignment), and avoid excessive congestion (separation). These three movement tendencies come from the Boid model that explains collective movement in flocks and crowds.

2.2 System Components

The shopping mall network consists of 20 nodes, each representing a store. Among them, one node (node 0) is the anchor, while the others are tenants with one of three categories: *similar*, *complementary*, or *different*. The edges between nodes represent spatial adjacency — whether two stores are close enough for customers to move between them directly — and are generated randomly with a connection probability of 0.2, following an Erdős–Rényi model.

There are 100 customers (agents) who start at the anchor. Each tick in the simulation represents 15 minutes, and the entire run of 10 steps corresponds to a 2.5-hour shopping session. This setup allows us to simulate short-term movement and purchasing patterns rather than long-term mall traffic trends.

2.3 Movement Rules

At every step, each agent decides whether to move to a neighboring node or stay at the current one. The probability of choosing a node depends on both random exploration and four Boid-inspired behavioral weights:

$$P(v) \propto base + (wcoh \cdot coh + wsep \cdot sep + wali \cdot ali + wlove \cdot love).$$

- *Cohesion* makes the agent move toward popular, crowded nodes.
- *Separation* discourages movement toward overly crowded nodes, preventing congestion.
- *Alignment* means following the majority flow from the previous step, creating a sense of collective direction.
- *Love* adds goal-oriented behavior, making agents move toward the nearest complementary store via the shortest path.

These scores are normalized into probabilities, and a small adjustment prevents negative or zero probabilities. Agents can also stay still if no better option is found, and they rarely return to the previous node due to the *anti-backtrack* rule.

2.4 Purchase and Data Collection

Whenever an agent visits a node, there is a certain chance of making a purchase depending on the store type: 0.20 for the anchor, 0.35 for complementary stores, 0.18 for similar stores, and 0.12 for different stores.

At each simulation step, the model records several statistics: 1) the number of visits (footfall) per store, 2) total sales per store, and 3) which Boid component was dominant in the agent's decision at that step. This data allows us to connect micro-level movement rules with macro-level sales outcomes.

3. Process of Modeling

The model was built gradually through several steps:

- Step 0: Random Walk – Agents move randomly to test reproducibility and verify that the total population is conserved.
- Step 1: Threshold Rule – Introduces same-category clustering, letting similar stores attract each other beyond random chance.
- Step 2: Complementary Bias – Adds directional movement from the anchor to complementary stores.
- Step 3: Sales Metrics – Implements purchase probabilities and validates whether the sales distribution is realistic.
- Step 4: Boid-on-Graph – Integrates crowd-based interactions (cohesion, separation, alignment) and the "love" rule to produce emergent shopping patterns.

Each stage expands the behavioral complexity of agents and improves the model's realism. Step 4 is our final and most complete model. It extends the previous version by applying the full Boid framework to a graph-based mall layout. The main goal is to observe how customers' interactions with each other and with store types lead to emergent diffusion patterns — in particular, how the "love" term enhances the flow toward complementary stores.

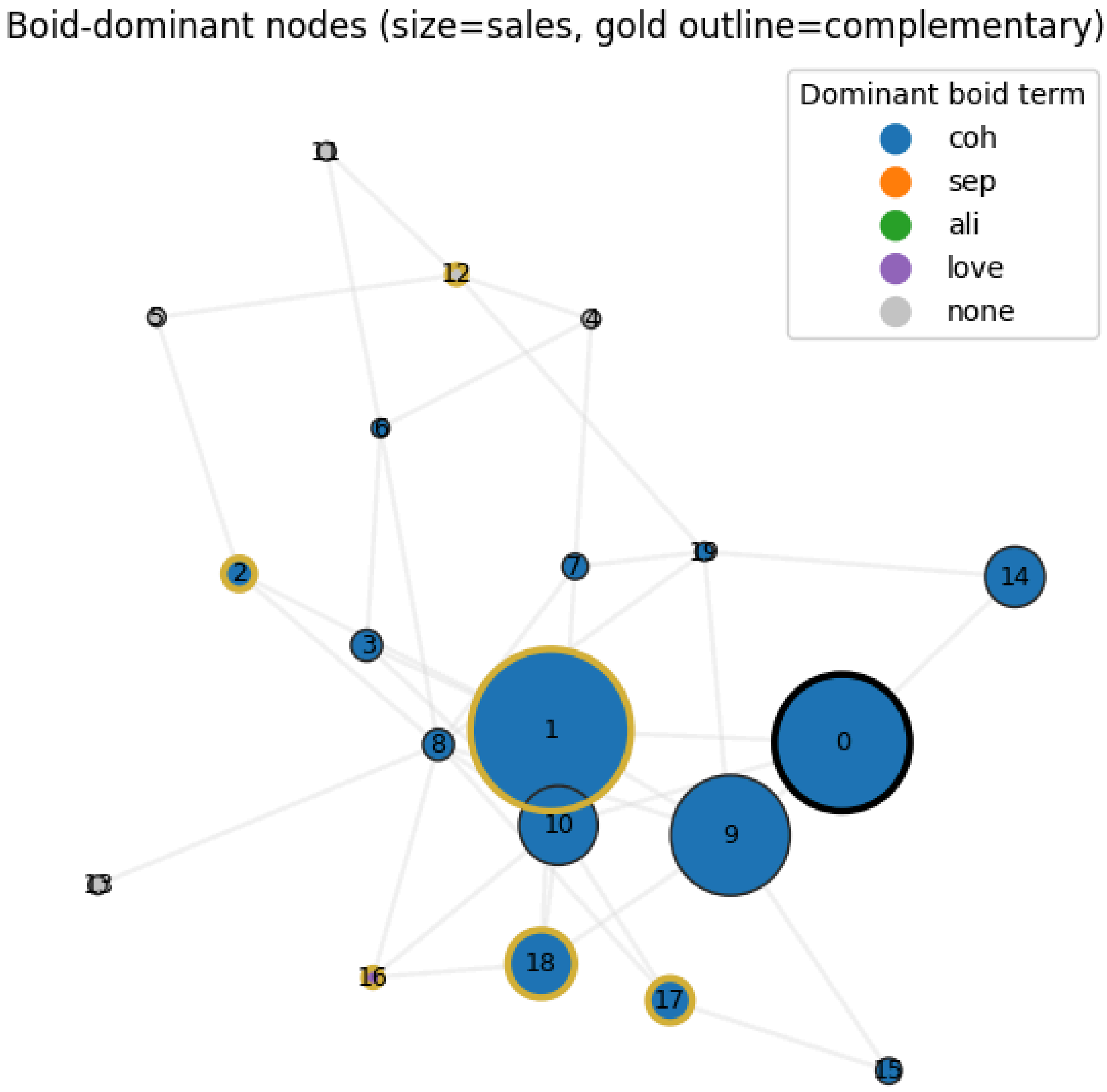
We used a medium-quality anchor because it provides balanced dynamics. When the anchor is too strong, customers stay clustered near it, so there is no visible diffusion. When it is too weak, customers move almost randomly. The medium anchor allows both attraction and exploration to coexist, making it ideal for analyzing realistic spillover effects.

Cohesion, separation, and alignment terms are calculated based on the number of agents within a one-hop neighborhood, while the love term uses the shortest path to identify the closest complementary node. All these terms are linearly combined to determine where the agent moves next.

4. Results

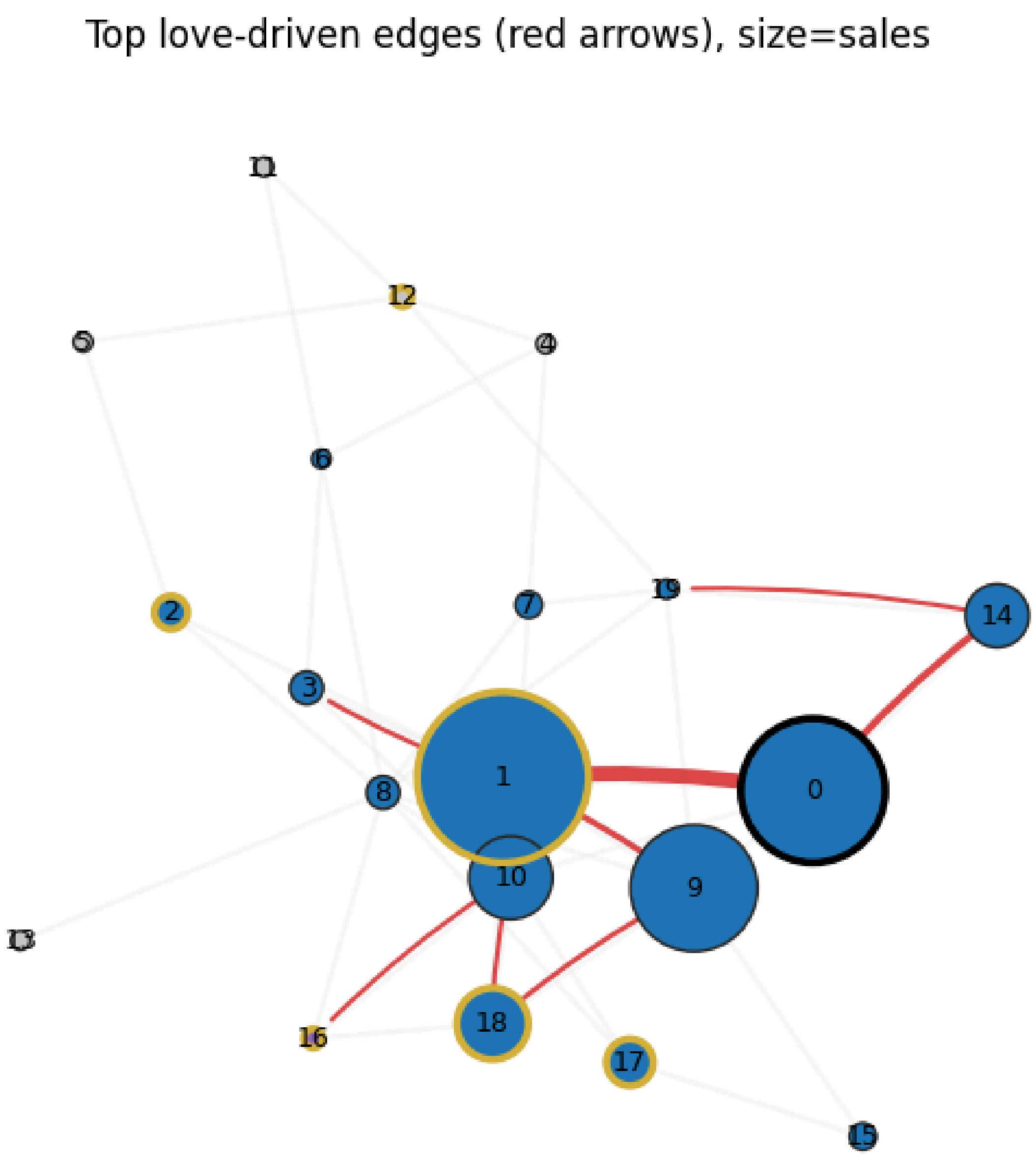
The simulation outcomes show that the coverage, or the proportion of stores that received at least one visit, is around 0.80. This means that customers explored about 80% of all stores in the network, indicating healthy diffusion without being overly scattered. The Top-3 Sales Share is 0.76, showing that although most stores are visited, the highest sales are still concentrated near the anchor and its immediate neighbors. This reflects a realistic mall scenario, where central stores generate most of the revenue. Finally, the Complementary Sales Share is 0.51, meaning about half of all purchases happened at complementary stores. This confirms a strong spillover effect — customers start from the anchor but often end up buying from nearby complementary stores. To visualize these results, two maps were created:

Figure 1. Boid-dominant node map



In the Boid-dominant node map, each node's color represents the most influential Boid term, and its size represents total sales. Most nodes appear in blue (cohesion-dominant), showing that customers naturally gather in lively areas. The complementary stores, highlighted with gold outlines, act as spillover hubs that attract customers leaving the anchor.

Figure 2. Love-driven edge map



In the Love-driven edge map, red arrows represent movements specifically driven by the love rule. These arrows clearly illustrate the anchor → complementary transitions, especially toward nodes 1, 10, and 18. Together, the two maps show how local crowd behavior and goal-directed movement combine to form a stable interaction core around the anchor area.

5. Conclusion

This project successfully modeled the anchor attraction and spillover effects within a simplified mall network using an agent-based approach. By integrating Boid-inspired rules, the simulation demonstrated how small, individual decisions—such as following crowds or seeking complementary stores—can together create realistic large-scale patterns of movement and sales. The results showed that complementary stores located near the anchor gained higher sales and improved the overall network connectivity. Medium-quality anchors provided the best balance between attraction and diffusion, avoiding both over-concentration and random movement. These findings suggest that Boid rules can effectively connect micro-level shopper behavior to macro-level outcomes, helping us understand how shopping flows naturally form inside a mall.

From a practical perspective, complementary stores should be positioned within one-hop distance of anchors to capture spillover customers, and medium-quality anchors can achieve the most stable balance between attraction and exploration. The separation rule can also be applied in mall layout design to improve circulation and reduce congestion.

However, the current simulation does not include real shopping mall floorplans or movement data, and factors such as emotional, social, and branding influences were not modeled. Future research can extend the model using actual trajectory data, multiple anchors, and dynamic store types to make the simulation closer to real-world shopping behavior.

References

Shanmugam, R. (2013). *Anchor-store quality in malls: An economic analysis. International Journal of Retail & Distribution Management, 41*(2), 90–112.

Mizuta, H. (2017). *Large-scale distributed agent-based simulation for shopping mall and performance improvement with shadow agent projection.* In *Proceedings of the 2017 Winter Simulation Conference* (pp. 1157–1167). IEEE.