# Design for Market Systems with Network-Based Product Competition Analysis

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***Abstract*—A deep understanding of the factors that influence product competition is crucial to the design of products for market systems, thus beneficial for an enterprise to maintain its competitiveness in the market. However, conducting a competition analysis faces several challenges, such as limited customer survey data and the existence of market heterogeneity, making competition difficult to quantify. To address these issues, this study first introduces a survey design to ensure the collection of reliable data on customers' preferences. Second, we present a local network-based approach to competitiveness representation that supports product competition analysis for engineering design. Taking household vacuum cleaners as a case study, the proposed representation approach offers a novel method to quantify product competitiveness in a heterogeneous market.**

***Index Terms*—Product competition, network analysis, customer preference, survey design.**

## I. INTRODUCTION

In market systems, a company's competitiveness is determined by external and internal factors. External factors include market characteristics, such as size and differentiation, and the competitive environment shaped by stakeholders. Internally, organizational forms, product strategies, and adaptability to market changes play a crucial role [1]. To sustain long-term competitiveness, companies must analyze both factors and study the market environment and customer preferences so as to better understand the market niche for their own products. Such analyses require quality customer preference survey data, which includes information on customer considerations and purchase decisions. It is one of the most important types of data to support product competition analysis [2]. However, many customer-related data contain valuable commercial information and thus cannot be shared publicly. This has hindered the reproducibility and repeatability of many existing models [3].

Another challenge is that existing studies focus primarily on homogeneous market analysis instead of heterogeneous. In marketing science and economics, a perfectly heterogeneous market indicates that each small segment of demand is satisfied by a single unique segment of supply [4]. In this study, we define the heterogeneity of a product market as the degree to which customer preferences vary between different products on the market. With this definition, we propose to use the ratio $r_h = \frac{M}{N}$ to measure a market's heterogeneity, where $M$ represents the unique products that construct the markets, all of which are stated by $N$ customers through a survey. A higher ratio signifies greater dispersion in customers' preferences, leading to a more heterogeneous market and posing challenges in quantifying various forms of competition (inter or intra-brand). In the case study of the US household vacuum cleaner market, the ratio of 0.65 exceeds the ratio of 0.008 found in our previous work [2] on the vehicle market. This highlights the greater heterogeneity of the household vacuum cleaner market, attributed to the larger number of product options available to each customer.

To overcome data scarcity and the competition unquantifiable issue caused by market heterogeneity, we first conducted a survey study to collect customer consideration and choice data that can support a variety of customer preference analysis and product competition analysis. This survey also collects customer social network data, which is critical for investigating the effects of social relationships on customer purchase decisions [5]. Second, in product competition analysis, we define a new competitiveness representation based on network motif theory [6] to quantify the competitiveness of a product in a heterogeneous market. We illustrate this new representation method in a case study on the US household vacuum cleaner market.

## II. TWO-STAGE CUSTOMER PREFERENCE SURVEY DESIGN

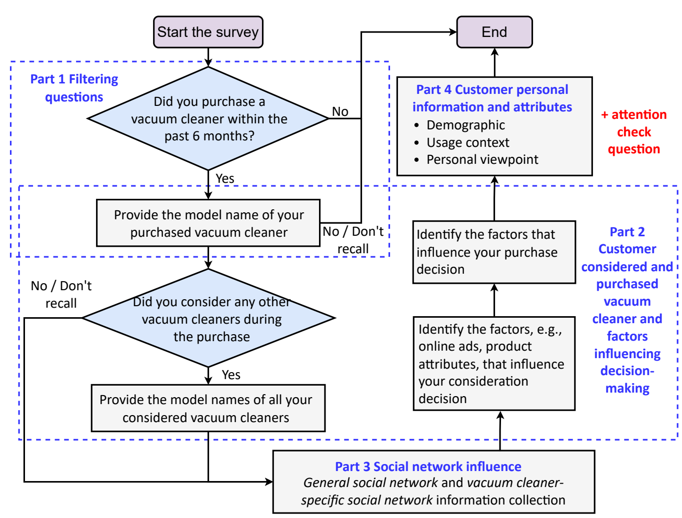


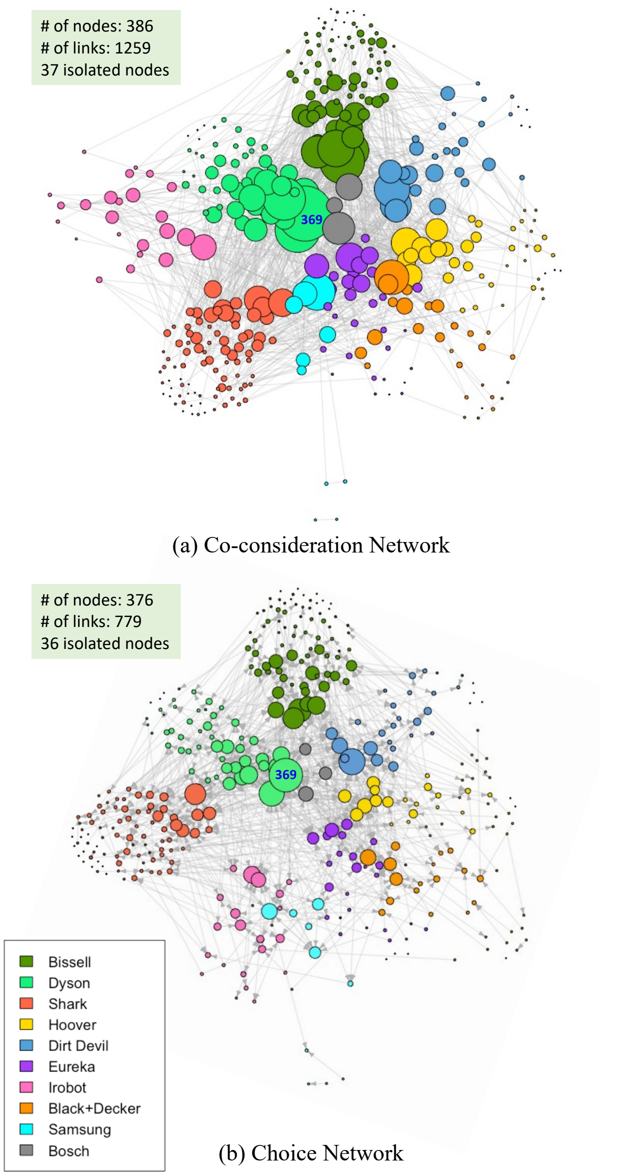

Fig. 1. Two-stage customer preference survey questionnaire flowchart [7]

As shown in Figure 1, the survey questionnaire consists of four parts. **Part One** includes two filtering questions to collect respondents' purchased vacuum cleaners, which are the most important information for collection. Only the respondents who purchased a vacuum cleaner within the past six months and could recall their purchases are allowed to participate in the rest survey. In **Part Two**, the respondents are asked to provide information about the type, brand, and exact models of vacuum cleaners they have considered and purchased, as well as the top-rated design attributes (product features) that influenced their choice-making.

In **Part Three**, we design questions to collect participants' social network data. Participants are asked to provide information on their general social networks (GSN) as well as product-specific social networks (PSN), both of which have the potential to influence participants' choice behaviors [8]. The GSN is a natural social relation network that captures the people with whom respondents communicate about important issues in their daily lives, such as their spouses and parents. The PSN refers to the people with whom respondents have discussed product purchases, such as their coworkers who have endorsed their purchase, and they may or may not be from respondents' GSN. These individuals' demographic data and their contact frequencies with the respondents are also recorded.

**Part Four** aims to collect personal information and general preferences of the participants, such as their demographics and viewpoints about vacuum cleaners. Additionally, this part of the survey focuses on understanding the product usage context of the participants, including how often they use the vacuum cleaner and where they use it. To ensure the quality of the survey data, we employ several strategies [9]: 1) design and implemented attention check questions; 2) conduct both internal and external pilot studies to collect feedback on the questionnaire; 3) incorporate experts' inputs and feedback from multiple disciplines, including engineering design, social science, and psychological science, etc.

We launched our survey on Cint, a digital insights gathering platform with quality assurance mechanisms such as artificial intelligence (AI)-driven fraud detection system. The survey was conducted over two months, from April 25 to June 25, 2021, with data collected in four phases, and a total of 1002 responses were received, with a completion rate of 15.21%.




(a) Co-consideration Network

(b) Choice Network

Fig. 2. Competition networks of top-ten household vacuum cleaner brands

## III. Network-Based Product Competition Analysis

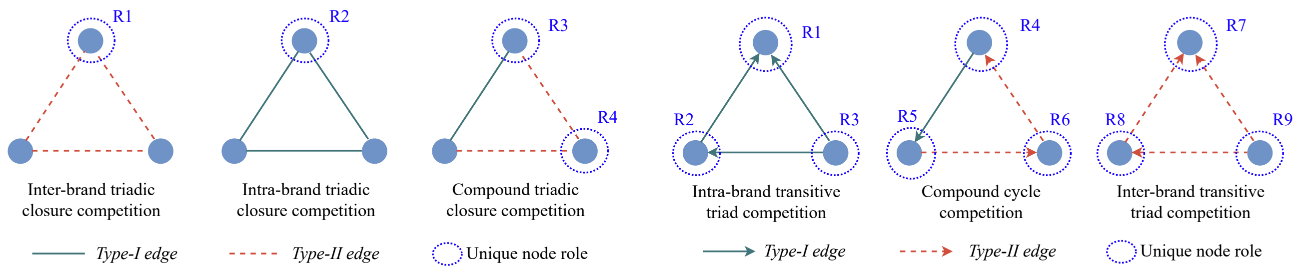
In this section, we introduce how we use the survey data to generate the co-consideration and choice networks, as well as how the competitiveness of a product in a heterogeneous market is quantified.

### *A. Co-consideration and Choice Network Modeling*

We first use customer preference data, i.e., the vacuum cleaner alternatives respondent considered and their final choices, to build the co-consideration network and choice network. The nodes in both networks represent the unique product models considered by customers. In the co-consideration network, the links are undirected and represent co-consideration relations between two products. In the choice network, the links are directed, denoting two products being co-considered, but the direction points to the one that was purchased. The link weights in both networks show the number of respondents sharing the same co-consideration behaviors. In this study, we focus on the top-ten dominant brands in the market. These brands are identified by ranking the frequencies that the respondents considered and purchased the products. The visualizations of the co-consideration and choice networks are shown in Figure 2.

### *B. Network Motif-Based Representation for Product Competitiveness*

In the new competitiveness representation, we first label the edges in the competition networks into two types: *type-I edge* indicates that two vacuum cleaners share the same brand, and *type-II edge* refers to the different brand types. Given




(a) Significant size-3 competition motifs and corresponding node roles in co-consideration network

(b) Significant size-3 competition motifs and corresponding node roles in choice network

Fig. 3. significant size-3 competition motifs and corresponding node roles in co-consideration and choice networks

the essential role of triad census in networks science [10], we concentrate on size-3 sub-networks. Then, the network motif mining tool, FANMOD [11], is adopted to identify the most significant size-3 motifs of competition. As shown in Figure 3, each motif represents distinct competition relationships between brands (inter-brand) and within a brand (intra-brand), and they are named by their edge types and topological characteristics.

After obtaining the key competition motifs, We define different types of *node roles* in the co-consideration network and choice network, respectively, based on the position where a node locates in the motifs, highlighted by dot circles in Figure 3. For the motifs in the co-consideration network, there are four node roles, each of which represents a distinct competitive position. For example, role R1 delineates the competition when one product competes with two products from the other two different brands, whereas R2 represents the competition among products with the same brand. In the choice network, the topology becomes more complex because of the existence of link direction. So, there is a total of nine distinct node roles, depending on the position of each node in the motifs, as shown in Figure 3 (b).

After generating node roles, we define the competitiveness of each vacuum cleaner model as

$$C_{ij} = \frac{{n_i}^{R_j}}{d_i}, i \in M, j \in [1, 9], \quad (1)$$

where $\frac{{n_i}^{R_j}}{d_i}$ indicates the number of times that product $i$ is involved in the role $R_j$, $d_i$ is the network degree of product $i$ to normalize $\frac{{n_i}^{R_j}}{d_i}$, and $M$ is the number of unique products in the network. Taking Hoover Powerdrive as an example, it is involved in R1 four times, R2 zero times, R3 three times, and R4 two times in the co-consideration network. Its network degree is 14; therefore, its competitiveness vector is [0.29, 0, 0.21, 0.14]. This indicates that in three-way competitions, it more frequently competes with products from distinct brands rather than within the Hoover product family.

## IV. Conclusion

In this work, we focus on the study of product competition analysis in a heterogeneous market, serving as a vital component in competitive product design. To begin, we employ a survey design to collect data on customers' preferences, specifically targeting their consideration-then-choice decision-making. We, thereafter, propose a unique local network-based competitiveness representation approach to quantify the competitiveness of a product in a heterogeneous market. Different from certain existing statistical models, such as ERGM, which are susceptible to convergence issues stemming from market heterogeneity, the proposed representation approach prioritizes the exploration of network topology and exhibits greater resilience to the challenges posed by heterogeneity. Future work will involve utilizing these competitiveness measurements to formulate a design optimization problem, aiming to achieve optimal product design for enhanced market competitiveness.

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