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Operational Optimization of the Terminal Supply Chain of Cainiao Station

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Abstract. With the continuous development of logistics and online shopping, Cainiao Station, as the last link of the logistics system and an important facility for convenient public services, is gaining increasing importance in urban daily life and industrial development. However, it still has some obvious problems that seriously affect its operational efficiency. This paper uses the methods of ergonomics, facility planning and operations research to analyze the existing problems from the aspects of distribution efficiency, station location design, spatial layout and utilization rate, and user pick-up experience, and puts forward feasible solutions one by one, so as to improve the operational efficiency of the station and the user pick-up experience. Finally, by observing the common problems and operational status of some Cainiao Stations and combining the actual situations of different stations, this paper proposes a set of universally applicable and highly practical optimization templates to improve the operational efficiency and customer satisfaction of Cainiao Station.

Keywords: last-mile logistics, distribution efficiency, station layout, space utilization, user feedback

1. Introduction

The last-mile delivery of terminal logistics has always attracted wide attention due to its extremely high ratio of travel distance to cost, as well as its status as the final link of direct contact with consumers [1]. As a third-party terminal logistics service platform, Cainiao Station has built the world's largest digital terminal network, ranking among the top in the industry in terms of both scale and service coverage. At present, it has more than 170,000 service stations, covering 31 provinces, over 98% of districts and counties, and more than 200 cities nationwide. Its network has not only extended into tens of millions of communities and over 3,000 university campuses, but also reached more than 40,000 rural areas, forming a comprehensive and extensive service network. As a core node of terminal logistics close to users, it serves over 700 million consumers and handles 80 million parcels per day on average. Relying on its extensive network layout and large service volume, it has become a highly universal infrastructure in daily logistics scenarios, deeply integrating into and even changing people's daily lives and habits. It is thus evident that research on the optimization of terminal logistics is of great necessity. This paper focuses on Cainiao Stations in various universities, and proposes feasible optimization solutions by combining data with analytical methods from operations research, ergonomics and facility planning.

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2. Current operation status of Cainiao Station

Over the past 20 years, e-commerce and online shopping economy have witnessed unprecedented growth, with their development momentum reflected in the all-round breakthroughs in multiple dimensions such as market scale, user base, business model and infrastructure. In terms of market volume, the industry has achieved leapfrog expansion. The transaction volume of China's e-commerce was only 0.56 billion US dollars in 2002, but it soared to 37.21 trillion yuan in 2020, among which the online retail sales reached 11.76 trillion yuan. Segmented tracks such as physical goods, cross-border e-commerce and rural online retail have risen simultaneously. In 2020, the online retail sales of physical goods stood at 9.76 trillion yuan, the total import and export volume of cross-border e-commerce reached 1.69 trillion yuan, the rural online retail sales hit 1.79 trillion yuan, and the revenue scale of e-commerce service industry also reached 5.45 trillion yuan. The prosperity of supporting industries has laid a solid foundation for the growth of industry. From the user perspective, the pattern of nationwide online shopping has taken shape. The number of online shoppers in China was only 193.95 million in 2011, and increased to 974.43 million in 2024, nearly a fourfold increase in 20 years. Even after the expansion of the user base, it still maintained a year-on-year growth rate of over 6.5% from 2023 to 2024. Platforms such as Pinduoduo have further driven the penetration of online shopping into the rural sinking market, activating a large number of groups that had not participated in online shopping before.

The continuous innovation of business models has injected a steady stream of vitality into the industry. E-commerce forms have evolved from early traditional shelf-based e-commerce represented by Taobao and JD.com, to brand e-commerce like Tmall and social e-commerce such as Pinduoduo, and then to content e-commerce including Douyin and Kuaishou. Consumption scenarios have also expanded from physical commodity sales to service sectors such as online education, medical care, food delivery and tourism. In 2020, the sales volume of online education increased by more than 140% year-on-year, and the transaction volume of service-based e-commerce reached 8.08 trillion yuan. Against the backdrop of such a prosperous market, the collection, distribution and transportation of logistics have reached an extremely mature stage, yet the closely related terminal logistics facilities and delivery services seem to lag far behind.

3. Existing problems of Cainiao Station

As one of the most common living infrastructure facilities, the general public's satisfaction with the package pickup process of Cainiao Station is not high. Based on a comprehensive SERVQUAL model-based study covering multiple aspects, the public's satisfaction with all indicators of the station is lower than expected, among which the gap between responsiveness and reliability is the largest. Specifically, most respondents believe that the efficiency of the package pickup process is low with insufficient feedback; meanwhile, the update of package warehousing information is not timely. The low reliability indicates a high possibility of picking up the wrong items in the pickup process, and the labels on the shelves are not clear enough. During the package pickup process, there are also problems such as insufficient personalization of the station and the staff's reluctance to actively provide services and assistance [2]. In terms of user experience, the pickup experience varies from place to place. In other words, each station has different requirements for package pickup—sometimes users need to scan a QR code via the corresponding app to complete pickup, and sometimes they are required to show an identity code for the process. The cumbersome and inconsistent pickup procedures make it difficult for most users to form a fixed pickup habit. In addition, the poor UI design of the app makes it troublesome to use during pickup, and the lack of

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on-site guidance for system operation makes some app-based pickup procedures extremely inconvenient for the elderly [3].

In terms of last-mile delivery efficiency, the delivery process is frequently plagued by delayed information updates, with packages showing as "in delivery" but failing to arrive for long periods. Meanwhile, during peak periods such as Double 11 shopping spree or around the Spring Festival, Cainiao Stations often experience delivery delays due to overwhelming package volumes or staff shortages.

The location of the delivery station often makes it difficult to pick up parcels. Sometimes online shopping often results in items being stored at different stations due to differences in size or being purchased from different platforms, and the two stations are usually far apart. And it could be really hard for user to pick up their parcels. Taking Shanghai University as an example, there are three service stations on the campus, with the distance between the two farthest stations exceeding two kilometers which makes it extremely difficult to pick up parcels at both stations at the same time, and the postal express points are located off-campus in the East District, more than two kilometers away.

There are issues with the spatial arrangement within the station and the shelving numbering system. The shelving numbers at certain stations are disorganized and lack clear signage, making it difficult for users to quickly and accurately locate the shelves meanwhile when two shelves are arranged side by side, parcels are prone to getting mixed up during searching or stacking resulting in significantly prolonged pick-up times and even situations where the goods cannot be found or lost in individual cases.

4. Solutions

4.1. Improving user satisfaction

The poor user pickup experience is mainly reflected in the low satisfaction with the responsiveness and reliability of the stations. Specifically, the stations fail to provide users with a sound service process and information management during pickup; the operating procedures vary from station to station; the station staff lack guiding services for on-site users; and the messy arrangement of packages on shelves also reduces the user experience.

For responsiveness, post stations should follow up on the logistics information of goods in a more timely manner and improve the intelligence of pick-up equipment. Reduce unnecessary communication with station staff in the relay station. If the logistics information of some goods is not updated in a timely manner, they can be added to the self-service query machine. And promptly follow up on logistics information to reduce the occurrence of this situation. At the same time, large post stations should strengthen guidance for users. Post shelf number indicators at the entrance and exit to facilitate users in searching for goods on their own. At the same time, strengthen the training of station staff and enhance their communication skills with users.

For reliability, post stations should focus on improving the consistency and simplicity of the pick-up process. In order to enable all users to independently adapt to this process and complete the pick-up process. Simultaneously cultivating user habits to further improve the efficiency of the relay station. During the process of picking up items, some places require an identity code for outbound, some places only require scanning the code, and some places can be directly taken away, frequent changes in operational procedures can make it difficult for users to develop habits. At the same time, standardize the stacking of packages and use shelves with compartments to prevent packages from falling off during the search process. Simultaneously optimize and fix the process of navigating to

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the identity code interface in the software, making it more convenient for users to exit the warehouse which greatly improve the reliability of users in the outbound process. At the same time, it reduces the difficulties encountered by the elderly and children when independently leaving the warehouse, cultivates good outbound habits for users, and facilitates information management at the post station.

4.2. Improving last-mile delivery efficiency

Due to the significant instability of the quantity of goods purchased online, for example during shopping festivals such as Singles' Day, the volume of goods surged, and during peak hours, it could even reach as much as 1.87 times the usual amount. However, the end logistics such as post stations lack methods to handle the surge in cargo volume. There is also a lack of flexible human resource allocation mechanisms and efficient sorting equipment support, resulting in a significant decrease in parcel sorting efficiency. Not only does it affect consumers' receiving experience, but it is also prone to problems such as package misplacement and loss, further exacerbating the operational pressure on end of pipe logistics.

In terms of improving delivery efficiency, consideration can be given to adding unmanned delivery vehicles to enhance the capacity of last-mile logistics [4,5]. Unmanned delivery vehicles can work around the clock with high flexibility, which can better adapt to the sudden surge in package volumes while effectively saving labor costs [6]. Nevertheless, the supporting facilities for such equipment are not yet mature at present, so this can be regarded as an important direction for future development [7]. Under the current technical background, efforts can also be made to strengthen the information management of packages. Timely update the logistics status information when each batch of goods departs. At the same time, using existing logistics information such as today's arrival quantity and the arrival time of each item, a more accurate estimation of the arrival time can be made through big data methods. To prevent users from waiting for a long and meaningless time, thereby reducing their satisfaction. At the same time, during holidays when transportation capacity is insufficient, priority can be given to delivering smaller items to quickly meet the needs of most customers. Reduce the priority of goods with high delivery costs and difficulty. People can also reduce the pressure of final delivery by rewarding self pickup [8,9].

4.3. Optimizing the site selection model

The popularity of post stations in cities has reached a high level now however, for some special scenarios such as university campuses, there is still significant room for optimization in their distribution. Meanwhile, due to the unique characteristics of campuses—large occupied areas and scattered dormitory distributions—packages are often automatically assigned to a station that is not actually the closest in terms of travel distance. In some cases, users even have to make a special detour to pick up their packages, which is unfriendly to them.

In terms of station location design, the siting of on-campus Cainiao Stations should take full account of the distance to peer stations, while also incorporating the pedestrian flow of the campus. Stations should be built as far as possible along main roads, allowing most students to pick up packages on their way, instead of merely focusing on the station's own location. At present, when placing an order, users can only see their specific delivery address, but have no idea which exact station their packages will be delivered to, which often causes inconvenience in pickup. So it is suggested that the system should provide users with the option to select specific stations when placing orders to enhance their pick-up experience. For example the stations at Shanghai University

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are divided into on campus and off campus stations [10]. Often, the address filled in is Shanghai University, but the package may appear at different stations which make the pick-up process extremely cumbersome [11]. At the same time, the standardized labeling of station addresses makes it difficult for users to distinguish often letting people know the address but unable to find it. Adding some lifestyle landmarks such as the south gate or the cafeteria can reduce the difficulty of identification.

4.4. Optimizing shelf coding rules and storing goods

At present, there is no unified coding rule for the shelves of the relay station. Often there is a situation where the shelf corresponding to the number cannot be found. This situation is not conducive to users developing habits, and it is also not convenient for management and standardization. The most obvious are in large post stations and campus post stations. At present, most post stations also use a single entrance and exit, which makes the repeated flow of personnel easy to cause congestion. When retrieving multiple items at the same time, it is common for the goods to be placed on different shelves, making the retrieval process cumbersome.

In terms of interior space layout, the shelves inside the station should be strictly arranged in ascending order of numbers. If space conditions permit, the movement of personnel can be optimized, such as by designing in an L-shape or a straight line which enable people to pick up their items smoothly without having to turn back, reducing unnecessary congestion. At the same time, the storage of goods should also follow certain rules, such as storing large items at a distance from the door and store smaller items in a more external location. More detailed regional differentiation can also be done within the post station. For example buildings 1-3 correspond to 1 shelf, and buildings 4-6 correspond to 2 shelves [12]. Partition management is used to reduce the average pickup time for users and help them develop pickup habits, which is beneficial for further improving the efficiency of the courier station.

5. Conclusion

This paper focuses on the operational optimization of the terminal supply chain of Cainiao Station, takes university campuses as the core research object by combining the methods of ergonomics, facility planning and operations research, and systematically analyzes the core problems, causes and solutions in current operations. The research finds that the existing problems of Cainiao Station are concentrated in four major dimensions. First, user satisfaction is relatively low, which is mainly caused by insufficient responsiveness and reliability, specifically manifested in inconsistent package pickup procedures, delayed information updates, lack of staff service guidance, and cumbersome software operations. Second, last-mile delivery efficiency is restricted, the main reasons being the large fluctuations in online shopping package volumes (e.g., the peak volume during Double 11 reaches 1.87 times the usual level), lack of flexibility in transportation capacity and manpower allocation, and delayed synchronization of logistics information. Third, station location selection is unreasonable, especially the unbalanced distribution of stations in university scenarios, the absence of independent selection rights for users, and unclear address labeling, which further increases the difficulty of package pickup. Fourth, the internal space and shelf management of stations is chaotic, featuring no unified coding standards, unreasonable moving line design, and disorderly package storage, which leads to low pickup efficiency and high incidence of package misplacement or loss. To address the above problems, this study proposes targeted solutions. To improve user satisfaction, it is necessary to unify package pickup procedures, optimize software operations, add self-service

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equipment, and strengthen staff training. To enhance delivery efficiency, big data can be used to predict package volumes, delivery priorities can be optimized, self-pickup incentives can be promoted, and unmanned delivery equipment can be planned for long-term deployment. For location optimization, scientific layout should be carried out based on pedestrian flow characteristics, the function of independent station selection should be opened to users, and daily-life landmarks should be added to address labels. For internal station management, a standardized coding system of "shelf number - layer number - storage location number" should be implemented, moving line design should be optimized, and packages should be stored by zones; for university stations, shelves can be subdivided according to dormitory buildings.

The significance and impact of this study are remarkable. At the theoretical level, it enriches the research system of terminal logistics operation optimization and provides a multidisciplinary analytical framework for relevant studies. At the practical level, the formulated universally applicable optimization template can directly guide the operational upgrading of Cainiao Station, especially university campuses, effectively improving delivery efficiency, space utilization rate and user satisfaction, and facilitating the high-quality development of the terminal logistics network.

Objectively speaking, this study has certain limitations. It mainly focuses on the scenario of university stations, so the applicability of the conclusions to other types of stations such as community and rural stations needs to be further verified. Moreover, the implementation effect of some optimization schemes (e.g., unmanned delivery) has not been tested by empirical evidence. Future research can expand the coverage of research scenarios, verify the effectiveness of optimization schemes with empirical data, and explore the in-depth application of intelligent technologies (e.g., AI sorting, intelligent navigation) in terminal stations, so as to provide more comprehensive support for the intelligent upgrading of the terminal supply chain.

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