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SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Thesis Project in Logistics and Transport Management

Two-stage dynamic pricing mechanism to improve the flexibility of multi-stage logistics services and the profitability of logistics service providers

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Abstract

Logistics (transport) flexibility has been widely discussed. However, mature logistics service providers (LSPs) will not make frequent decisions to change the transportation path or build new logistics centers. This thesis proposes a set of feasible operation mode and pricing mechanism to transform current logistics service into mass customization service. By adding flexibility to the services, LSP can provide customized services for each client, thereby increasing profitability while maintaining (even promoting) client satisfaction. It is worth mentioning that, unlike the previous research that is mainly based on network theory (link/line perspective) to optimize logistics flexibility. This thesis weakens the role of links between logistics depots, and develops optimization strategies based on "depot/point perspective".

This thesis mainly applies the mathematical modeling method, and concludes what decisions the client and the LSP will make when applying the new mechanism. The mechanism of this thesis can be widely applied to various cargo and passenger transportation scenarios with multi-stage transportation.

Key word: Logistics flexibility, Pricing mechanisms, Mass customization service, Mathematical modeling method, Point perspective, Multi-stage transportation

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List of abbreviation and definitions

AE	Allocative efficiency
AHP	Analytic Hierarchy Process
BB	Budget balance
BLPP	Bi-level programming problem
CP	Client problem
DPD	Dynamic Parcel Distribution
IC	Incentive compatibility
IR	Individual rationality
LSP	Logistics service provider
LSSP	Logistics service provider problem
M-MDA	Multi-unit multi-attribute double auction
NP	Nondeterministic polynomial time
NRMWC	Network revenue management with competition
RMMWOC	Revenue management in multiple flight-leg control strategy without competition
RMSWOC	Revenue management in single flight-leg control strategy without competition
VCG	Vickrey–Clarke–Groves
VRP	Vehicle routing problem

1. Introduction

In this section, two reasons for conducting research in the area are presented in the background and problem discussion. Special emphasis is put on whether and how the transformation of traditional logistics services into large-scale customized services may become a solution to the inflexible service mode of logistics service providers (LSPs). Then, the research questions are formulated leading to the purpose and sub-purposes of the thesis. Finally, the structure of the remaining part of thesis is presented at the end of the chapter.

1.1 Background and Problem Discussion

There is mainly one reason that triggers this thesis. In the current logistics industry, LSPs' operation modes may not be flexible enough. When a service is established, both LSPs and their “customers” (hereafter referred to as clients) are confined within the framework of the agreement and cannot adjust service levels. If the LSP can respond to changes in client demand at any time, it means that each client enjoys customized services because each client's demand status will not be exactly the same. Transforming current logistics services into mass customization services seems to be a good solution, but it may bring another potential problem that the cost of LSPs may increase. This section will explain in detail why current LSPs' services are not sufficiently flexible.

Nowadays, LSPs usually provide differentiated services to clients and set different prices for different service levels. Such a strategy allows them to separate clients and improve profitability. Some LSPs also consider providing additive information services for clients to improve the client experience. For example, the Dynamic Parcel Distribution (DPD) group designed its own mobile application, where clients can determine the specific delivery time after the shipment reaches the shipping terminal (DPD, 2016). Undoubtedly, such optimization improves service quality while also reducing the efficiency loss in the delivery process.

Although the LSPs have increased the flexibility of the system to a certain extent, there still seem to be room for improving and optimizing system efficiency. In the current logistics industry, the payment function is mainly carried out by starting depots of logistics services chains. The terminals of chains are given the responsibility to interact with clients (DPD, 2016). In the whole process, the LSP will hardly interact with the client. Considering that modern information technology can support the real-time interconnection of LSPs and their clients, it can be considered to increase the exchange of information between the two parties during the transport period. Such a strategy will reform the operation mode of LSP, and then enhance the flexibility of the services and explore the possibility for LSPs to achieve higher profits.

In addition to the above reasons, this thesis believes that the current LSP service mode **might not flexible enough** because the clients of LSP are not static individuals and their timeliness requirements for logistics services might change. Clients might update their timeliness requirements based on events they encounter. For corporate clients, there might be a situation where raw material consumption exceeds expectations at a certain stage. Assume that in the normal case, the client's order cycle is fixed, but in the above case, the client might want a shorter delivery time (the goods are already in transit). Then, **whether the client can adjust the current service level has become a key issue**. Even without considering the emergence of unconventional events (unforeseen events), one logical situation is that clients' predictions for the near future might be more accurate than predictions for the more distant future since clients might face more uncertainty in a longer period. This situation may also result in clients expecting to have the opportunity to adjust initial service levels. **The current LSP**

service ignores this kind of flexibility requirement.

Zhang et al. (2005) prove that there is a strong positive correlation between logistics flexibility and client satisfaction. Without considering the cost, the LSP should try to meet the client's flexibility requirements (Hartmann et al., 2011). Kelley et al. (1990) classify the freight transportation as a highly customized service. In the process of service, the clients might play the role of partial employee because the clients provide appropriate demand information to LSP (Kelley et al., 1990). If the LSP does not respond positively to the client's demands, client satisfaction may be reduced (Kelley et al., 1990). In the current context, the client's demands mainly depend on the degree of customization of the service (Anderson et al., 1997). Currently, LSP does not provide clients with the option to adjust service levels during transit. **The efforts of LSP to meet the client's heterogeneous demands may not be sufficient and that is the main reason why the current logistics service mode might not be flexible enough (inflexible).** Is it possible to develop and propose an operation mode that can transform LSP's the conventional services into customized services?

Transforming current logistics services into large-scale customized services may increase the flexibility of services, but it may also bring about another problem that affects the profitability of LSPs. Hartmann et al. (2011) believe that LSPs should provide flexible services to clients as much as possible, but "flexibility" is expensive for LSPs. High flexibility means that the complexity and cost of logistics tasks will increase. However, as mentioned above, customized services can improve client satisfaction. **Client satisfaction has a strong positive correlation with clients' willingness to pay** (Homburg et al., 2005). In their study of the energy industry, Goett et al. (2000) also find that clients' willingness to pay will increase if they can receive effective feedback from the energy providers in their services. Comparing with the current LSP does not provide clients with the option to adjust the initial service level.

It is possible to increase a client's willingness to pay only if the LSP is willing to make a change.

From the above discussion, it is not difficult to find that in the context of this thesis, providing customized services and increasing service flexibility can be considered as equivalent concepts. In order to successfully introduce customized services into the operation mode of the LSP, it is also necessary to determine a corresponding pricing mechanism. Is it possible to develop and propose an operation mode and pricing mechanism that will lead to that LSPs do not only gain system flexibility, but also further improve profitability?

In the interaction with clients, LSPs improve client loyalty (Hartmann et al., 2011). Therefore, the idea of introducing clients into customized services seems to be consistent with the concept of “customer integration” that Piller et al. (2004) proposed in mass customization. If successful, the customization of logistics services clients will provide accurate information on market demand (reporting changes in their timeliness requirements).

1.2 Research questions

The research objects in this thesis include LSPs as well as their clients. Both decisions will affect the successful implementation of customized service strategies. The decisions of both parties will also have an impact on each other. Therefore, it may be worthwhile to analyze decisions that the single LSP and its clients might make under the new operation mode and pricing mechanism. Based on the above discussion, this thesis identify the following two research questions：

Research question 1: *How should an operational mode and pricing mechanism be* *designed for attracting clients to participate in logistics service customization?*

Research question 2: *What kind of decisions should logistics service providers make to maximize their profitability after introducing logistics customization strategies?*

It should be noted that in the design of this thesis, the pricing and interactive functions of the LSP are no longer limited to the starting depot and the terminal of the service (as shown in the figure 1.1). Through the design of operation mode and pricing mechanism for logistics services, service level can be adjusted at each depot, and the contractor of the intermediate logistics depot can be encouraged to actively participate in traffic management to enhance the service chain flexibility.

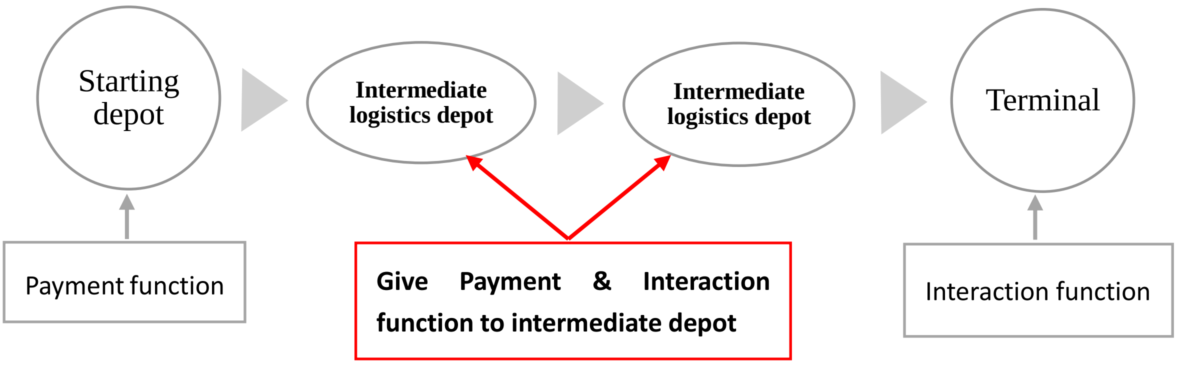

Figure 1.1 Reform of payment function and interaction function

1.3 Research purpose

The overall purpose of this thesis is to develop and propose feasible strategies that can transform current LSPs' logistics services into large-scale customized services.

The customization of logistics services may increase the flexibility of services. At the same time, however, it may lead to higher costs that affect the profitability of the LSP. In addition, the decisions of the LSP and its clients may have an impact on the actual effect of the strategy. Also related to the research questions, this thesis has two sub-purposes. First, by studying the client's decision after the logistics customization strategy is introduced, **knowledge about whether the client can accept the new strategy will be obtained**. Answering the first research question ensures that the new strategy proposed is recognized by the market and attracts rational target clients. Second, by studying the decision made by LSPs to increase their profitability after the introduction of the logistics customization strategy, it is **ensured that the cost impact of the new strategy can be hedged**. In other words, it is important to make sure that this strategy will improve the profitability of LSPs and not make the LSPs worse off than in the current situation. Hence, both sub-purposes are subordinate to the overall purpose of the thesis.

1.4 Structure of the thesis

After the introduction in Chapter 1, readers understand the background, research questions and motivations in this thesis. In the next chapter, relevant literature streams in the thesis area are summarized. This chapter also provides the definition and measurement of flexibility, and revenue management in multi-stage transportation. Subsequently, the third chapter formally introduces and motivates the methodology approach. In Chapter 4, the decision processes of LSPs and their clients are mathematically modelled. Thereafter, a pricing mechanism is developed and proposed in Chapter 5. Finally, Chapter 6 concludes the study by also emphasizing management implications.

2. Literature review

This thesis will improve the flexibility of logistics services and profitability of LSP. The logistics services discussed in this thesis means a multi-stage logistics process which means cargo will pass multiple depots. A dynamic pricing mechanism based on auction is applied as solution. Therefore, there are three literature streams related to thesis. First, giving a clearly definition of flexibility will be a very important part of this thesis. This section is mainly divided into three parts. The first two parts compare the flexibility with the other two properties (resilience and robustness) that are often used to measure certain object, and then summarize the previous articles that studied the "flexibility" of the transportation system (Abrahamsson et al., 2003; Barad et al., 2003; Morlok et al., 2004; Zhang et al., 2005; Naim et al., 2010; Nelson et al., 2010; Chen et al., 2011; Hartmann et al., 2011; Mulley et al., 2012; Bai et al., 2013; Emele, Oren et al., 2013; Yu et al., 2017;). Through the reference and summary of previous research results, the definition of flexibility of logistics services discussed in this thesis has been determined. The other two literature streams related to this thesis are revenue management of multi-stage transport and auction mechanism design.

2.1 Flexibility

In order to make sure the internal validity of this thesis, a clear definition of flexibility (in the discussed context) should be given. In Chapter 3 there will be a more detailed discussion of internal validity.

This section begins with a comparison of flexibility and other properties. This is done to separate the flexibility from resilience and robustness, and to ensure that the objects being studied are consistent with the objects that this thesis is expected to study. In the following part, the literatures about flexibility in transportation will be summarized to determine whether the definition of "flexibility" in previous studies is still appropriate in the context of this thesis.

2.1.1 Flexibility vs. resilience

All along, there are many similarities between flexibility and resilience. Many scholars have blurred the concept of both, for example, Abdel et al. (1991) defines flexibility as the resilient relationship between buyers and sellers under the changing supply system. In fact, there is a clear boundary between the two concepts.

Flexibility is the ability of the system to change, not to eliminate the effects but to adapt to changes in the environment, so flexibilities indicate the ability to change or react. Flexible systems can adjust the structure or operations to respond to changes in the environment. Flexibility is an element of a contract that is made jointly between the parties to the transaction. For the demand side, it represents the expectation of future changes. For the supplier, it is an estimate of the fluctuations in demand that oneself can bear (Shihua, 2003).

Resilience is an inherent property of the system. The system can change dramatically when it comes to a devastating impact, but because of its resiliency, the system quickly regains its normal function. Walker (2004) proposes that resilience is the ability of the system to absorb disturbances before the equilibrium changes. Therefore, the resilience of the system can be measured by the extent to which the system absorbs the disturbance. Ponomarov et al. (2009) define it as the system's ability to cope with unexpected incidents and help system keeping the business operating continuously at the desired level. In other words, resilience is the ability of the system to continually respond to sudden and significant changes.

2.1.2 Flexibility vs. robustness

Unlike system resilience, robustness primarily controls the quality of day-to-day operations within the system and handles events that move within reasonable limits. Therefore, the robustness of the system is defined as the ability of the system to maintain the continuous operation of the system under the influence of uncertainties such as internal operation and external emergency (Li et al., 2007).

Therefore, flexibility can be considered as an attribute that is used to measure **how a certain research object can respond to external changes using its own resources**. In the following sections, the focus of the discussion is whether the definition of flexibility in previous studies can be applied to the environment discussed in this thesis.

2.1.3 Flexibility in transport

Some scholars have explored flexible service or flexible pricing in passenger transportation, for example, Nelson et al. (2010) summarize the technologies used by European countries for public transport to support flexible transport services. Mulley et al. (2012) explore some of the obstacles in implementing flexible transport services. Emele, Oren et al. (2013) study the dynamic pricing problem of manned traffic in rural areas, adjusted prices by intelligently identifying some external factors. In their research, they divide existing pricing methods into two categories based on journey and passenger-based, and combine these two methods to form what they called "variable pricing" strategy. By using the mechanism of dynamic pricing, they got better operating efficiency and profitability comparing to using fix price. This finding reflects, to some extent, the efficiency and profitability of the transport system operation could be affected by the price strategy and may be improved at the same time.

Research on flexible services is often linked to client satisfaction and service levels. Zhang et al. (2005) explore the flexibility of logistics services by defining a complete framework and using large sample data to study the impact of service flexibility on client satisfaction. Hartmann et al. (2011) explore the impact of logistics service flexibility on client loyalty, but they adopted a different approach to research. Because they think the concept of LSPs 'flexibility is rather vague, they use LSPs' capabilities such as resources to represent flexibility and finally discover the importance of knowledge sharing and collaboration.

In addition to the summary and exploration of the application of flexible services, some scholars devote themselves to studying the framework for evaluating the flexibility in transportation networks. Researches in this field is closely related to this thesis. This thesis hopes to propose a logistics system operation model and pricing mechanism that can improve the flexibility of the logistics system. Therefore, the framework used to measure system flexibility in previous studies can provide theoretical support for the results of this thesis. Morlok et al. (2004) and Chen et al. (2011) both propose two approaches to measure the flexibility of the system. What they have in common is that they all propose an estimation method based on the concept of "reserve capacity". The other approaches they discuss are different, the former discussing the use of other forms of transport, and the latter relaxing the constraint on demand patterns.

Barad et al. (2003), Naim et al. (2010) and Yu et al. (2017) also conduct the empirical research which are related to logistics flexibility, the former utilizes the action research based approach and embed the logistics flexibility into supply chain strategy. The latter apply statistical approach to explore the supplier-buyer relationships, and one hypothesis in the thesis is about how logistics flexibility affect services quality.

Abrahamsson et al. (2003), Barad et al. (2003) and Bai et al. (2013) study the flexibility measurement, flexibility in logistics platform and flexibility of reverse logistics respectively. The former two are modelling research and the latter is a review article. All of them have completed a comprehensive review of the flexible logistics papers related to their respective research. Barad et al. (2003) summarize the flexibility in the logistics system into three broad categories: basic flexibility, system flexibility, and aggregate flexibility. Basic flexibility includes the flexibility of fundamental module, such as product flexibility and transportation tool flexibility. System flexibility define as the flexibility related to transshipment and decision-making etc., and the aggregate flexibility means the flexibility about long-term plan including design of distribution system. The mechanism in this thesis, according to such classification, is related to the first two kind of flexibility. Mechanism in this thesis are seeking the product flexibility and system flexibility.

Similar to the flexibility in the general sense, the flexibility in transportation also represents the system adapting to external changes by adjusting itself (in system/operational level). Of course, the flexibility here is subject to some additional restrictions. For example, the service has perishability (Parry et al., 2011). Therefore, the flexibility of transportation includes the guarantee of the timeliness (service level) of the service. If the service can't be realized at specific time, it will cause some losses and even make the service lose its meaning.

The logistics environment to be discussed in this thesis is summarized as below:

1. LSPs are mature logistics companies do not consider planning at strategic level, such as large-scale investment.
2. The logistics network is definitive, and the transport path between any two depots is determined, so it is not feasible to change the path to optimize flexibility.
3. As logistics networks determine, the way to improve flexibility by adding new

depots is also not applicable.

4. Since the logistics network determines that the maximum capacity that can be accommodated in the network is determined, the concept of "network capacity flexibility" no longer applies to the context of this thesis.
5. The flexibility of logistics services needs to be subject to a restriction, that is, the timeliness (service level) of logistics.

Therefore, in the flexible evaluation system of this thesis, the freight volume is no longer an appropriate criterion. **Flexible service** to allow clients to have more choices, and therefore affect the **client's utility**. When the client's demand for flexible services cannot be met, potential utility improvements cannot be realized, which may result in greater opportunity costs. At this point, the social welfare loses opportunities for improvement. On the other hand, this thesis hopes to improve the flexibility of logistics services and enhance the profitability of LSPs. Therefore, this thesis considers the realization of social welfare as a criterion for evaluating flexibility. The social welfare mentioned here refers to the sum of the profit of the LSP and the utility of the clients. Flexibility in this thesis is defined as follows:

*While maintaining a dynamic and consistent relationship with the client regarding service levels and prices, **the ability of** logistics system can **achieve higher social welfare** by using current resource when the timeliness demands of clients change.*

This thesis links service flexibility with social welfare by defining the concept of “flexibility” that applies to the current context. Although this thesis redefines the flexibility here, it does not lose the common characteristics of flexibility in previous studies, that is, **the ability of a subject to apply its own resources to deal with external uncertainties**.

2.2 Revenue management of multi-stage transport

The logistics service being discussed in this thesis is a multi-stage transport process. As discussed in last section, the flexibility in thesis seeking optimal higher social welfare. Therefore, it is necessary to summarize the literatures on revenue management in multi-stage transportation.

Revenue management is the sale of limited and perishable products (resources) to different types of clients (Grauberger et al., 2013). The type mentioned here may refer to the client's willingness to pay.

The literature listed here is mainly about the research of multi-stage air transport. These studies are similar to this thesis in that they all have multiple stages and all involve the concept of space capacity, which has the limitation of timeliness. Therefore, multi-stage air transportation can be considered as a special case of the problem discussed in this thesis. It should be noted that passenger transportation and cargo transportation are indifferent here, since the (multi-stage) transportation services purchased by the client can all be considered as time-limited space capacity. In passenger transportation, one client can also purchase multiple units of space, for example, one client purchases tickets for multiple persons.

There is an important concept that needs to be explained here, **flight leg**, as shown in the following figure 2.1, the air route shows by solid line arrow represents leg. The main reason for airlines to build hub-and-spoke networks is that under this network structure, the number of "flight legs" required is smaller than the number of products that can be provided (Grauberger et al., 2014). For example, there are two legs, S-H and H-T in figure 2.1. The products that can be provided in the figure are S-H, H-T and S-

T. Therefore, by applying this kind of network structure, airlines can not only integrate clients' demand but also save resources. The hub refers to the stopover point of the network. In figure 2.1, it refers to the point H. The spoke is the two legs in the figure.

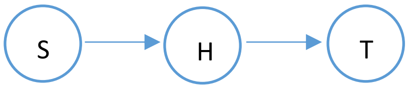

Figure 2.1 Air transport network with two flight legs

This thesis classifies the revenue management in air transportation into three categories. The first one is revenue management in single flight-leg control strategy without competition, which means that in this case, the airline does not need to consider the impact of competitors when making decisions, and only needs to formulate a pricing strategy on the single leg (Gerchak et al., 1985; Alstrup et al., 1986; Sawaki, 1989; Brumelle et al., 1990; Curry, 1990 Wollmer, 1992; Brumelle et al., 1993; Lee et al., 1993; Robinson, 1995; Lautenbacher et al., 1999; Subramanian et al., 1999). In this kind of research, the commonly used method is dynamic programming (Gerchak et al., 1985; Alstrup et al., 1986). The advantage of this approach is that the calculation is relatively convenient, but the results obtained may not optimal, because no strategy has been formulated at the system level (You, 1999).

Subsequently, the second type of research emerges that introduces method of formulating pricing strategies on multiple flight-leg simultaneously. By using this approach, it is possible to plan from a higher level, to avoid falling into a partial optimum. Airlines can obtain better benefits of, at the cost of the problem (network income management) becoming a computationally difficult (Talluri et al., 2004, p. 92). Therefore, this type of research attempts to improve computational efficiency (Hersh et al., 1978; Dror et al., 1988; Feng et al., 1995; Gallego et al., 1997; Liu et al., 2008; Zhang et al, 2009).

In recent years, the issue of revenue management of air transportation with competition/alliance relationships has been widely discussed, which is the third type of research. Competitive network revenue management becomes more complicated, because solving the Nash equilibrium in non-competitive non-zero-sum game itself is also a computationally hard (Papadimitriou, 1994).

As more factors were included in the scope of the study, the complexity of the problem gradually increased. From the time sequence of these three types of research (according to table 2.1), it also shows the trend of research (RMSWOC-RMMWOC- NRMWC).

Table 2.1

Research field	Authors
Revenue management in single flight-leg control strategy without competition (RMSWOC)	Gerchak et al. (1985); Alstrup et al. (1986); Sawaki (1989); Brumelle et al. (1990); Curry (1990); Wollmer (1992); Brumelle et al. (1993); Lee et al. (1993); Robinson (1995); Lautenbacher et al. (1999); Subramanian et al. (1999);
Revenue management in multiple flight-leg control strategy without competition (RMMWOC)	Hersh et al. (1978); Dror et al. (1988); Feng et al. (1995); Gallego et al. (1997); Liu et al. (2008); Zhang et al (2009)
Network revenue management with competition (NRMWC)	Li et al. (1998); Netessine et al. (2005); Li et al (2007, 2008); Gao et al. (2010); Jiang et al. (2011); Grauberger et al. (2014&2016&2018); Liu et al. (2017)

The above three kinds of research, the main problem to be solved is how to make the airline can achieve higher profits by setting the corresponding prices for different services. However, in addition to the booking control by adjusting the price strategy, Lin et al. (2017) provides another idea to apply the buy-back policy to the airline's revenue management problem. The background of their research is that the cargo airline will outsource some of the positions (capacity) to the agents, and the agents will sell them to clients. Lin et al. (2017) studies whether airlines should buy back capacity from agents, as well as the quantity of buy-back and the time of implementing buy-back. This idea of treating the right to transport cargos as an option (in other words, a commodity) is consistent with this study. However, the method of this thesis is different, which is to form a dynamic pricing mechanism by inducing the transactions between clients and clients.

2.3 Auction mechanism design

Another research stream related to this thesis is auction mechanism design. Dynamic pricing mechanism in this thesis includes two stages. First stage is clients choose certain services level based on their situation. And in second stage, client can choose to adjust their services level. The initial price of services in stage 1 is based on cost accounting which will make sure LSP will have a negative income and the profitability will improve once LSP can achieve positive income. In second stage, clients' cargo will pass certain depots on the way from origin to destination. The cargo will occupy the capacity when they transport to next depots. When clients want to accelerate their cargo, they need to buy the capacity in earlier departure time which means that they need to exchange the order of departure with other clients. Such a mechanism makes the clients' capacity in each departure truck/plane as a resource that can be trade. The capacity is the commodities with multi-attribute including time, departure depot and next arrival depot. Two parties (buyer and seller) will join the auction. It's necessary to build a mechanism that can make them report their reservation value honestly (reservation value here means the payment that can make up the changes of their utility). Therefore, there are two kinds of auctions related to this thesis.

2.3.1 Multi-attribute auctions

Ryu (1997) might be the first in studying the exchange mechanism about commodities with requirement of non-quantitative attributes. Later, Li et al. (2013) propose one truthful multi-attributes auction mechanism. Based on his previous work, Li et al. (2016) then design a framework that can avoiding bidders' collusion due to commodity diversity. Baranwal et al. (2015&2016) study the distribution of cloud computing resources and designed a multi-attribute combinatorial (reverse) auction mechanism. Xu (2017) studies the business-to-business e-commerce logistics problem with with multiple attributes (ELP-MA), which is mainly to match the clients' logistics orders and the services of LSPs. In the article, Xu (2017) proposes two auction mechanisms that guarantee truthful bidding. Chetan et al. (2018) design a two-stage auction mechanism in which the vendors (the sellers in this thesis) make a commitment to a variety of quality attributes of the product in the first stage. This mechanism achieves vendors-side competition and leaves them without motivation to deviate from the first-stage quality commitment in the second stage.

Pham et al. (2015) give a more detailed review about the multi-attribute auctions. Interested readers may refer to this article.

2.3.2 Truthful double auctions

There are works discuss multi-stage method to dwindle the buyer (seller) set and achieve truthful bid (Chu et al., 2006&2008; Chu, 2009). Chu et al. (2008) propose Modified Buyer Competition Mechanism (MBC) and Chu (2009) introduces Integer-Program-Based Padding Mechanism (IPB) which are both buyer competition mechanism.

Both Wang et al. (2011) and Cheng et al. (2016) have done research on auction mechanisms for perishable products. Wang et al. (2011) design a virtual competition auction model applied to airline tickets and hotel services, and proved in experiments that the mechanism is more effective than English auctions. Cheng et al. (2016) conduct research on perishable products such as roses that have a variety of attributes.

Cheng et al. (2016)'s work' is most related to this thesis. Cheng et al. (2016) build two exchange mechanism for multi-unit multiple-attributes auction firstly. The Multi-unit multi-attribute double auction (M-MDA) is based on padding method proposed by Chu (2009).

The difference between Cheng et al. (2016)'s work and this thesis is that the mechanism here involves two stages. The auctioneer in this thesis (LSP) have other decision variable which is not related to bids. In the second stage (auction pricing stage), an algorithm based on the M-MDA mechanism is used to reduce the computation complexity. The second stage can be seen as a special application of M-MDA, besides, other multi-attribute multi-item auction mechanisms might also be applied here.

3. Methodology

This chapter will explain the methodology applied in this thesis. Different dimensions of the theory are applied to this thesis, and each method has its own reason for being applied. The research paradigms and types of this thesis will be clarified. The purpose of this chapter is to give readers a clear understanding of the methodology applied in this thesis. In the final part of this chapter, the delimitation of the research will also be clarified.

3.1 Research paradigm

Research paradigm is the framework indicating how the research being conducted (Collis et al., 2007, p.43). The research paradigm of this this thesis is positivism. The aim of this thesis is finding appropriate operation mode and pricing mechanism that can promote the flexibility of logistics services and profitability of LSP. Therefore, it is necessary to first give the explanation of how pricing strategy affect the flexibility and profitability, then it's possible to give feasible solution. Theories under positivism provide explanation of the phenomenon that being studied and then try to predict, even control it. According to Collis et al. (2007), under positivism, mathematical proof can be given to assertion. This thesis conducting modeling research, and all conclusions are based on quantitative proof.

3.2 Research strategy

This thesis mainly applies quantitative research methods. To improve the flexibility of logistics services and the profitability of LSP, this thesis proposes to transform the services provided by LSP into large-scale customized logistics services by establishing a new operation mode and pricing mechanism. The actual effect of the new strategy will be influenced by the client and the LSP's decision. In order to ensure that the new strategy can achieve the desired results, it is necessary to fully understand what decisions the clients and the LSP will make under the new strategy. Therefore, the process of forming a solution in this thesis is a deductive study (the reason will be in the type of research). This thesis mainly follows the following steps:

(1) The intention of implementing the logistics customization strategy is to improve the flexibility of logistics services in the context of this thesis. it's necessary to define the concept of flexibility of logistics services in the special context mentioned in this thesis. The concept borrowed from other areas such as supply chain (Shihua, 2003) and transportation (Nelson et al., 2010; Oren et al., 2013), but without losing the common differentiated characteristics. Therefore, Chapter 2 start by summarizing the definition and evaluation system of "flexibility" in previous studies, and then analyze whether the previous results can be applied to the research context of this thesis. The general definition of "flexibility" in previous studies is summarized and compared to other properties (resilience and robustness) in literature review. Later, the researches related to this thesis that the scholars have conducted in terms of the "flexibility in transport" are further explored. Finally, this thesis gives definition of flexibility in the literature review and links service flexibility with social welfare.

(2) This thesis intends to propose a two-stage dynamic pricing mechanism and related operation mode. In the second stage, the new mechanism will guide the client to exchange the order of departure of the cargos, thereby transforming the unilateral market into a bilateral market. The second stage is an auction process. The ideal application scenario for the new strategy in this thesis is a multi-stage transportation service. Therefore, it is necessary to explore the previous research on the revenue management in multi-stage transportation. Searching for auction mechanism that can

be applied in the second stage is also one of the aims of the literature review.

(3) In order to ensure the validity of this thesis, it is necessary to clarify and summarize some features of the research context in this thesis. With the above summary, this thesis can propose a mathematical model to simulate the LSP and the client's decision-making process.

(4) Based on the previous discussion, the next important part of this thesis is a complete description of the pricing mechanism proposed in this thesis. A two-stages dynamic pricing mechanism is considered. First stage is clients choose initial service level based on their situation. And in second stage, clients can choose to adjust their services level. This means that the clients need to exchange the order of departure of cargos with other clients at depot, so extra payment is required. This thesis defines the client who wants to adjust the service level as a buyer. Clients who exchange order of departure with the buyer receive compensation and this type of client is referred to seller. The second stage of the pricing mechanism is the transaction between the seller and the buyer. Both parties submit prices that they are willing to accept, and LSPs are responsible for matching supply with demand. Specifically, the strategies proposed in this thesis can be summarized as speeding up part of cargo, while slowing down another part. According to the previous research, despeeding the supply chain, which means decrease transport speed and increase load fill are environmental friendly strategy with high potential in CO2 abatement and assessed index of feasibility (World Economic Forum, 2009). This means that the strategy proposed in this thesis might be environmentally friendly. This thesis chooses to use mathematical modeling to show the mechanism, and then draws some conclusions through mathematical derivation. By analyzing the mathematical model, this thesis can infer what decisions the client and the LSP will make to maximize their own utility (profit).

3.2 Mathematical modeling

As mentioned above, the main research method applied in this thesis is mathematical modeling.

This thesis will simulate the possible reactions of clients and LSPs in trading by establishing mathematical models. The purpose of modeling research is not to completely restore the situation in reality, but to use a simple mathematical language to more accurately describe the key elements of the entire process. During the research process, important details will be abstracted. For example, the capacity occupied by the client's in-transit cargos is simply defined as parameter k. Parameter means measure factor that can indicate features of a certain object (thefreedictionary, 2018). In reality, the description of the size of the cargos may involve two dimensions of volume and weight, but in the study, it set to be a parameter. This is because the intrinsic concrete expression of a single factor is less important in this thesis. The most important thing is the interaction between different factors. As mentioned before, modeling research is not to perfect the restoration of real life, but to help people understand the reality during analysis.

There is some difference between this thesis and the previous research (Morlok et al., 2004; Chen, et al.,2011). In previous studies, searching for a better route or combination of transportation modes has become the main means of optimization. However, in real life, most mature LSPs have fixed transportation routes. Therefore, the optimization scheme presented in this thesis will not involve changes to the original vehicle network.

Figure 3.1 shows the logistics network discussed in this thesis, one transport routine including **starting depot**, **middle depot** and **terminal** also shows in figure. The depots in the middle are mainly driven by the upstream traffic and are mechanically operated. When an unexpected situation (such as a surge in traffic) occurs, it may exceed the capacity of a depot, interrupting the logistics process. The LSP does not respond to this situation, such as dynamic pricing to limit traffic. Therefore, when the LSPs are overloaded, they may not be able to guarantee that the delivery time is within the original commitment period (the service level cannot be guaranteed). This is mainly because there is no interaction between LSPs and clients during the execution of each single service, and they cannot realize the dynamic agreement about service level.

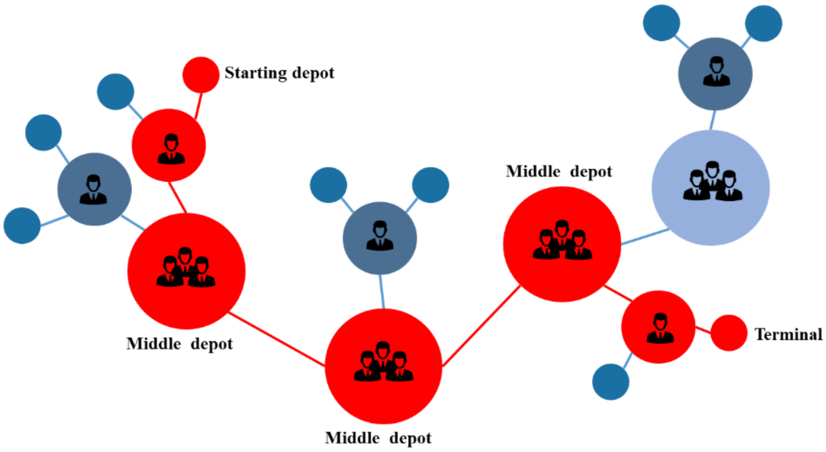

Figure 3.1 Logistics network

To find a solution to improve service flexibility, it is necessary to understand the concept of flexibility. In the past research on transport flexibility, the concept of **network capacity flexibility** is formed and widely used. Scholars primarily optimize the system's capacity by modifying the vehicle path and depot locations in the logistics network (Morlok et al., 2004). Under this concept, the goal of the LSP is to maximize the ability to accommodate traffic within the system.

Scholars try to improve the system's network flexibility by establishing a bi-level programming model. Specifically, they set the objective function of the upper-level planning to maximize the volume of freight, and to explore the reserve flexibility of the system by changing the strategies of vehicle routing. In addition, they seek better solutions by relaxing the constraints on demand patterns and traffic patterns. Therefore, the issues discussed in these studies are that, with the existing infrastructures unchanged, researchers can improve the flexibility of the system by allocating the origin–destination (O–D) demand to different paths or modes of transport. Such research has a certain connection with the **vehicle routing problem (VRP)**. Bi-level programming problem (BLPP) is a system optimization problem with a two-level hierarchical structure. The upper level problem and the lower level problem have their own decision variables, constraints, and objective functions. Bi-level programming is a method to solve planning and management problems with two-level systems. The upper-level decision-makers do not directly interfere with the lower-level decision-making, but use their own decisions to guide the lower-level decision-makers. The lower-level decision-makers only need to use the upper-level decision-making as a parameter to make free decisions within a certain range. This decision-making mechanism makes upper-level decision-makers must consider the adverse effects of the strategies that lower-level decision makers may take on the upper-level.

In reality, for a mature LSP, its transportation network is usually determined, and there is only one path in the two logistics depots. As shown in Figure 3.2, the cargos of two villages (level-1 depot) located in different provinces must first be transported from the village to the city (level-2 depot), then transported to the provincial capital (level-3 depot), then to another provincial capital (level-3 depot), and finally to a lower-level destination. Therefore, optimization methods such as path planning and facility location might not suitable for large mature LSPs seeking to improve system flexibility.

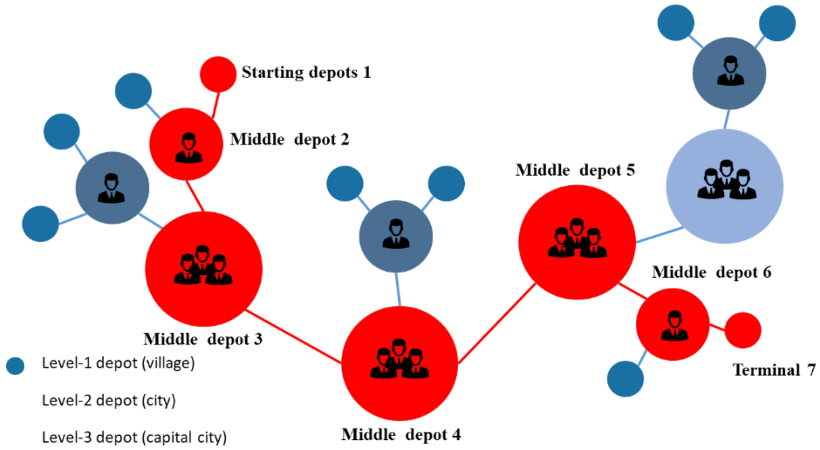

Figure 3.2 Logistics network with different level depots

The link between depots and transportation facility will not change, and the upper bound traffic volume between depots are also fixed. Within a fixed period, LSP's maximum traffic between any two depots is also determined.

Therefore, this thesis will ignore the details of the transport links between depots, and implement the optimization strategy on the period when cargos stay at each depot. This thesis wants to apply the dynamic pricing strategy to the entire transport process, so that LSPs and clients can make dynamic adjustments to the agreed service levels. Therefore, the optimization idea in this thesis is based on "point/depot perspective" instead of "line/link perspective" (the perspective of previous research).

This thesis selected a programming-based approach to demonstrate the decision-making process of clients and LSPs. There are two main reasons as follow:

1. Since the second stage of the pricing mechanism proposed in this thesis is an auction process, the programming method is widely applied to the auction mechanism design (Chu et al., 2006&2008; Chu, 2009; Xu et al., 2017). The M-MDA mechanism applied in this thesis is also a solution scheme based on the programming method (Cheng et al., 2016). Therefore, it can be considered that in the design of the auction mechanism, the

programming method is a research method approved by the academic community. In order to be consistent with the form of the second stage, this thesis also uses the programming method to express the client's decision in the first stage.

2. In order to ensure the feasibility of the new strategy, it's necessary to analyze the decisions that LSPs and clients will make after the introduction of mass customization logistics services. However, there are two important points that cannot be ignored which are **the influence of one party's decision-making on the other's decision-making** and **the influence of both parties' decisions on the efficiency of the mechanism**. Therefore, the relationship between the various major elements (decision variables) mentioned in the model is the very important. **The decision-making problem studied in this thesis is not to sort the existing decisions of a certain decision-making subject but to decipher the interrelationships between the decisions (of different subjects).** At this time, methods such as the Analytic Hierarchy Process (AHP) are no longer applicable, because the focus of this thesis is not on the decision of a single client, but on the decision-making choice of one subject under other influences. Besides, the mechanism proposed in this thesis has not been applied to reality, it is difficult to obtain secondary data. Therefore, statistically based research methods are also not applicable here. Taking all the influencing factors into account, in order to study the interrelationship between various decision variables, the application of a programming-based approach may be a rational choice when this thesis is intended to use mathematical modeling to study problems.

3.4 Type of research

Next, the type of research in this thesis will be clarified based on the four classification principles of research type proposed by Collis et al. (2007, p.3). It should be noted that when Collis et al. (2007) summarized all the research methods, almost no study of mathematical modeling based on operations research was considered, and the quantitative research was mainly based on statistics or econometrics. Therefore, the mathematical modeling approach applied in this thesis may not be 100% fitted into the following categories. The significance of this section is to give readers a better understanding of the methodology used in this thesis in multiple classification discussions.

3.4.1 Purpose of research

The types of research under this classification include explanatory, descriptive, analytical and predictive (Collis et al., 2007, p. 4).

This classification means the reason for this study. This thesis might be considered as a predictive research. Collis et al. (2007, p.5) defines a predictive research as a study of why certain situation occur and provides a method for predicting the probability of similar occurrences. This thesis simulates the process of LSP and client interaction through mathematical modeling. Based on the above process, the mechanisms that can improve flexibility and profitability is derived. Therefore, the mechanism in this thesis is designed to respond to clients' choices under different conditions.

3.4.2 Process of research

The types of research under this classification include quantitative research and qualitative research (Collis et al., 2007, p. 5).

Collis et al. (2007, p. 5) define quantitative studies as the collection of quantitative data and analysis using statistical methods. Although the above quantitative study method has not been adopted, this thesis still defines itself as a quantitative study because this thesis is mainly based on mathematical modeling methods.

This thesis redefines the logistics flexibility in special context through literature review, but this thesis does not define this part as qualitative research. The purpose of redefinition is to facilitate subsequent mathematical modeling. A vague definition will weaken the validity of the model. The definition of logistics flexibility in this thesis successfully linked two optimization goals (service flexibility and social welfare). However, if it is based on the criteria of qualitative research, the process of its argument may not be rigorous enough. Therefore, this thesis defines itself as a quantitative study.

3.4.3 Outcome of research

The types of research under this classification include applied research and qualitative research (Collis et al., 2007, p. 6).

Collis et al. (2007, p. 6) define applied research as a study to solve a specific problem. As mentioned above, the operation mode and pricing mechanism proposed in this thesis are applicable to multi-stage logistics services. It can therefore be classified as applied research.

3.4.4 Logic of research

The types of research under this classification include deductive research and inductive research (Collis et al., 2007, p. 7).

Collis et al. (2007, p. 7) believe that the characteristics of deductive research range from general to special. This thesis applies mathematical modeling based on operational research and auction theory, and then derives a pricing mechanism that can be applied to multi-stage transportation. Therefore, this thesis is a deductive research.

3.5 Principles of auction mechanism design

In this thesis, a new operation mode and corresponding pricing mechanism are designed. There two stages in the design, in first stage, clients need choose the services level based on their own situation, then they can adjust the services level in second stage which makes second stage a dynamic pricing process. The core of the dynamic pricing mechanism is the auction mechanism to induce client to join in the services customization (second stage).

The auction mechanism is mainly based the M-MDA method proposed by Cheng et al. (2016), which is derived from padding method (Chu, 2009). What Chu (2009) studies is how design auction mechanism for buyer with indivisible bids for multiple type commodities, then Cheng et al. (2016) give their contribution in give the commodities multiple features. In this thesis, the departure priority of the cargos at a certain depot can be regarded as cargos with multiple attributes (such as destination and departure time) which is reason why M-MDA can be applied in the model.

Here an introduction to the four principles of auction mechanism design is given:
Allocative efficiency (AE) means the maximizing the social welfare.

Individual rationality (IR) and **incentive compatibility (IC)** are two important concepts in auction mechanism design.

In the mechanism design, when an **Agent A** participates in the auction and the utility obtained is not less than when **A** does not participate (**A** has understood personal valuation for the auction item), this mechanism can be considered as **individual-rational**. The agent represents individuals who may be involved in the auction. A mechanism is incentive-compatible, and if **Agent A** acts according to personal real situation (preference), then **A** can obtain optimal results. In the auction, a Bayesian Nash equilibrium can be formed in the **incentive-compatible mechanism**, and all the **Agents** can obtain the best results by revealing their real situation.

Budget balance (BB) means the trade is not going on when there is budget deficit. However, even a mechanism with all above features is great, Myerson et al. (1983) prove its impossible to build a mechanism that can have AE, IR, BB simultaneously in two-sided market.

Here are two important concepts need to be introduced, one of which is the Padding Method.

Chu (2009) proposes this approach in order to deal with potential budget deficits when applying some truthful mechanism. The idea behind this approach is to assume that there is a virtual competitor in a market with countless budgets. The competitor only has a preference for certain commodity. After competitor exchange a certain commodity. The equilibrium price of this commodity rises slightly (demand curve shift to the right). If the buying price is kept at this level, the transaction volume will decrease slightly, and the selling price at this time will also fall. Therefore, by using this method, a gap (budget surplus) is formed, as shown in Figure 3.3.

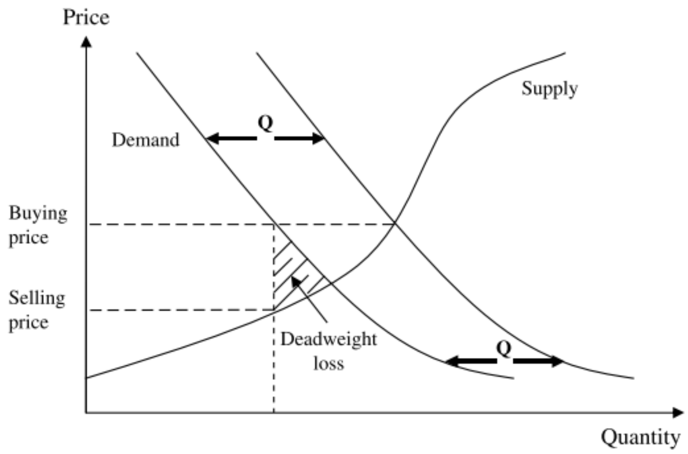

Figure 3.3 Padding in an Atomless Market (Chu, 2009, p.1187)

The other is the Vickrey–Clarke–Groves (VCG) auction (Vickrey,1961 Clarke,1971; Groves, 1973).

The VCG auction is a sealed auction mechanism in which bidders only know their own valuations and do not know the valuations of others. This mechanism can motivate everyone to bid according to their actual valuation. In this mechanism, the actual price paid by the winner is the damage it causes to other bidders.

The main reason for introducing the above two concepts is that the matching method used in the second stage of this mechanism is based on the above two concepts

3.6 Data collection

There are two main analysis processes in this thesis:

(1) When defining the logistics flexibility in the context of this thesis, a review of past research related to "flexibility" was conducted. In this process, many published documents have been read and quoted.
(2) When forming and answering the second research question, reference was made to

many reports published by the internet and news companies. The information obtained from it is used to form the assumptions in the modeling in this thesis. In addition, some mathematical modeling research methods related to this thesis have also been applied to this thesis. These knowledges are obtained from published literature or books.

Therefore, it can be considered that the research in this thesis has applied second-hand data. According to the definition of Collis et al. (2007, p. 59), the secondary data is data obtained from existing resources such as publications, databases, and network resources.

Since this thesis does not use interviews to collect primary data, it does not use statistical or econometric methods to analyze data from certain databases. Therefore, this thesis will not discuss too much on the "data collection" process in this section.

3.7 Validity, reliability, generalizability

In this section, the reliability and validity of this thesis will be explained. The definitions of reliability, validity and generalizability refer to the Collis et al. (2007, p. 52-54).

3.7.1 Validity

Validity refers to whether the measurement in the study is consistent with what the investigator intends to measure (Collis et al., 2007, p. 53).

The research method of mathematical modeling is to describe the problems in reality in a simple mathematical language. Convert some of these key features into elements of the model such as assumptions, constraints, and decision variables.

In this thesis, some assumptions were applied. For example, the rational people assumes that the subjects involved in the model are rational individuals. Rational people clearly understand their own preferences in the state of complete information, have a strong computing power, and aim at maximizing their own interests. These assumptions may not be able to 100% restore the characteristics of real individual clients (on the other hand, corporate clients may be more in line with these characteristics). However, as mentioned above, the purpose of mathematical modeling research was not to completely simulate reality, but to extract key elements and understand their relationship.

In the second stage of the auction, the M-MDA used in this thesis can promote honest bidding. Therefore, the mechanism proposed in this thesis is a relational analysis tool that can be used to understand the influence of the LSP on the client's decisions in the interaction process.

There are some abstract parameters in mathematical modeling, such as the client’s time utility preference coefficient, which are considered to be known in the model. Although the LSP may not be able to fully understand all client preferences and formulate appropriate strategies. However, the LSP can get some characteristics of client groups to a certain extent through the analysis of historical data. Combining these features with the analysis framework of this thesis may yield some valuable management implications.

Although the study in this thesis does not completely simulate all the details in reality, it has studied the interactions between some major factors. Therefore, it can be considered that the mechanism in this thesis has a certain degree of validity.

3.7.2 Reliability

Reliability refers to whether the measurement method used in the study is accurate and whether the same result be obtained when the study is repeated (Collis et al., 2007, p. 52). In mathematical modeling research, all conclusions are based on mathematical proofs. Therefore, the mechanism and conclusions of this thesis has a certain degree of confidence in maintaining the delimitation of this thesis.

3.7.3 Generalizability

Universality refers to whether the conclusions in this study are applicable in other studies (Collis et al., 2007, p. 54). As mentioned above, mathematical modeling research summarizes some of the major features of reality and studies their relationships. In the delimitation of this thesis, the mechanism and conclusions proposed in this thesis are applicable to multi-stage transportation services, including corporate clients sector, individual consumers sector, and passenger transportation sector and freight transportation sector.

Of course, for specific application scenarios, some minor adjustments need to be made under the framework of this thesis. Therefore, it can be considered that within the delimitation of this thesis, the mechanism and conclusions in this thesis have certain generalizability in multi-stage transportation services.

3.8 Delimitation

This thesis mainly has four aspects of delimitation. The first is that this thesis abstracts the concept of "capacity" into an abstract parameter. This is to better highlight this feature. Therefore, it does not adopt a more realistic description method such as volume or weight. In addition, because the packing problem itself is an NP-hard problem (The nondeterministic polynomial time (NP) problem is a set of problems that can be verified by the deterministic polynomial-time algorithm to correct the solution. NP-hard means at least as difficult as the NP problem. If an algorithm can be used to solve NP-hard problems, then it can be used to solve any NP problem.). If the specific parameters of volume, weight, and shape are introduced in the concept of capacity, the problems will be complicated and the focus of this thesis will be distracted.

Another delimitation of this thesis is that it does not consider the time of transportation. Because once the cargos leave the current depot, the time to reach the next depot is determined. Therefore, this thesis focuses only on the waiting time of the cargos at the node. This approach is also due to the desire to focus the research on the decisions made when the cargos arrive at each logistics depot.

The third delimitation it this study does not consider the competition between LSPs, although there may be multiple LSPs in the same region in reality. This thesis focuses on the introduction of the second stage of the dynamic pricing mechanism, can improve the flexibility of the service and the benefits of LSP. In the first stage, the initial price chosen by the client is still based on the price calculated by cost accounting, which is consistent with the current LSP pricing method. Therefore, clients who choose the LSP in the first stage will not be affected by this mechanism. Therefore, this thesis does not consider the competition among LSPs.

The final delimitation is this thesis simply defines different levels of service as departure priorities (different waiting times at depot), but in reality, the situation may be different. For example, the actual departure priority may be more flexible, and different levels of service may not use the same transportation tool (truck or plane). Therefore, this thesis only considers how the different levels of service under the same traffic mode are adjusted in the second stage.

4. Model establishment

This section first describes the problem studied in this thesis. A comprehensive analysis was then performed to obtain all the hypotheses in the context of this thesis. Finally, mathematical modeling will be carried out for the two stages of the pricing mechanism in this thesis (model establishment in the heading refers to the process of describing problems, analyzing problems, and establishing mathematical models).

4.1 Problem description

In traditional transport services pricing problem, the focus point is how to set (static) price standard and make clients choose the services which maximize LSPs' profit (Kunkel et al., 2011; Haller et al., 2012; Ke et al., 2014; Cachon et al., 2015; Borsenberger et al., 2016; Jauhari et al., 2016; Vega et al., 2017; Donder et al., 2018; Ke et al., 2018). LSPs realize that differentiated product strategies can be used to differentiate between high value-added and low value-added requirements. However, the flexibility of services can be further improved. The approach of this thesis is to allow clients to modify the service level after determining the initial service level.

Clients are not static subjects and their timeliness requirements for logistics services may change. To the best knowledge, the current LSPs do not provide strategies for responding to changes in client timeliness requirement. This makes it impossible to modify the service levels that were initially determined.

At present, the service mode provided by LSPs is usually to provide clients with different timeliness service, and different service levels correspond to prices that related to freight volume. When the client selects a specific service level that corresponds to a specific delivery time range, the cargos may reach terminal at any time within this time range. Another problem with such an operation mode and pricing mechanism is that the **processing capacity** of the logistics system **cannot be increased simultaneously** when the **demand explodes** (subjected to the cost factor), the actual service level of the entire system will be affected. This is the main reason for the large-scale delay in the Chinese logistics market in early 2017 (Wataru, 2018).

In fact, when the service level is initially determined, the ability of the mechanism to further distinguish the client is limited since the logistics service is not a customized service. Therefore, in the design of this thesis, LSP allows clients to adjust the service level in transit. This **adjustment** may be due to **sudden changes** in the client's timeliness requirements, or it may be due to the client's **better understanding of their own needs** by that time. In this thesis, the LSP gives the system more flexibility by offering clients second (or even more) chance to change their timeliness requirement for services. In the meantime, LSPs might also gain their profitability.

Another reason why using such an optimization strategy is that, as mentioned before, transportation process studied in this thesis is not terminal distribution, but trunk transportation. Mature LSPs have a relatively stable transport network. The LSPs are not likely to change the vehicle routes frequently, which means the optimization measure used in pickup and delivery problem (Yang et al., 2004; Srour et al., 2014; Cherkesly et al., 2016; Ghilas et al., 2016; Iassinovskaia et al. 2016; Li et al., 2016; Mahmoudi et al., 2016; Veenstra et al., 2017) is not applicable in such situation. Therefore, the core of strategy proposed in this thesis can be considered as **the capacity transfer mechanism** between clients. The timeliness of events discussed in this study is shown in Figure 4.1.

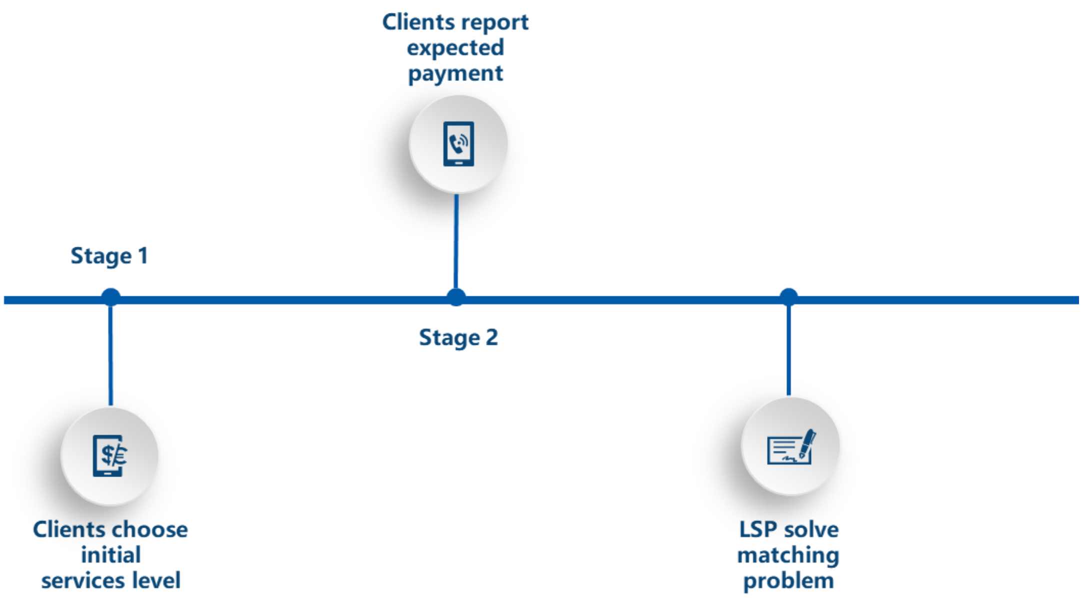

Figure 4.1 Timeliness of events

One gap this thesis wants to fill is that **prior literature usually considers clients' type (timeliness requirement) constant** (Li et al., 1994; Borsenberger et al., 2014; Castillo et al., 2016; Chen, 2016; Bellos et al., 2017; Guda et al., 2017; Kostami et al., 2017; Ma et al., 2017). There are few papers discuss that the opportunity cost caused by timeliness requirement change which might be worth to optimize. Even if the reserved utility of the clients in the market meets a certain distribution function, they can still be regarded as deterministic, since the characteristics of a certain client will not change in the later period of analysis.

An example is given here to explain the situation in the thesis that Clients' timeliness requirement of services might change. When the client initially purchases logistics services, it takes a relatively long time to deliver and the client does not have sufficient understanding of their own needs. As delivery times approach, new events may emerge, allowing clients to **update their beliefs about their own needs**. Clients may suddenly need to get their parcels faster. Therefore, they hope to increase service levels by paying extra fees. Assuming there is a limit to the **capacity (K)** that can be transported each time between 2 depots, and the proportion of the capacity occupied by the cargo is different (different in weight/volume). The service price is positively related to the capacity of the cargo might occupied. **Client A(B)'s** cargos occupy a part of the capacity less than K. The cargos of **client A and client B** arrive at depot H in the same period. According to the initial service level, **B's cargo** leaves at **t=1** and **A's cargo** leaves at **t=2**. Client **A** can exchange the departure order with B by **paying an additional fee**. If the exchange is successful, **B** will get a **compensation** (price discount). The above process is shown in Figure 4.2. In this example, **A is defined as buyer** and **B is seller**.

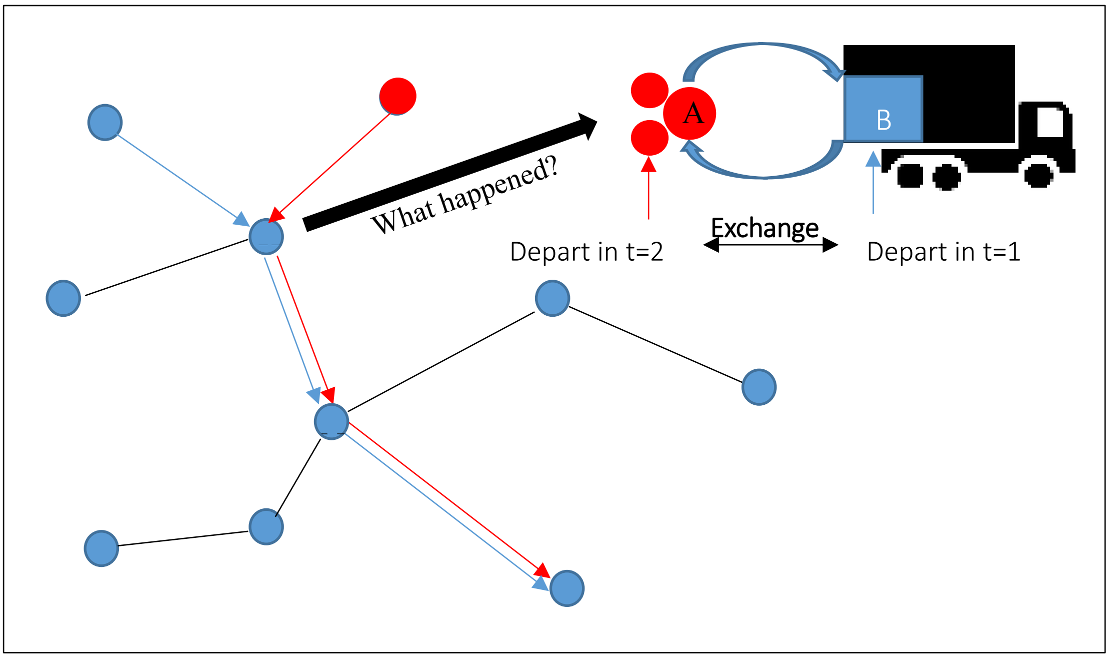

Figure 4.2 Exchange example

The above example is only for a brief description of what happened in the second stage. In actual operation, there will be multiple "buyers" and "sellers" who will submit their price, that is, how much they are willing to pay(get) for exchange. Therefore, in the process of this auction, the task of the LSP is to complete the matching of the supply and demand sides and to maximize their own revenue.

From the above description, it is worth mentioning that although this thesis studies the traditional market (unilateral market), it has some characteristics of the two-sided market, that is, clients get a set of capacity will depart at each depot in specific time when they book the services. Such capacity, can be considered as one kind of resource they have and they can use it maximize they utility. In this process, LSPs need to find the optimal combination of two parties, which is similar to the "matching" research in the study of the sharing economy (Hu et al., 2016&2017; Zhou et al., 2017). In the study of sharing economy, such as research about taxi-hailing application Uber, the purpose of "matching" is to match passengers and vehicles. In the context of this thesis, auctioneers (LSPs) provide a platform that allows clients to trade by using their perishable resources (the capacity that can be shipped at a particular time). There is still an example in Figure 4.2 to explain that when client A purchases services, it is equivalent to purchase a set of tradable cargos (from H to N, t=2, the capacity is 3; from B to a next depot, t=4, the capacity is 3, etc.). Because the cargos will pass through multiple depots, and exchanges may occur at any depots. Therefore, even if clients do not trade at point H, they may also trade at subsequent depots.

Comparing to the research about sharing economy, the difference is that this thesis does not subject to strong time constraints for completing "matches". Since the LSP only need to match the two parties in each cycle (for example, every day). The extra price paid by the **A** to the LSP and the price discount provided by the LSP to the **B** are similar to the price paid by the client in the two-sided market and the salary provided to the supplier. The mechanism in this thesis only needs to summarize the supply and demand information in the current cycle, and then complete the matching and decide the next cycle delivery order.

Next, a summary of the assumptions in the research context of this thesis is given:

(1) Assuming there is a mature LSP with a definite transport network. There is a single

path between any two depots. For example, cargos with different starting depots and ending depots in different provinces need to be transported from low-level logistics depot (city level) to provincial-level depot first, then to another provincial-level depot, and then to low-level logistics depot.

(2) The LSP receives vehicles in all directions at fixed times every day, and then sends out vehicles in all directions. The vehicle departs in time q from depot n to depot n' with capacity $K^{q}_{(n,n')}$.

(3) Since any two depots in the network have a definite path and there are certain transit times between the depots, this means that once the cargos are sent from depot n, they will definitely arrive at depot n' within a certain time. Therefore, this thesis will ignore all the constraints arising from the "transportation" section and focus only on how the capacity K sent out in a certain direction (such as $n - n'$) is used. Because the differentiated service time is related to the time the cargo stays at the depot, it has nothing to do with the transport time.

Therefore, the entire logistics service process can be described as follows:

(1) In stage 1, client i chooses the services level according to the private information a^{0}_{i} and b^{0}_{i}, the initial price is $P_i(T_i, k_i)$ which depends on the cargo volume and services level S. The price and service level are not necessarily linearly related. Different services level has different delivery time range $[\widehat{T^{s}_{i}}, \widetilde{T^{s}_{i}}]$, the probability of arrival of express mail is evenly distributed in the range of $[\widehat{T^{s}_{i}}, \widetilde{T^{s}_{i}}]$.

(2) In stage 2, clients who want to be “seller” or “buyer” submit their requests for modifying their service level and the payment e^{i} they accept (buyers’ a^{0}_{i} and b^{0}_{i} changed into a^{1}_{i} and b^{1}_{i} which means their timeliness preference might change).

(3) The LSP completes the matching of both parties.

(4) After the transaction is successful, the cargo of buyer (the client who initially chose the low-level service) will depart at the time originally belonging to the seller (the client who chose relatively high-level service), and enjoys a high level of service at

each subsequent depot. Correspondingly, the seller enjoys a low level of service at this depot, but still enjoys a high level of service at rest depots.

This design is mainly to increase the profitability of the platform, because both parties will honestly report their expected payments if the mechanism can prevent dishonest bidding. Buyers will pay relatively more money for the remaining services to become high-level services. The seller's payment to make up for the lost effect will be relatively small (because only the current phase of the service becomes a low-level service). As shown in Figure 4.3, buyer and seller participate in the exchange by submitting bids (prices) to the LSP. The LSP then informs both parties of the matching result.

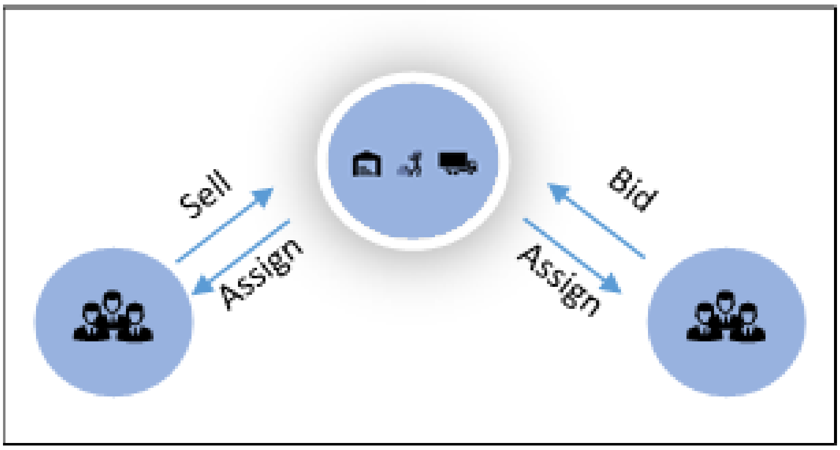

Figure 4.3 Interaction mechanism

This thesis was initially inspired by the plight of LSPs in the real world as mentioned in Chapter 1. Later, in the process of retrieving related literature, this thesis was inspired by the work of Lai et al. (2017). Although the content of literature and this thesis are not essentially the same (the former is essentially a Pickup and delivery problem, but this thesis is closer to the boxing problem). Lai et al. (2017) apply auction methods to solve the matching problem between the two parties. However, in Lai et al. (2017)'s design, the "commodities" traded between different carriers are transportation tasks, such as transportation task from depot H to depot N, and therefore such optimization method can be considered as based on "line/link perspective." In this thesis, the seller and buyers are both clients of LSP, the optimization method is based on "point/depot perspective" since the focus point of optimization strategy is the departure order of cargo at each depot.

The interaction process between the client and the LSP can be divided into two stages. In the first stage, the client determines the optimal service level required by solving the client problem (CP) refers to the zero-one programming problem (one kind of integer programming problem where the decision variable is 0 or 1) for clients.

Stage 1

Client problem (CP)

$$\mathrm{Max}\,U_i^*(L_i) = a_i^0 T_i^2 + b_i^0 T_i - P_i^L(T_i, k_i)\cdot \rho_i^L - P_i^H(T_i, k_i)\cdot \rho_i^H \quad (1)$$

$$\text{s.t. } \widehat{T_i^L} \le T_i \le \widetilde{T_i^L} \quad \forall i \in G, \rho_i^L = 1 \quad (2)$$

$$\widehat{T_i^H} \le T_i \le \widetilde{T_i^H} \quad \forall i \in G, \rho_i^H = 1 \quad (3)$$

$$T_i = \sum_{n\in N} t_n^i \cdot x_n^i,\ t_n^i = w_n^S \ \ \forall i \in G, \rho_i^S = 1 \quad (4)$$

$$x_n^i = \begin{cases} 1 & \text{if } t_n^i \in L_i; \\ 0 & \text{otherwise;} \end{cases} \quad (5)$$

$$\rho_i^L + \rho_i^H = 1 \quad \forall i \in G \quad (6)$$

$$\rho_i^L = \left\{0,\ \ 1\right\} \quad \forall i \in G \quad (7)$$

$$\rho_i^H = \left\{0,\ \ 1\right\} \quad \forall i \in G \quad (8)$$

$$S = \{H, L\} \quad (9)$$

$$t_n^i \ge 0 \ \ \forall i \in G, n \in N \quad (10)$$

$$T_i, b_i^0, P_i, k_i, \widetilde{T_i^s}, \widehat{T_i^s} > 0 \ \ a_i^0 < 0 \ \ \forall i \in G \quad (11)$$

Table 4.1

Notations		Meaning
Sets	L_i	The set of time span of each depots client i's cargo will stay,

		L_i:={t^i_O, … , t^i_n, … , t^i_D}
	W^L_n	The set of time span of cargo stay at each depot in low-level service, W^L_n:={w^L_1, … , w^L_n, … , w^L_N}
	W^H_n	The set of time span of cargo stay at each depot in high-level service, W^L_n:={w^L_1, … , w^L_n, … , w^L_N}
	N	The set of depots, n= {1, 2, …, N}
	G	The set of clients, g= {1, 2, …, G}
Clients' characteristic	a^0_i, b^0_i	Client i's preference of timeliness in stage 1
	a^1_i, b^1_i	Client i's preference of timeliness in stage 2
	t^i_n	Time span of each depots client i's cargo will stay
	x^i_n	Variable indicates whether client i's cargo will pass Depot n
	w^L_n	Time span of cargo stay at each depot in low-level service
	w^H_n	Time span of cargo stay at each depot in high-level service
	k_i	Client i's cargo capacity
	T_i	Client i's total transport time span according to selected service level
Decision variables	ρ^L_i	Variable indicates whether client i choose Low-level service
	ρ^H_i	Variable indicates whether client i choose High-level service
Other variables	P^S_i	The price for logistics service according to the service level, S= {H, L}
	$\widehat{T_i^S}$	Variable indicates the lower bound of total transport time span according to corresponding service level, S= {H, L}
	$\widetilde{T_i^S}$	Variable indicates the upper bound of total transport time span according to corresponding service level, S= {H, L}

The objective function is maximizing **client i**'s utility. The objective function here shows there are a negative relationship between utility and price. $\widehat{T_i^S}$ is the lower bound of client i's time requirement, while $\widetilde{T_i^S}$ is the upper-bound. Constraint (2) means the total services time is within the time range of certain service level which prevent LSP from break commitment to the services level. $\mathbf{t_n^i}$ means how long clients i's cargo stay in depot n. N is set of the depots in network and G is the set of clients. Since the transport time between two depots is constant, time used on transport will only ignore the and emphasize will be put on the time cargo keep in each depot. $\mathrm{k_i}$ is the capacity occupied by i's cargo.

Define $\mathrm{U_i T}$=$\mathrm{U_i^*(L_i) = a_i^0 T_i^2 + b_i^0 T_i}$ as the **timeliness utility** of client i and $\mathrm{P_i}$ as price utility.

Set the client's timeliness utility function as unary quadratic function that takes transit time as an "independent variable". For the client, the cargo arrive at a particular period may produce optimal efficiency. The cargos that delivered prematurely might cause lower utility since the client cannot receive the cargos normally (for example, there is no inventory space). The late delivery of the cargos is faced with a similar problem, it may have missed the opportunity for the cargos to produce maximum utility (for corporate clients, the peak production period may have passed; for individual clients, they may receive gifts after birthday.) Therefore, the main reason why this thesis set this up is the following characteristics. Even if do not consider the impact of price, for the client, the fast transport does not necessarily bring the highest utility. Therefore, setting the utility function to this form seems more logical: the function is optimal at a certain point in time (phase). Being too early or too late will lead to a reduction in utility. As mentioned above, there may be an optimal timing of arrival which is depends on clients' preference of timeliness and this thesis use two parameters to describe them as a_i^0, b_i^0.

Example 1

Here, using an example to illustrate client decision making in stage 1.

Assume that there is a client i whose initial time utility coefficient is $a_i^0 = -1, b_i^0 = 16$. Client **i** has a batch of cargos to be transported from Depot 3 to Depot 6. There are 5 depots on the path from Depot 3 to Depot 6. If **i** chooses a low-level service (ρ_i^L), **i** needs to pay 15 now (P_i^L=15), and the guaranteed waiting time is 9 to 11 days (($\widehat{T_i^L}, \widetilde{T_i^L}$)). If **i** chooses a high-level service (ρ_i^H), **i** needs to pay 27 (P_i^L=27), and the guaranteed waiting time is 4 to 6 days (($\widehat{T_i^H}, \widetilde{T_i^H}$)).

At this point, the purpose of the client is to maximize the utility.

The optimal timing for client i is $T_i = -\frac{b_i^0}{2 \cdot a_i^0} = -\frac{20}{-2 \cdot 1} = 10$ ($T_i = -\frac{b_i^0}{2 \cdot a_i^0}$ is the value of the independent variable when the unary quadratic function takes the maximum value). In such condition, if client i chooses high-level service, the expected total utility is (-1) $*(10)^2$+(20) *(10)-27=73 ($U_i^H(L_i) = a_i^0 T_i^2 + b_i^0 T_i - P_i^H(T_i, k_i) \cdot \rho_i^H$). If client i chooses low-level service, the expected total utility is $(-1) * (5)^2 + (20) * (5) - 15 = 60$ ($U_i^L(L_i) = a_i^0 T_i^2 + b_i^0 T_i - P_i^L(T_i, k_i) \cdot \rho_i^L$). The possibility of cargo arrive timing is evenly distributed on each guaranteed time range, and that is the reason why client uses expected timing 10 and 5 as T_i here.

Therefore, as a rational client, client i should choose high-level services for a higher utility.

In second stage, every client that wants to change their service level will submit the bids including the expected payment.

Stage 2

For client that wants to be "buyer", the expected payment is

$$e^i = \begin{cases} -\frac{(b_i^1)^2}{4a_i^1} - a_i^1 T_i^2 - b_i^1 T_i & \text{if } \emptyset < -\frac{b_i^1}{2a_i^1}; \\ \{a_i^1 \emptyset_i^2 + b_i^1 \emptyset_i - a_i^1 T_i^2 - b_i^1 T_i, 0\}^+ & \text{otherwise}; \end{cases} \tag{12}$$

Where $\emptyset = t_{(O,n)}^i - t_O^i + t_{(n,D)}^H$

Proof in Appendix A.

Table 4.2

Notations		Meaning
Variables	$\emptyset$	The time span that cargo transform starting depot O to terminal if switch the service
	t_O^i	The time when i's cargos departed from the starting depot
	$t_{(O,n)}^i$	The time when i's cargos arrive at Depot n according to current service level
	$t_{(n,D)}^H$	The time span that cargo transport from Depot n to destination according to High-level services

When the client's timeliness requirements change, if all subsequent services convert to high-level allow clients to achieve greater utility, clients have the incentive to pay money equal to such utility. If the theoretical arrival time is shorter than the theoretical optimal time after the service is changed, the client will still pay according to the optimal time efficiency. In actual transportation, unforeseen circumstances may cause delay. Therefore, by changing the service level, clients may receive the cargos at the optimal timing.

For client that wants to be "seller", the expected payment is

$$e^i = \begin{cases} -(a_i^1 T_i^2 + b_i^1 T_i - a_i^1 ð_i^2 - b_i^1 ð_i) & \text{if seller i decide to sell the capacity}; \\ -\infty & \text{otherwise}; \end{cases} \tag{13}$$

Where $ð = T_i + w_n^L - w_n^H$

Proof in Appendix A.

According to assumption of rational person, sellers have an incentive to join the exchange if they obtain the money to make up for the losses they have received at this stage. Note that the seller's expected payment here is negative, and in fact they will get a positive payment. The reason for this setting is to facilitate the writing of the formula behind.

As mentioned above, when client trade their held capacity, this resource become commodities. Therefore, when considering matching the buyer's and seller's needs, referring to the previous research on the auction mechanism of the product become one option. The formation in second stage of this thesis is inspired by Cheng et al. (2016).

Similar to problem in this thesis, Cheng et al. (2016) also discuss how to design polynomial time exchange mechanism to solve the mixed integer program (MIP) to maximize social welfare in their paper.

The logistics services provider problem (LSPP) can be seen as a special application of Cheng et al. (2016)'s MIP. Now show their model of Mixed integer program (MIP) as following:

Mixed integer program (MIP)

$$\text{Max } \prod^{*}(\mathrm{V},\mathrm{F}) = \sum_{\mathrm{v}\in\mathrm{V}} b^{v}\xi^{v} + \sum_{\mathrm{f}\in\mathrm{F}} \mu^{f}\eta^{f} \quad (*1)$$

$$\text{s.t.} \quad \sum_{\mathrm{f}\in\mathrm{F}} \alpha_{\mathrm{vf}} = Y^{v}\xi^{v} \quad \forall \mathrm{v} \in \mathrm{V} \quad (*2)$$

$$\sum_{\mathrm{v}\in\mathrm{V}} \alpha_{\mathrm{vf}} = \eta^{f} \quad \forall \mathrm{f} \in \mathrm{F} \quad (*3)$$

$$0 \leq \alpha_{\mathrm{vf}} \leq X^{f} Z^{vf} \quad \forall \mathrm{f} \in \mathrm{F}, \forall \mathrm{v} \in \mathrm{V} \quad (*4)$$

$$\xi^{v} \in \{0,1\} \quad \forall \mathrm{v} \in \mathrm{V} \quad (*5)$$

$$0 \leq \eta^{f} \leq X^{f} \quad \forall \mathrm{f} \in \mathrm{F} \quad (*6)$$

$$\eta^{f} \in \mathbb{Z} \quad \forall \mathrm{f} \in \mathrm{F} \quad (*7)$$

Table 4.3

Notations		Meaning
Sets	F	The set of sellers
	V	The set of buyers
variables	b^v	The variable indicating buyer v's expected payment
	ξ^v	The variable indicating whether buyer v participated in the transaction
	μ^f	The variable indicating seller f's expected payment
	η^f	The variable indicating quantity that seller f sells
	α_{vf}	Capacity buyer v got from seller f
	X^f	The capacity that seller f has.
	Y^v	The capacity that buyer v needs.
	Z^{vf}	The variable indicating whether if seller f fulfills buyer v's requirement about (direction and time)

MIP want to maximize the social welfare. The social welfare mentioned here is the sum of the clients' utility and the auctioneer's payoff. Constraint (*2) means the total capacity buyer v acquire in the transaction ($\sum_{\mathrm{f\in F}} \alpha_{\mathrm{vf}}$) should equal to the total capacity that v needs (Y^v). Constraint (*3) means the total capacity **seller f** sell in all the transaction ($\sum_{\mathrm{v\in V}} \alpha_{\mathrm{vf}}$) should equal to the total capacity **f** sells (η^f). Constraint (*4) means the two parties can trade if the requirement is fulfilled (Z^{vf}). In the case of this thesis, there are three conditions that need to be satisfied: the current depot where the cargos are located, the next depot that transits, and the departure time at the current depot. According to Cheng et al. (2016), the first two conditions are "hard constraints" in the form of "equal to" notation. The third condition is a soft constraint, that is, the form is an inequality. For buyer, they will only exchange with sellers who leave earlier. Constraint (*5) means ξ^v is a binary variable indicating if buyer join in the transaction ($\xi^v = 1$). Constraint (*6) means the quantity seller f sell η^f cannot beyond total capacity that f has X^f.

Now the model of second stage is given with the consideration about the other terms about the income and cost of LSP. The constraint (*2) - (*6) in MIP is the constraint (18) - (22) in LSPP.

Logistics services provider problem (LSPP)

$$\text{Max} \quad \prod^{*}(\mathrm{V},\mathrm{F},\mathrm{C_n^h}) = \sum_{i\in G}\mathrm{P_i}(\mathrm{T_n^i},\mathrm{k_i}) - \sum_{i\in G}\sum_{n\in N}\mathrm{k_i}\cdot\mathrm{C_n^h}\cdot\mathrm{t_n^i} + \sum_{v\in V} b^{v}\xi^{v} + \sum_{f\in F}\mu^{f}\eta^{f} \quad (14)$$

$$\text{s.t.} \ \sum_{i\in G}\mathrm{k_i}\cdot \mathrm{z}_{(n,n')}^{\varpi,i} \leq \mathrm{K}_{(n,n')}^{\varpi} \quad \forall i\in G, n\in N, n'\in N \quad (15)$$

$$T_i = \sum_{n\in N}\mathrm{t_n^i}\cdot \mathrm{x_n^i} \quad \forall i\in G \quad (16)$$

$$\mathrm{z}_{(n,n')}^{\varpi,i} = \begin{cases} 1 & \text{if } \varpi = \mathrm{t}_{(O,n)}^{i} + \mathrm{t_n^i}, \text{next stop for i is } n'; \\ 0 & \text{otherwise}; \end{cases} \quad (17)$$

$$\sum_{f\in F}\alpha_{vf} = Y^{v}\xi^{v} \quad \forall v\in V \quad (18)$$

$$\sum_{v\in V}\alpha_{vf} = \eta^{f} \quad \forall f\in F \quad (19)$$

$$0\leq \alpha_{vf} \leq X^{f}Z^{vf} \quad \forall f\in F, \forall v\in V \quad (20)$$

$$\xi^{v}\in\{0,1\} \quad \forall v\in V \quad (21)$$

$$0\leq \eta^{f} \leq X^{f} \quad \forall f\in F \quad (22)$$

$$v\in V: =\{v=i|e^{i}>0\} \quad (23)$$

$$b^{v} = e^{v}, Y^{v} = \mathrm{k_v} \quad \forall v\in V \quad (24)$$

$$f\in F: =\{f=i|e^{i}<0\} \quad (25)$$

$$\mu^{f} = e^{f}, X^{f} = \mathrm{k_f} \quad \forall f\in F \quad (26)$$

$$\mathrm{t_n^i} \geq 0 \quad \forall i\in G, n\in N \quad (27)$$

$$\mathrm{P_i},\mathrm{k_i} > 0 \quad \forall i\in G \quad (28)$$

$$\mathrm{C_n^h} \geq 0 \quad \forall n\in N \quad (29)$$

Table 4.4

Notations	Meaning

Deterministic	C_n^h	The unit management cost of cargos stored at Depot n.
variables	$K_{(n,n')}^{\varpi}$	The maximize capacity can be transported from Depot n to Depot n' at time ϖ
Variables	$z_{(n,n')}^{\varpi,i}$	The i's will depart from n to n'at time q

The objective function of LSP is maximizing social welfare. Constraint (15) mean the cargo transport to certain route cannot exceed the transport capacity $K_{(n,n')}^{\varpi}$ in each unit time. $z_{(n,n')}^{\varpi,i}$ is a binary variable which equals 1 if i's cargo leave n to n' when absolute time $\varpi = t_{(O,n)}^{i}$ (the time clients i's cargo arrived at n) plus the time span cargo keeps in **Depot n** (t_n^i). Besides, the time span stay in depot will incur a unit manage cost C_n^h. Constraint (18) make sure transaction is successful only if the buyer got all capacity needed which means buyers' bid is indivisible. Constraint (19) indicate transaction will happen when **seller f** fulfills **buyer v**'s requirement (transport direction and time). Constraint (23) - (26) assign the seller and buyer identity to clients. Clients with positive expected payment are buyer according to constraint (23) and (24). Clients with negative expected payment are seller according to constraint (25) and (26). The difference between $z_{(n,n')}^{\varpi,i}$ and Z^{vf} is, the former indicates when and where the cargo will go, while the latter indicates whether two clients' $z_{(n,n')}^{\varpi,i}$ is consistent.

Remark 1

It is worth noting that the prices in the initial service are exogenous (in second stage) and are based on cost accounting and historical data. The reason why this thesis applies such initial price here is that the price based on cost accounting won't makes the profit of the LSP worth than current static pricing mechanism. Therefore, as long as the LSP can obtain positive returns in the subsequent exchange process, the profitability of the LSP is improved.

Example 2

Here introduces an example to illustrate the exchange problem.

Assuming six clients, three with high-level services and the other three with low level services. Their cargos arrive in same depot in same day and 5 of them have same next transit depot. Seller 3 cannot join the exchange since fail to meet the requirement. High-level services will wait in depot for 1 day while low-level will wait 2 days. Assuming all low-level buyers want to accelerate their parcel. **Buyer 1, 2** and **3** want capacity 1, 2, 3 with expected payment as 6, 7 and 8 respectively. Seller 1,2 have the same destination with them can provide 2 capacities respectively with expected payment as 4 and 6 respectively.

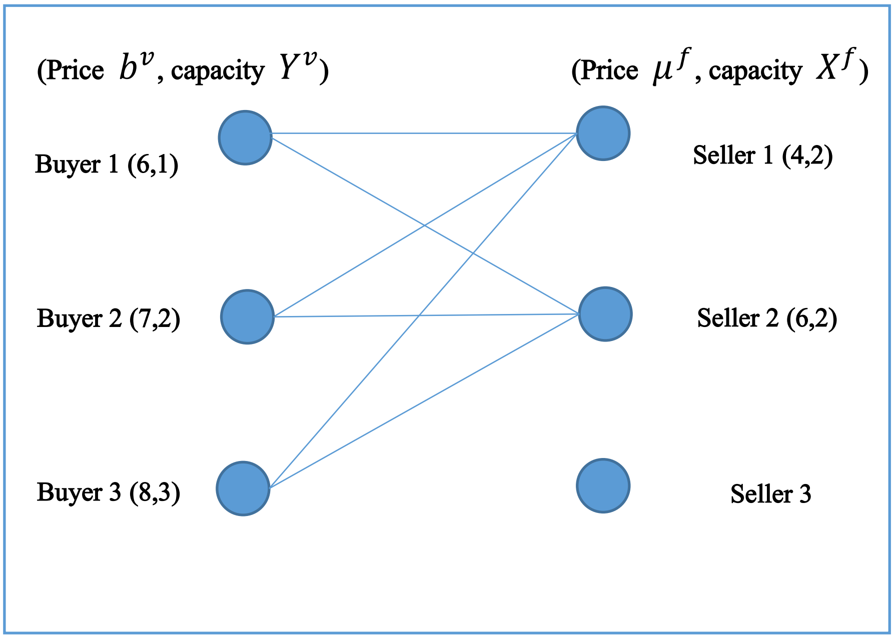

Figure 4.4 Exchange mechanism example

Now what LSP need to do is to match the **buyer 1, 2 and 3** and **seller 1 and 2**. The reason why seller 3 haven't been taken into account is seller 3's destination is not same with other 5 clients and they cannot trade.

Assuming LSP applies a mechanism can make all clients report their prices and LSP get all the surplus (which is impossible in reality, but such setting is applied in this example for simplicity). Since LSP wants to maximize social welfare, it can be easily found that the optimal solution is buyer 1 and 3 get all capacity they want and seller 1 and 2 sell their capacity and they will get their payment (use enumeration to list all possible scenarios). The profit of LSP is 6+8-4-6=4.

Such conclusion can be obtained by list every possible solution of this example. By directly solving the LSPP, it can be concluded that in this mode, the level of profitability of LSPs can be improved. However, due to the indivisible of the buyer's bids in the LSPP, the problem become an NP-hard problem (Sandholm et al., 2002). As the scale of problem increase, the time needed to calculate the results is enormous (exponential growth).

Remark 2

The objective function (14) in LSPP is the profit function of LSP, but here it can represent social welfare. The first part of the formula ($\sum_{\mathrm{i}\in\mathrm{G}} \mathrm{P_i}(\mathrm{T_n^i}, \mathrm{k_i})$) represents the revenue of the LSP under the framework of the first stage of service. The last part of the formula ($\sum_{\mathrm{v}\in\mathrm{V}} b^{\,v}\xi^{v} + \sum_{\mathrm{f}\in\mathrm{F}} \mu^{\,f}\eta^{f}$) represents revenue under the service framework of the second stage (both revenues are not net profits). Assuming all clients are honestly submitting prices and paying at the that prices, the additional utility of the client in the second stage is 0. This is because the LSP has obtained all the remaining. In this case, social welfare is maximized. Of course, if a proves Myerson et al. (1983) prove its that it is impossible to build mechanism in the bilateral market with AE, IR, BB simultaneously. Therefore, the LSP cannot obtain all the remaining.

As mentioned above, although solving the LSPP directly can maximize the benefits, this result is not feasible in practical decisions. Because there is no mechanism can make all clients to pay their full value. And the time cost of solving LSPP directly is high. Therefore, there is a need to apply an achievable method that enables clients to bid honestly and with high computational efficiency (achieve polynomial-time calculation). In next section, the mechanism based on M-MDA method proposed in Cheng et al. (2016) is applied.

4.2 The mechanism design problem

Since the original problem (LSPP) is an NP-hard problem, it's necessary to apply a more efficient auction mechanism.

Algorithm based on M-MDA mechanism

Stage 1

Input the variable

Clients decide initial services level

New event happens, part of client's timeliness preference changed

> **Stage 2**
>
> Clients choose whether to join the exchange and submit the bids
>
> According to clients' expected payment, assign them an identity
>
> Calculating the padding q= $((X^f)_{f\in F},\ (Y^v)_{v\in V})$ (proposed by Chu (2009))
>
> Solve LSPP-1
>
> Got new buyer set V^*, the set of buyers with $\xi^d = 1$. The padding vector for buyer d is $\boldsymbol{Q}_d = (Q_d^v)_{v\in V}$. Q_d^v=q when v=d; Q_d^v=0 otherwise
>
> **Solve LSPP-2**
>
> Got new buyer set V^{**}, the set of buyers with $\xi^v = 1$ is in the optimal solution to $\prod_N^{***}(\mathrm{L}, V^*, \mathrm{F}, \mathbf{Q}_\mathrm{d})$. The trading price for buyer d is $e_d^b(\mathrm{L}, V^*, \mathrm{F}, \mathbf{Q}_\mathrm{d})$ which is the infimum of bid price b^d when $\xi^d = 1$ is in the optimal solution to $\prod_N^{***}(\mathrm{L}, V^*, \mathrm{F}, \mathbf{Q}_\mathrm{d})$.
>
> Solve LSPP-3
>
> Got final results, then conduct trading according to the optimal solution of LSPP-3, the actual payoff of seller f is VCG payment,
>
> e_f^s=$\mu^f\eta^f + \prod_N^{**}(\mathrm{L}, V^{**}, \mathrm{F}) - \prod_N^{**}(\mathrm{L}, V^{**}, \mathrm{F}\backslash\mathrm{f})$

LLSP-1

Max $\prod_{N}^{**}(\mathrm{V},\mathrm{F},\mathrm{C}_{\mathrm{n}}^{\mathrm{h}}) = \sum_{\mathrm{i}\in\mathrm{G}} \mathrm{P_i}(\mathrm{T}_{\mathrm{n}}^{\mathrm{i}},\mathrm{k_i}) - \sum_{\mathrm{i}\in\mathrm{G}}\sum_{\mathrm{n}\in\mathrm{N}} \mathrm{k_i}\cdot\mathrm{C}_{\mathrm{n}}^{\mathrm{h}}\cdot\mathrm{t}_{\mathrm{n}}^{\mathrm{i}} + \sum_{\mathrm{v}\in\mathrm{V}} b^{\,v}\xi^{v} + \sum_{\mathrm{f}\in\mathrm{F}} \mu^{\,f}\eta^{f}$

St. Constraint (15)-(20), (22)-(29)

$$0 \le \xi^{v} \le 1, v \in V \qquad (30)$$

LSPP-2

Max $\prod_{N}^{***}(V^{*},\mathrm{F},\mathrm{C}_{\mathrm{n}}^{\mathrm{h}},\mathbf{Q}_{\mathrm{d}}) = \sum_{\mathrm{i}\in\mathrm{G}} \mathrm{P_i}(\mathrm{T}_{\mathrm{n}}^{\mathrm{i}},\mathrm{k_i}) - \sum_{\mathrm{i}\in\mathrm{G}}\sum_{\mathrm{n}\in\mathrm{N}} \mathrm{k_i}\cdot\mathrm{C}_{\mathrm{n}}^{\mathrm{h}}\cdot\mathrm{t}_{\mathrm{n}}^{\mathrm{i}} + \sum_{\mathrm{v}\in\mathrm{V}} b^{\,v}\xi^{v} + \sum_{\mathrm{f}\in\mathrm{F}} \mu^{\,f}\eta^{f}$

St. Constraint (15)-(17), (19), (20), (22)-(30)

$$\sum_{\mathrm{f}\in\mathrm{F}} \alpha_{\mathrm{vf}} = Y^{v}\xi^{v} + Q_{\mathrm{d}}^{v} \quad \forall \mathrm{v} \in \mathrm{V} \qquad (31)$$

LSPP-3

Max $\prod_{\mathrm{N}}^{***}(\mathrm{V}^{**},\mathrm{F},\mathrm{C}_{\mathrm{n}}^{\mathrm{h}}) = \sum_{\mathrm{i}\in\mathrm{G}} \mathrm{P_i}(\mathrm{T}_{\mathrm{n}}^{\mathrm{i}},\mathrm{k_i}) - \sum_{\mathrm{i}\in\mathrm{G}}\sum_{\mathrm{n}\in\mathrm{N}} \mathrm{k_i}\cdot\mathrm{C}_{\mathrm{n}}^{\mathrm{h}}\cdot\mathrm{t}_{\mathrm{n}}^{\mathrm{i}} + \sum_{\mathrm{v}\in\mathrm{V}} b^{\,v}\xi^{v} + \sum_{\mathrm{f}\in\mathrm{F}} \mu^{\,f}\eta^{f}$

St. Constraint (15)-(20), (22), (27)-(30)

Here, the M-MDA mechanism proposed by Cheng et al. (2016) in their paper satisfies the requirements perfectly. The main difference in the algorithm of this thesis is taking the other terms of income and cost into consideration. After applying the above method, truthful bidding of clients can be realized. The final payment prices for buyers and sellers are as follows

The final payment for buyer v is (Cheng et al., 2016)**:**

$e_{v,actual}^{b} = \frac{\partial \prod_{N}^{***}(V^{*},\mathrm{F},\mathrm{C}_{\mathrm{n}}^{\mathrm{h}},\boldsymbol{Q}_{v}^{'})}{\partial(\xi^{v})^{+}}$, v∈ V

In above padding vector:

$$Q_v^{d'} = \begin{cases} \dot{q} - 1, \text{where } \dot{q} \text{ means the smallest integer no smaller q;} \\ 0, \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{otherwise;} \end{cases}$$

The final payment for seller f is (Cheng et al., 2016)**:**

$e^s_{f,actual} = \mu^f \eta^f + \prod_N^{**}(\mathrm{L}, V^{**}, \mathrm{F}) - \prod_N^{**}(\mathrm{L}, V^{**}, \mathrm{F} \backslash \mathrm{f}), \mathrm{f} \in \mathrm{F}$

By applying the above-mentioned M-MDA method, a feasible solution is obtained by solving a finite number of linear programming in the second stage, and a set of matching schemes that can be executed is obtained. M-MDA's solution process mainly uses two methods. One is linear relaxation, transforming the original 0-1 integer programming into linear programming, and using the solution to simplify the original input set (which is buyer set in this thesis). In addition, applying the padding method avoids budget deficits.

In addition to enabling clients to respond honestly to their types, the M-MDA method has other outstanding properties, so the following theorem is proposed:

Theorem

The properties of M-MDA mechanism still hold in this model.

Properties:

(1) $e_v^b(\mathrm{L}, V^*, \mathrm{F}, \mathbf{Q}_\mathrm{d})$ is trading price for buyer v and M-MDA mechanism is IC for the buyers for any nonnegative q (Cheng et al., 2016).

(2) The M-MDA mechanism make sure buyers get all quantity that they need or nothing at all, while sellers can provide part of commodities (Cheng et al., 2016).

(3) The M-MDA mechanism is IC, IR and (weakly) BB (Cheng et al., 2016).

(4) The M-MDA mechanism is computationally efficient (Cheng et al., 2016).

Proof

Since the LSP's income from clients' initial services payment $(\sum_{i\in G} P_i(T_n^i, k_i))$ can be considered as exogenous parameter since they generate from the first stage. When set the unit management cost of cargos stored at each depot C_n^h as same constant, it can be found the LSPP degrade into MIP and which make all properties of M-MDA mechanism hold.

The next chapter will focus on analyzing the mathematical model of this thesis to explore the impact of the LSP's decision. Finally, analysis of whether the advantages in M-MDA are maintained in this thesis is conducted.

5. Analysis

In order to answer the research questions in this thesis, this chapter will deduct the mathematical model in Chapter 4. This chapter will analyze what decisions the client and the LSP will take after introducing a new operation mode and pricing mechanism. How their respective decisions affect the other party and how the two parties' decisions affect the efficiency of the mechanism are discussed in this chapter.

This chapter will be mainly divided into two parts, the first part includes the propositions related to client decision-making and the proofs.

5.1 Client decisions

The mechanism proposed in this thesis involves two stages. The first stage is consistent with the current logistics service mode, that is, the clients select the initial service level according to their own situation and the prices offered by the LSP. In the second stage, clients will exchange the order of departure for the cargos they own. The "buyer" defined in this thesis is the source of the demand for flexible services. Therefore, it is necessary to determine which type of clients is motivated to become a buyer to participate in the second stage of the exchange. Therefore, the first proposition is about the characteristics of buyers participating in the second stage.

Proposition 1

For clients who desire to be buyers, if their initial optimal timing $-\frac{b_i^0}{2 \cdot a_i^0} > \widetilde{T_I^H}$, then their optimal timing in second stage $-\frac{b_i^1}{2a_i^1} < \widehat{T_I^L}$.

Proof

There are three situations

1) $\widetilde{T_1^H} > \widehat{T_1^L}$

When the clients' timeliness utility indicates they should choose Low-level services ($-\frac{b_i^0}{2 \cdot a_i^0} > \widetilde{T_1^H}$), then they will definitely choose low-level since the price is also lower. They would have incentive to switch to high-level services only if new optimal timing isn't inside the original time range, which means they will join the exchange when $-\frac{b_i^1}{2a_i^1} < \widehat{T_1^L}$.

2) $\widetilde{T_1^H} = \widehat{T_1^L}$

Same in 1), the only difference is now $\widetilde{T_1^H} = \widehat{T_1^L}$.

3) $\widetilde{T_1^H} < \widehat{T_1^L}$

When the initial optimal timeliness $-\frac{b_i^0}{2 \cdot a_i^0} > \widetilde{T_1^H}$ and the client chooses the low-level services (since clients being discussed choose lower-level in first stage), it means $U_i(L_i^H) < U_i(L_i^L)$. Client would have incentive to make exchange only if $-\frac{b_i^1}{2 \cdot a_i^1} < \widehat{T_1^L}$.

Proposition 1 is established under the three product strategies that LSPs may adopt (whether the delivery times of different service levels have intersections). The discussion related to the "seller" will be integrated into Proposition 3 and the proposition of LSP decision.

After determining the types of clients that are generating demand for flexible services, another issue worth exploring is how the new strategy affects client decisions.

Proposition 2

For any clients, if their initial optimal timing $-\frac{b_i^0}{2 \cdot a_i^0} < \widetilde{T_1^H}$, but $U_i(L_i^H) < U_i(L_i^L)$, then it will be the **dominant strategy** to choose low-level services then custom their own services.

Proof

There are two stages in current problem, in first stage, clients need choose a certain level of services. When $-\frac{b_i^0}{2 \cdot a_i^0} < \widetilde{T_1^H}$, the timeliness utility in high-level services $UT_i^H > UT_i^L$. However, if total utility $U_i(L_i^H) < U_i(L_i^L)$, then it means money utility $P_i^H > P_i^L$ and $UT_i^H - P_i^H < UT_i^L - P_i^L$. $P_i^H > P_i^L$ is obvious, but this situation means the money effect is greater than timeliness effect.

In such situation, there two ways in strategy profile to achieve the actual arrival timing close to original optimal timing with lower prices (asymptotic optimal timing). First strategy is choosing lower-level in first stage and then choose to accelerate the cargo in second stage (be the buyer). The second strategy is choosing high-level first then be the seller in second stage to obtain asymptotic timing. However, choosing high-level services is not the optimal strategy in first stage.

Therefore, for clients with $-\frac{b_i^0}{2 \cdot a_i^0} < \widetilde{T_1^H}$, but $U_i(L_i^H) < U_i(L_i^L)$, it will be the dominant strategy to choose low-level services then adjust.

Proposition 2 points out that a certain type of client will certainly make a choice when the rational person hypothesis is established. In fact, when a real corporate client or an individual consumer (with certain knowledge of decision theory) has complete information, it is possible to make a choice consistent with the situation in Proposition 2.

The benefits of the mechanism in this thesis will be largely influenced by the scale of demand. Therefore, a problem that needs to be explored is whether the strategies in this thesis are still valid when there are not enough clients to encounter unconventional emergencies (their time utility coefficients do not change).

Proposition 3

Even clients' timeliness preference coefficients remain unchanged, client will join the exchange when it can provide higher utility.

Proof

Clients will join the exchange when their timeliness preference coefficients change and they can benefit from accelerate their cargos. However, if clients cannot achieve initial optimal timeliness, they might still incentive to join the exchange.

1) $-\frac{b_i^0}{2 \cdot a_i^0} < \widetilde{T_1^H}$, but $U_i(L_i^H) < U_i(L_i^L)$, when $\widetilde{T_1^H} \geq \widehat{T_1^L}$

   In such situation, clients' dominant strategy is choosing the low-level services first then adjust the services. In this case, there is overlap in the time range of low-level services and high-level services. Even if the client chooses a low level of service, the cargos may still arrive in the overlapping period. Therefore, clients should choose to adjust the service when the cargo is close to the destination.

2) $\widetilde{T_1^H} < -\frac{b_i^0}{2 \cdot a_i^0} < \widehat{T_1^L}$, when $\widetilde{T_1^H} < \widehat{T_1^L}$

   Similar as the situation 1), the clients cannot reach the initial optimal timing in stage since the timing is not inside the two range of initial services, then clients should choose the services first, but they can still choose to adjust the services to get the actual arrival timing close to initial optimal timing when their timeliness preference variable remain unchanged.

This thesis is based on the belief that with the approach of transit time, clients will have a better understanding of their own timeliness requirements when delivery time is getting close. However, through mathematical proof, a conclusion can be drawn that **even if the client's time utility coefficient has not changed, they still have incentives to participate in the exchange**, because they did not achieve the optimal utility in the initial service in the first stage.

5.2 LSP decisions

LSPs are also a rational interest subjects as clients, and they will make choices to maximize their interests in decision-making. In this thesis, the decision variables of LSP mainly consist of three types which are s**ervice level (delivery time)**, **service price**, and **unit management cost of cargos in each depot (C_n^h)**. Among them, the management cost is actually a tool used by an LSP to control the second stage of the transaction, not the actual cost. To some extent, C_n^h in the model represents the degree of busyness of a depot. The logic of answering question 2 is to directly analyze how the LSP should make adjustments to the three types of decision variables in order to improve its profitability.

Proposition 4

Defining $\left|-\frac{b_i^1}{2 \cdot a_i^1} - \widehat{T_1^L}\right|$ as the potential of clients to achieve the higher utility by accelerating the cargo, and $t^{rL} - \frac{t^{rL}}{\lambda}$ as the ability of LSP can help clients to adjust services in second stage, where $\lambda = \frac{\frac{\widehat{T_1^L}+\widetilde{T_1^L}}{2}-\widehat{T_1^H}}{\frac{\widehat{T_1^H}+\widetilde{T_1^H}}{2}-\widehat{T_1^H}}$ denotes how difference the high-level services and low-level services is. t^{rL} denotes the time left when clients want to adjust the services.

Then $\chi = \frac{t^{rL}-\frac{t^{rL}}{\lambda}}{\left|-\frac{b_i^1}{2\cdot a_i^1}-\widehat{T_1^L}\right|}$ denote the system's ability adjust services to the clients' optimal timing, which is meaningful in [0, 1].

System profit will increase as λ (the difference the high-level services and low-level services) increases.

Proof

$\left|-\frac{b_i^1}{2\cdot a_i^1}-\widehat{T_1^L}\right|$ is the distance between optimal timing and upper-bound of low-level service, while $t^{rL}-\frac{t^{rL}}{\lambda}$ denotes the measure of difference the two types of services. It can be easily found that λ increases, χ also increases, which indicate the system's ability adjust services to the clients' optimal timing increase. Give the situation that initial services is exogenous, the ability of draw clients into exchange capacity is equal to systems' profitability. Clients would prefer to join the exchange to maximize their profit since they cannot reach their initial optimal timing when they select services in first stage. When $\chi = 1$ it means LSPs have completely ability to respond to clients' requirement to adjust services.

Proposition 4 indicates how the LSP should adjust the level of service identified in the first stage after the introduction of the new strategy proposed in this thesis. As mentioned above, in the two-stage mechanism proposed in this thesis, the initial service levels and prices in the first stage are consistent with the current traditional services. The advantage of this is that as long as no losses occur in the second stage, the benefits of LSP are at least not worse than it is now. Proposition 4 proves that, after applying the new operation mode and pricing mechanism, LSP can collect data of client groups during operation and reset the initial service level (delivery time) based on these data, and can obtain greater income. Next, what needs to be explored is how the LSP will modify the initial service price based on the new data collected. In Proposition 5, the LSP decision is related to one kind of client who may be a seller.

Proposition 5

Increasing the price difference between different levels of services may increase the profitability of LSPs.

Proof

Based on the above description, it can be found that even if the client's time utility preferences have not changed. Clients who do not have the best time utility achieved in the first stage have the incentive to adjust the service at a later stage.

Similarly, for some clients, their time utility $\mathrm{UT}_i^H > \mathrm{UT}_i^L$ and total utility $U_i(L_i^H) > U_i(L_i^L)$ indicate that they should choose a high level of service. But when $\widetilde{\mathrm{T}_1^{\mathrm{H}}} < \widehat{\mathrm{T}_1^{\mathrm{L}}}$, there are part of clients who optimal timing $\widetilde{\mathrm{T}_1^{\mathrm{H}}} < -\frac{\mathrm{b}_i^0}{2\cdot \mathrm{a}_i^0} < \widehat{\mathrm{T}_1^{\mathrm{L}}}$. This means that when these clients become sellers, their timeliness utility will increase because of the exchange (delay is better), but at the same time they will also enjoy the price discount provided by LSP. In order to avoid this situation, certain measures need to be taken. First find the boundary value. For some clients, there is no difference in the choice of two levels of service.

$$\frac{1}{\left(-\frac{\mathrm{b}_i^0}{2\cdot \mathrm{a}_i^0}-\frac{\widehat{\mathrm{T}_1^{\mathrm{H}}}+\widetilde{\mathrm{T}_1^{\mathrm{H}}}}{2}\right)*\mathrm{P}_i^H}=\frac{1}{\left(\frac{\widehat{\mathrm{T}_1^{\mathrm{L}}}+\widetilde{\mathrm{T}_1^{\mathrm{L}}}}{2}+\frac{\mathrm{b}_i^0}{2\cdot \mathrm{a}_i^0}\right)*\mathrm{P}_i^L} \qquad (**1)$$

For clients who can benefit from being sellers

$$\frac{\left(\frac{\widehat{T_1^L}+\widetilde{T_1^L}}{2}+\frac{b_i^0}{2\cdot a_i^0}\right)}{\left(-\frac{b_i^0}{2\cdot a_i^0}-\frac{\widehat{T_1^H}+\widetilde{T_1^H}}{2}\right)} \geq \frac{P_i^H}{P_i^L} \tag{**2}$$

Denotes $\frac{P_i^H}{P_i^L}$ as the measurement of the difference between the price of different services. Assuming LSP want such clients as less as better, then LSP should set prices as

$$\frac{\left(\frac{\widehat{T_1^L}+\widetilde{T_1^L}}{2}+\frac{b_i^0}{2\cdot a_i^0}\right)}{\left(-\frac{b_i^0}{2\cdot a_i^0}-\frac{\widehat{T_1^H}+\widetilde{T_1^H}}{2}\right)} \leq \frac{P_i^H}{P_i^L} \tag{**3}$$

When the difference in service levels at different levels is widened, the proportion of the increase in the price gap will need to exceed the proportion of changes in the service level. Now, the probability of occurrence of the second type of clients will decrease.

The reason why this thesis compares the value of delivery time directly with the price is based on a consideration that the client is risk neutral, and the effect of price on utility can be directly written as the objective function (14). Therefore, the utility in the expression itself is an abstract concept. The derivation here is not to determine the critical value, but to prove the existence of mutual relations.

Therefore, it can be considered that within a certain range, increasing the difference between service prices can make LSPs more profitable. Based on Proposition 4&5, the following judgments can be made that when the gap between initial services (delivery time and price) is increased, the profitability of LSPs will increase.

Based on the findings in Proposition 3&5, there are three types of clients in the current context:

1. Clients select high-level services in the first stage and then choose to lower their service levels. However, lowering the level will reduce their timeliness utility, so they

need LSP subsidies.

2. Clients choose a high-level of service in the first stage and then choose to lower the service level, but the act of lowering the service level will improve its time utility.

3. Clients select low-level services in the first stage and then choose to improve service levels. They were willing to improve time utility through additional payments.

In fact, in the proposed mechanism, there are three situations that are different from ordinary auction problems.

1. The buyer and seller do not trade the same product. The buyer's goal is to enjoy a high-level service from the current depot to all subsequent depots. The goal of the seller is to enjoy a low level of service only at the current depot.

2. Once a seller participates in a transaction, even if its capacity is not sold, the remaining capacity will not be left.

3. Because of the existence of the second type of clients among the above three types of clients, the auction mechanism may fail.

The second type of client has the effect that when the seller participates in the transaction, as long as the seller sells the capacity (even at a price of 0), the exchange is also beneficial to the seller.

It should be noted that the thesis is not sure whether the behavior of such clients who want to become sellers should be defined as moral hazard. Because they do contribute their own resources, it seems logical to be compensated. The main reason why this thesis aims to reduce such clients as much as possible is that the M-MDA auction mechanism used in this thesis does not consider the existence of this type of seller. Usually, sellers who are willing to trade even if they have negative transaction prices will rarely appear in real auctions. Therefore, when such clients are introduced into the mechanism of this thesis, they may have some unknown effects.

However, the current mechanism cannot distinguish the existence of such clients. It is uncertain whether this will lead to dishonest bids from other clients. Therefore, Proposition 5 is proposed to reduce the impact of the second type of client on the mechanism. The essence of Proposition 5 is to infer the characteristics of the client group by applying historical data. The LSP adjusts the price of the initial service based on the information obtained so that the probability of occurrence of the second type of client is as small as possible.

Unlike the object (flower) studied by Cheng et al. (2016), in this thesis, when the sellers did not completely sell out their product, the remaining product did not belong to the sellers. The perishable product studied in this thesis is space capacity, although it has some characteristics of multi-attribute perishable products, it is indivisible. This thesis does not set up indivisible bids for both buyers and sellers. The main reason is that some situation, if a transaction can be achieved, the corresponding space waste can be tolerated.

Proposition 6

LSPP not only provides clients with the flexibility to adjust services, but also enables LSPs to react to changes in traffic within the system, avoiding possible waste of space under the M-MDA mechanism.

Proof

The management cost coefficient ($\mathrm{C_n^h}$) of cargos at different depot is tool for LSP to control the transaction in second stage. By changing the coefficient of management cost, LSP can control the tolerance to space waste that may be generated in the second stage. For example, if there are many cargos the current **Depot n**, to avoid space waste, LSP consider increasing the management cost coefficient of subsequent depot n' in future.

Seller A sells a part of the capacity to buyer B, but there is a part of the space left. This waste of space will lead to a decline in social welfare.

Assuming $k_A \cdot (C^h_{n'})' \cdot t^A_{n'} > k_A \cdot C^h_{n'} \cdot k_A$, where $(C^h_{n'})'$ is the management cost coefficient of depots n' in future. In order to control the space, then must have $k_A \cdot (C^h_{n'})' \cdot t^A_{n'} + k_B \cdot C^h_{n'} \cdot t^B_{n'} > k_A \cdot C^h_{n'} \cdot k_A + k_B \cdot (C^h_{n'})' \cdot t^B_{n'}$. The former is the cost when exchange successful.

The above formula equal to $(C^h_{n'})' > C^h_{n'}$, Therefore, by promote the future management cost in subsequent depot, the LSP can simply control the current depot's transactions. Once the improvement in the welfare generated by a certain transaction is less than the increase in management costs, the transaction will be blocked.

Therefore, the space waste in the second stage can be limited by setting the management costs coefficient at different depots. Such a mechanism provides the system with a method of responding to changes in traffic within the system.

6. Conclusion

The lack of flexibility in the logistics service mode is a problem faced by current LSPs. The solution proposed in this thesis is to transform the current traditional logistics services into large-scale customized services by introducing a new operation mode and pricing mechanism. In this thesis, customized services and flexible services are equivalent. If LSPs can successfully achieve the customization of logistics services, they will improve the flexibility of logistics systems, clients' satisfaction and willingness to pay. The profitability of LSP will also increase accordingly.

The contribution of this thesis can be mainly categorized into two parts. One is the developed and proposed strategy (a new operation mode and pricing mechanism) that can transform the traditional logistics service into a large-scale customization service. The other is the knowledge gained from interpreting the model (answers to research questions). Such knowledge ensures the feasibility of the strategy.

In order to enable the new strategy proposed to achieve the desired effect, it is necessary to understand how the clients and the LSP will make decisions after the introduction of the new strategy to maximize their utility (profit), which is also important for answering the research questions of this thesis. The decision of the two research subjects of this thesis will affect the benefits of themselves, the other party, and the efficiency of mechanism. Therefore, this thesis establishes the mathematical model to analyze the relationship between major elements. In Chapter 5, six propositions related to the decision-making of both parties were presented and proved, drawing the knowledge of what decisions the parties would make under the new mechanism.

The operation mode and pricing mechanism proposed in this thesis can be widely applied to any multi-stage transportation services, whether it is freight service or passenger service. In addition, it can also be applied to consumer services and enterprise client services which is why this thesis chooses to use "client" instead of consumer (to avoid ambiguity). In the case of a global logistics company gradually losing its share in the Chinese market (Wataru, 2018; Daniel, 2018), the introduction of this mechanism may help LSPs enhance their competitiveness.

This thesis is based on the belief that with the approach of transit time, clients will have a better understanding of their own timeliness requirements when delivery time is getting close. Providing more flexible services allows client to have more choices and therefore can improve client satisfaction to some extent. The second stage of the mechanism proposed in this thesis is based on transactions between clients and clients, transforming traditional markets into bilateral markets. When clients participate in the second stage of the transaction, the level of service they enjoy changes. Therefore, the essence of this mechanism is to guide clients to participate in the process of custom logistics services. In the process of implementation, the mechanism proposed in this thesis has no major changes in logistics operations, except for the investment in communication platform construction.

No numerical experiments were performed in this thesis. This is mainly because the algorithms in this thesis are mainly based on the M-MDA method. The excellent characteristics of this meth have been proved (Cheng et al., 2016). Without the formation of new algorithms, repeating the steps in previous studies may lack value. The previous chapter also proved that under certain circumstances, the excellent attributes of M-MDA are preserved. The more valuable part of this thesis is that the model proposed is applied in a special scenario. The main factors considered are different from previous studies. Therefore, the emphasis of this thesis is on the mathematical relationship in the model.

The other part contribution of this thesis which is the knowledge gained from the analysis model, will be summarized in the recommendations.

6.1 Recommendations

This section will summarize the impact of the introduction of new strategies on clients and LSPs, and provide suggestions for their decisions. That is, through the above discussion, the research questions mentioned in thesis can be formally answered. Later, some application scenarios for the new strategy in this thesis will be introduced.

The application of new mechanisms might always be beneficial **to clients**. On the one hand, the motivation of LSPs to provide customized services (flexible services) is to improve clients' satisfaction. Proposition 1 points out the characteristics of the buyers who participated in the second stage, which shows that the mechanism proposed in this thesis is to attract the original target clients (clients who encounter unexpected events). On the other hand, Proposition 3 proves that when the LSP allows clients to adjust the service level of cargos in transit, the clients are always motivated to join the exchange in second-stage. From a realistic point of view, this is because the logistics service of the clients' needs should be categorized into a customized service (Kelley et al., 1990).

The decision made under the current operation mode is a last resort choice for clients. The LSP can only provide clients with limited options (combination of price and service level), and clients may not get their own optimal choice from the very beginning. Unless the LSP can provide an infinitely subdivided product portfolio, but this is not realistic, it is equivalent to provide clients with customized services in the first stage, so the cost incurred could be very high. The decision-making system that supports such an operation mode will also be very complicated, and might even make the LSP's revenue worse than it is now. The mechanism proposed in this thesis allows clients to adjust in the subsequent stages after determining the initial service level. The clients will take the initiative to propose the exchange requirements, and the LSP is only responsible for matching. In such situation, even if clients don't encounter unconventional emergency, they have the incentive to join the service. This thesis even finds one type of client's dominant strategy under the new mechanism (Proposition 2).

The logic of answering question 1 is that since the new strategy proposed in this thesis has been clarified in Chapter 4, it is only necessary to analyze whether the client has the incentive to apply new services (participate in exchange), and it can prove that the new strategy is attractive to clients.

The answer of research question 1:

The mode that can attract clients to join the logistics customization should meet two requirements. One is the basic requirement, that is, the client can obtain basic logistics services (the first stage). The other is advanced requirements, Clients can adjust service levels later while LSPs set rules and provide technical support (the second stage). It can be found that the mechanism proposed in this thesis not only meets the needs of the original target clients, but also has a wider range of potential client groups. Mechanism proposed in this thesis is attractive to clients who are dissatisfied with the service level of the first stage. They are always motivated to join the exchange in second stage to maximize their utility. Therefore, the strategy proposed in this thesis is theoretically attractive to clients in the current market.

In a certain range, LSPs can be recommended to use the proposed strategy to improve their profits. According to the contents of the previous chapter, the new price mechanism in this thesis can be used on multi-stage transportation services. In the context of applying the mechanisms proposed in this thesis, LSPs can extend the gap in timeliness commitments between different service levels within a certain range, and can also try to widen the gap in service prices. These measures may increase the profitability of the LSP.

On the other hand, on the premise of not changing the initial price and service level of the first stage, some clients always have the motivation to participate in the exchange of the second stage. In this situation, LSPs can always benefit from new dynamic pricing mechanisms.

The last way to improve profits of LSP is to adjust the management cost coefficient (C_n^h) to limit the appearance of space-wasting transactions. The management cost coefficient here is not a specific influencing factor that actually appears in the operation, but an abstract coefficient existing in the decision system of the LSP, which is used to represent the busyness of a certain logistics depot. The specific application scenario is that when the workload of a certain depot is heavy, the LSP is less likely to waste space in the exchange. Therefore, increasing the future management cost coefficient of the subsequent depot can limit the success of space-wasting transactions.

The answer of research question 2:

When the new strategy was just introduced, the service levels and prices in the first stage were consistent with the current standards. This ensures that the client groups that would otherwise choose the services of the LSP will still maintain the current choice. At this point, service levels and prices in the new strategy can be seen as exogenous. After the logistics customization strategy is implemented, based on the accumulated client group data, within a certain range, the LSP should expand the gap between different initial service levels. In addition, the gap between prices should be greater than the gap between service levels. According to the degree of busyness in the system, LSP should dynamically adjust the management cost coefficient. By taking the above measures, LSPs might improve their profitability, or, in the case of improving service flexibility, their profits are at least no worse than they are now.

The purpose of this thesis is to propose a feasible strategy that can transform current LSPs' logistics services into large-scale customized services. This purpose includes two aspects (sub-purposes). One is transforming the current logistics services into large-scale customized services which means the new strategy can be accepted by clients in market. The other is proposing operation mode and pricing mechanism can improve service flexibility and profitability. In the above discussion, it has been demonstrated that the client has an incentive to report their need to adjust services to the LSP and participate in the adjustment of the service level. Therefore, under the strategy proposed in this thesis, the first aspect of research purpose is achieved. Customized services are the equivalent to flexible services in the context of this thesis, and customized services can also increase clients' willingness to pay. The only problem is that customized services may generate higher costs. The good news is that mechanism designed in this thesis has an advantage which the cost required is relatively low, and there is no excessive impact on the daily operations, so it is relatively easy to implement. It should be noted that by applying the existing transaction data of the LSP, the characteristics of the client group can be better analyzed, and the improvement of the model can be achieved. Therefore, the feasibility of the strategy in this thesis is guaranteed.

Application scenarios

The strategy proposed in this thesis can improve the profitability of LSP under the condition of ensuring client satisfaction, so it is applicable to the transportation market in different regions. For example, in the case of the Chinese logistics market that is experiencing profitability dilemma (refer to Appendix B), the proposed strategy is a solution worth considering. In addition to the general multi-stage transportation services that this thesis focuses on, there are two other retail-specific application scenarios.

Air ticketing

Revenue management in air ticket sales is relatively complex. Airfare has been extensively studied and many mature strategies have been formed. Allowing transactions between clients may affect the airline's own sales plan. However, after setting some restrictions, perhaps the mechanism in this thesis is also feasible in this area.

First, open exchanges between clients when the airlines themselves have fewer open positions.
Second, limit the allowable exchange size based on the current free positions.
Third, the strategy can be applied on a small scale to certain routes, and after accumulating certain data, it compares with the profit under the regular pricing model.

Resource scheduling in industrial clusters

In some industrial clusters, their raw materials may be of a relatively high degree of similarity. Even with the same supplier, this mechanism can also be used for resource scheduling among these enterprises. For example, under the supplier's organization, the downstream clients perform relatively flexible allocations of the material. When an enterprise's raw material consumption rate exceeds expectations, the supplier can help the enterprises from obtaining part of materials that will be delivered to other companies through additional payments. Enterprises that transfer materials will receive compensation for funds.

6.2 Limitation and future research

Limitation

The dynamic pricing mechanism proposed in this thesis is mainly to enable LSPs and clients to have the second opportunity of adjusting the service level. When the scale of the demand increases greatly, the mechanisms proposed in this thesis have limited effects. In this thesis, by setting the parameter of management cost of cargos at each logistics depot, the waste of capacity that occurs in the second stage can be improved to some extent, but the effect is still limited.

Another limitation of this thesis is that it does not consider the risk of service failure. In actual operation, there may be some circumstances that result in the service not being realized. For example, because some factors cause the loss of cargos, or because of the LSP factor that caused a flight cancellation, the LSP would incur additional costs, which may result in the loss of the LSP's profits.

Future research

1. This thesis does not take into account the impact of outside competition. The inclusion of external competitors within the scope of consideration can further increase the generalizability of this mechanism.

2. Some of the conclusions and inferences in this thesis are based on the assumption that the timeliness utility of a client is in the form of unary quadratic function. In the future, if there are scholars who can get the real LSP's data, it may be possible to infer a more accurate form of the function.

3. The impact of risk is not considered in this thesis. After the introduction of the

dynamic pricing mechanism in this thesis, whether additional operational risk arises is therefore worth considering.

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Appendix A

Proof of Expected payment

Buyer

$$e^{i} = \begin{cases} -\frac{(b_i^1)^2}{4a_i^1} - a_i^1 T_i^2 - b_i^1 T_i & \text{if } \left(t_{(O,n)}^i - t_O^i + t_{(n,D)}^H\right) < -\frac{b_i^1}{2a_i^1}; \\ \{a_i^1 Ø_i^2 + b_i^1 Ø_i - a_i^1 T_i^2 - b_i^1 T_i, 0\}^+ & \text{otherwise;} \end{cases} \quad (9)$$

Where $Ø = t_{(O,n)}^i - t_O^i + t_{(n,D)}^H$

Since clients' timeliness utility is quadratic function then their extreme value point is $T_i = -\frac{b}{2a}$. When clients' preference change, their reservation utility for exchange is the optimal timeliness utility in new preference variable ($a_i^1(-\frac{b_i^1}{2a_i^1})^2 - b_i^1\left(-\frac{b_i^1}{2a_i^1}\right) = -\frac{(b_i^1)^2}{4a_i^1}$) minus the original guaranteed timeliness in new preference variable $a_i^1 T_i^2 + b_i^1 T_i$. However, when it's impossible to reach the new timing, then whether clients join exchange depends on the utility them can get from exchange ($a_i^1 Ø_i^2 + b_i^1 Ø_i - a_i^1 T_i^2 - b_i^1 T_i$). They will join the exchange when they can get positive utility.

$Ø$ denotes the total transport time after exchange.

For clients want to be "seller", their expected payment is

$$e^{i} = \begin{cases} -(a_i^1 T_i^2 + b_i^1 T_i - a_i^1 ð_i^2 - b_i^1 ð_i) & \text{if seller i decide to sell the capacity;} \\ 0 & \text{otherwise;} \end{cases} \quad (10)$$

Where $ð = T_i + t_n^L - t_n^H$

Sellers' expected payment is similar, they would like to obtain money that can offset their loss for parcel delay. However, it's possible for seller to obtain positive timing utility in the exchange, which means it might better for them to slow down the cargos.

Appendix B

In recent years, the development of China's logistics industry has been subject to multiple constraints on efficiency, profitability and operating costs. The rise of China's e-commerce market has directly led to this situation. China has become the largest e-commerce market in the world with sales of 1.4 trillion RMB (Chinese currency) generated by e-commerce in the first quarter of 2017 (pwc, 2017). According to estimation, in 2019, China's e-commerce market will account for more than the global online retail sales 50% share (Deloitte, 2016). However, China's logistics industry has not simply benefited from this. Alibaba achieved a 99% increase in profits in the second quarter of 2017, while the YTO Express Group, STO Express, and SF Holding, the three largest logistics companies in mainland China, experienced varying degrees of slowing profit growth (SCMP, 2017).

The rise of e-commerce has also led to the rapid development of the logistics industry. Singles' Day (take place in every Nov. 11, China) has become a world's biggest shopping event that exceeds the combined sales for Black Friday and Cyber Monday in the United States (Reuters a, 2017). Alibaba and Jingdong are the two largest e-commerce companies in China report its Singles' Day sales hit $44.49 billion in 2017 (Reuters b, 2017). The explosive amount of online purchases triggers a surge in logistics orders in a short period. On November 11, the number of logistics orders reach 850 million. The total number of logistics orders generated from November 11 to November 16 is expected to exceed 1.5 billion (Westdollar, 2017). Such a huge market means both an opportunity and a challenge for the logistics industry. It can also be found from Figure A that the volume of logistics orders has increased in recent years. Once the volume of logistics orders soars, parcels accumulate at logistics depots, resulting in low overall system efficiency while profitability is also affected. As competition has become fiercer, e-retailers have been providing benefits such as free shipping for the purchase of specific types or quantities of merchandise. And the industry relies heavily on the e-commerce market (which accounts for 65%), which leads to the industry's profits being continuously compressed (Chinadaily, 2017).

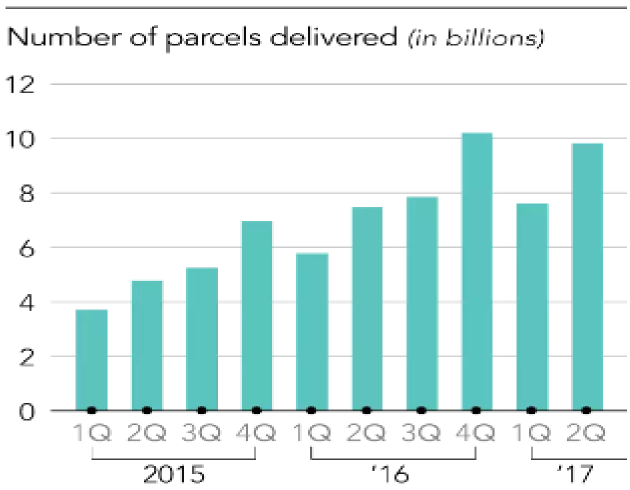

Figure A   Number of parcel delivered in China (Wataru, 2017)

Another problem is that, the express delivery industry in China has been providing higher-level services at a lower price. However, with the gradual disappearance of China's demographic dividend, labor costs continue to rise, and labor-intensive industries will be hit hard. As a result, the logistics industry is affected. The gross profit rate of China's parcel delivery industry decreased **from 30%** in 2007 **to less than 10%** in 2016 (Chinadaily, 2017). In the past two years, the average service price has dropped by another 20% as shown in figure B, while the company’s sales have increased (Wataru, 2017). Insufficient resources lead to a decline in service quality. In early 2017, there was a large-scale delivery delay and loss (Wataru, 2018).

Figure B China's delivery price decline (Wataru, 2017)

In October 2017, many LSPs in China announce to increase the services price (SCMP, 2017). This also shows that the high operating costs of the logistics industry exert tremendous pressure on the LSPs. LSPs also began to apply differentiated product strategies to increase profits, and tried to introduce automation equipment to reduce operating costs (Wataru, 2017). As mentioned above, the former might not provide sufficient flexibility for logistics systems, while the latter was difficult to achieve in the short term (since huge investment is needed). China's logistics industry must face the problem of how to increase its profitability with limited resources. For the current Chinese logistics industry, what LSPs might need is an operation-level strategy that can be implemented in the short term without being subject to cost and technology constraints.

Therefore, the logistics service customization strategy proposed in this thesis might be applicable.