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SIMULATION OF IMPACT OF RESOURCE COMPETITION ON SHARED RESOURCE UTILISATION

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Abstract
This study aims to address the problem that the uncontrolled business response process of resource-matching platforms (RMPs), which leads to resource competition. The system dynamics (SD) is applied to obtain optimisation policy of the platform's resource utilisation from a production system. The business transaction system of RMPs is considered as a complex social and economic system. Then the SD simulation model of the business response process of RMPs is established, for which the success rate of demander response and resource utilisation are used as observation indices. Simulations of influencing factors were conducted from the perspective of platform controllability. It is indicated that the decision attributes especially the expected profit and the resource distribution have impacts on the user response, transaction success rate and the resource utilisation; and the influence of decision distribution is more obvious than that of decision attributes. An improvement in each of these factors can promote the response success rate and resource utilisation. These conclusions provide guidance for the coordination of resource competition and resource scheduling of the platforms.
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Key Words: System Dynamics, Resource Matching Platform, Resource Utilisation, Demander Response Success Rate, Business Response

1. INTRODUCTION

With the advent of the Internet and sharing economy, several RMPs, such as cloud manufacturing or logistics information platforms, that support the sharing and integration of resources and services over the Internet and cloud technology are emerging [1-3]. These sharing platforms have effectively eliminated information asymmetry, provided a convenient location for supply and demand transactions, and increased the level of informatization in business transactions. On RMPs, various demand and service resources that are essential resources of each other randomly access the platform to do business. Their respective owners are both demanders; therefore, their matching is bilateral, and their trading attitudes and business response situations (i.e., whether to respond to a consent transaction) determine the practical transaction and resource utilisation results. Thus, the business responses play a crucial role in the overall transaction.

However, current RMPs mainly act as information intermediaries or provide simple functions to match supply and demand [4, 5], and do not control the business response procedure. The varying types and quantities of shared resources and fluctuating demands with time on RMPs, often result in one-to-many, many-to-one, many-to-many, or mismatched unbalanced supply-demand relationships. Consequently, ignoring the control of the business response (completely free respond) naturally leads to serious resource/demand competition for demander transactions. Generally, multiple demanders try to deal with the same resource owing to its relative advantages, or multiple resources strive for the most profitable demand, i.e., cargo with higher expected revenue. In contrast, inferior demands (or resources) such as low-paying cargo will generally receive less attention or be neglected. Note that a business transaction can be successful only when the demander accepts and responds to platform-matched resources.

Otherwise, business transactions fail, and the corresponding resources are wasted, or the demands are shelved (sharing resources adhere to certain lifecycles. For instance, a transport vehicle must leave at a certain time.). Thus, unbalanced matching and resource/demand competition not only reduces the transaction success rate of RMP users, but also causes systematic resource wastage because an RMP is essentially a production system. It weakens the roles of RMPs. This is not conducive to the healthy development of the platform and sharing economy (demanders become unsatisfied and may leave the platform and never return). Therefore, to ensure the platform's healthy growth and market competitiveness, RMPs must address to the key issues of solving resource competition in business responses, optimising and improving resource utilisation.

The RMP-based business transaction process is a complex social system involving numerous factors and has an intricate structure and feedback mechanism. The SD can reflect the internal structure of a complex system and integrate quantitative and qualitative considerations into the model [6]. Accordingly, to develop effective control measures of resource competition and improving total performance of RMPs from a production system, this study selects SD as the research method to investigate the impact of RMPs on resource utilisation, puts forward the simulation method to apply SD, and utilises Vensim software to establish an SD model of the business response process. Moreover, this study develops a simulation analysis based on platform controllability to generate an optimisation strategy for the platform and solve the resource competition problem.

2. LITERATURE REVIEW

Currently, most of the research on RMPs focuses on designing platform structures [1], studying price strategy [2, 3], and optimizing the matching process through developing matching models and designing solution algorithms. The primary aims of these studies are to provide better matching results for demanders, improve matching accuracy, and make business transactions easier. For instance, Yang et al. [4] built a manufacturing task-service dynamic matching network model to determine the optimal cloud manufacturing task combination. To improve the matching accuracy, Wang et al. [5] developed a bidirectional matching model that considers the loss aversion of both suppliers' and demanders'. Hou et al. [7] proposed a multi-dimensional cloud service semantic retrieval method that optimizes retrieval and matching processes. Xiao et al. [8] proposed a decision method for matching manufacturing service resources. Cheng et al. [9] proposed a new approach to match the supply and demand of manufacturing resources. Deng et al. [10] developed a vehicle and cargo matching probability prediction method that can improve resource decision making for demanders. Based on semantic similarity, Yuan et al. [11] proposed a manufacturing resource-matching mechanism for cloud manufacturing platforms. He and Qian [12] proposed a resource matching strategy based on multi-attribute matching between cloud resources and tasks. Xiong et al. [13] proposed a fair matching framework for P2P shared accommodation platforms based on preference consistency and resource compatibility. However, all these research is focusing on the business matching stage (Fig. 1). Few studies have considered the business response stage (i.e. acceptance and trading attitude of the demander towards the matching results), and no studies have been conducted on optimizing cloud service utilisation levels from the perspective of business responses. In addition, the above-mentioned studies on RMPs only used the platform as an intermediary for resource transactions. They did not improve the effect of resource utilisation from a controllable platform.

Meanwhile, simulation research based on SD has become widespread in supply chain, inventory, and natural resource systems. Moon et al. [6], Freile et al. [14], Zhang [15], Yang [16] and Oleghe [17] established supply chain SD models based on different backgrounds to observe the relationships between different factors and analyse their individual impacts. Saavedra et al. [18] reviewed the application of SD in renewable energy supply chains. Abadi et al. [19] developed a simulation model to study the effects of various scenarios on water resource sustainability. Berrio-Giraldo et al. [20] developed an SD model for a basin socio-ecological system with four interrelated subsystems and ecosystem services to examine land and land use dynamics. In summary, most studies use SD to investigate the influencing factors and dynamic changes in complex systems and provide recommendations to optimise system operation. However, few studies have been conducted on the operation of RMPs, and even fewer on the simulation analysis of platform-based resource service utilisation.

3. RESEARCH METHOD

3.1 Modelling ideas

RMPs are complicated systems that involve several parties, including the demander, resource, platform, government, and insurance companies. This study focuses on the business response stage of RMPs and selects SD as the research method to investigate the impact of resource competition on resource utilisation of RMPs. Therefore, the business response process is regarded as a dynamic process that occurs in a subsystem of RMPs and can be controlled, and the parties related to the process and their relationships constitute this subsystem. In this way, an SD model of the business response stage is developed through Vensim software, the impact of the controllable factors of the RMP on the resource utilisation level is discussed, and resource optimisation strategies are proposed.

To achieve this goal, we limit the modelling subsystem boundary as shown in Fig. 1. The subsystem contains the complete business response process, and has three leading players: the platform, resources, and demanders.

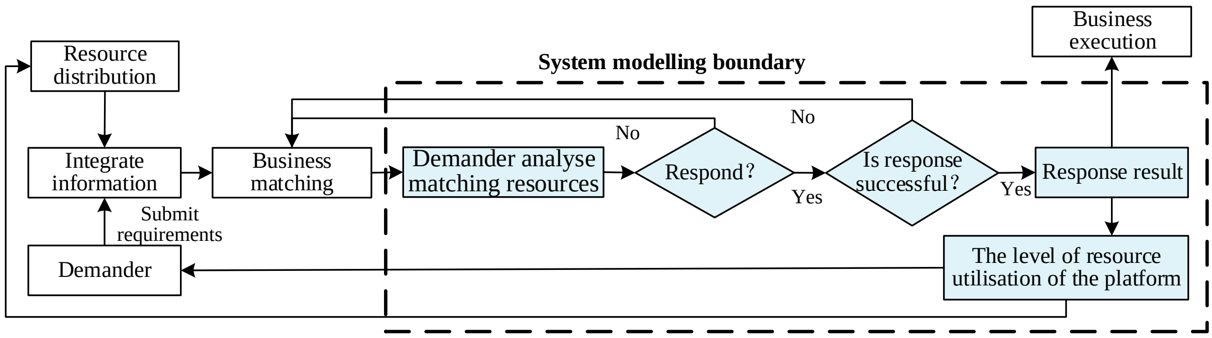


Figure 1: System modelling boundary.

Further, to investigate the impact of the controllable factors of the RMP on the resource utilisation level, the model will reproduce three main dynamic features of the transaction: (1) The response situation faced by the demander. Demanders evaluate platform-matched resources to decide whether to respond. (2) Changes in resources waiting for a response. (3) Level of resource utilisation by the platform. The level of platform resource utilisation results from a comprehensive analysis of the service resources and demand resource response results. Fig. 2 illustrates the modelling ideas. Moreover, the demander response success rate and resource utilisation were used as observable indicators, based on which the level of platform resource utilisation was assessed. The demand response success rate is given by Eq. (1). Resource utilisation is defined by Eq. (2).

$$DRS = \frac{SRRS}{SD} \tag{1}$$

$$RU = \frac{SRRS}{SR} \tag{2}$$

Here, *DRS* is the demander response success rate, *SRRS* is the number of successful business responses, *SD* is the total amount of demand, *RU* is the resource utilisation, and *SR* is the total amount of resources.

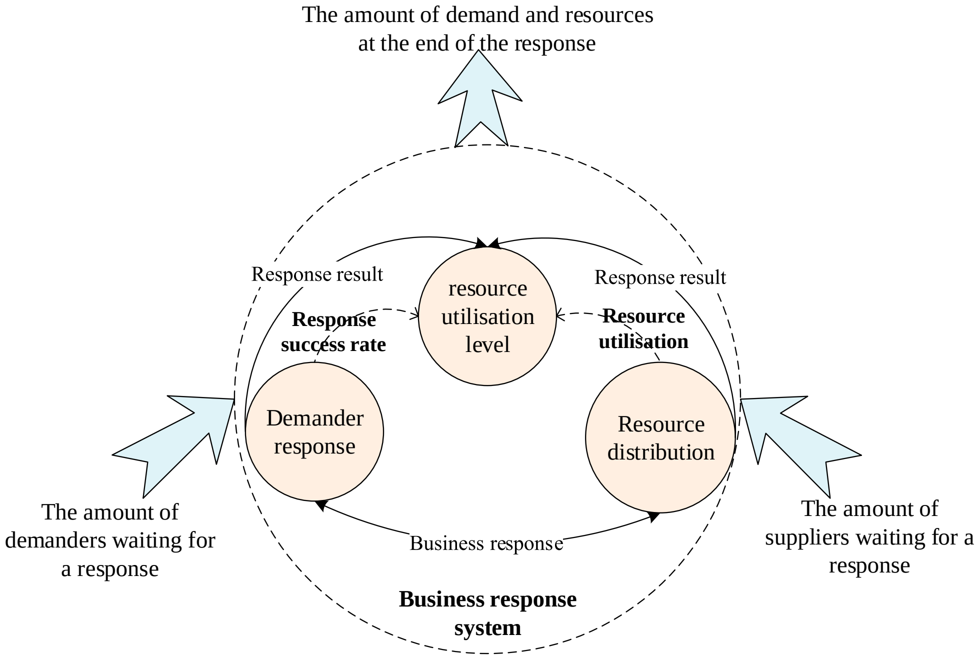


Figure 2: Modelling ideas.

3.2 System dynamics model of business response stage

This study considers a cargo search vehicle in the logistics information platform as an example for the simulation. Based on Section 3.1, the systematic factors (or variables) on the three parties and the business response process of RMPs were firstly identified as listed in Table I, then their initial action relationships were represented as the causal loop diagram (CLD) through Vensim, as shown in Fig. 3.

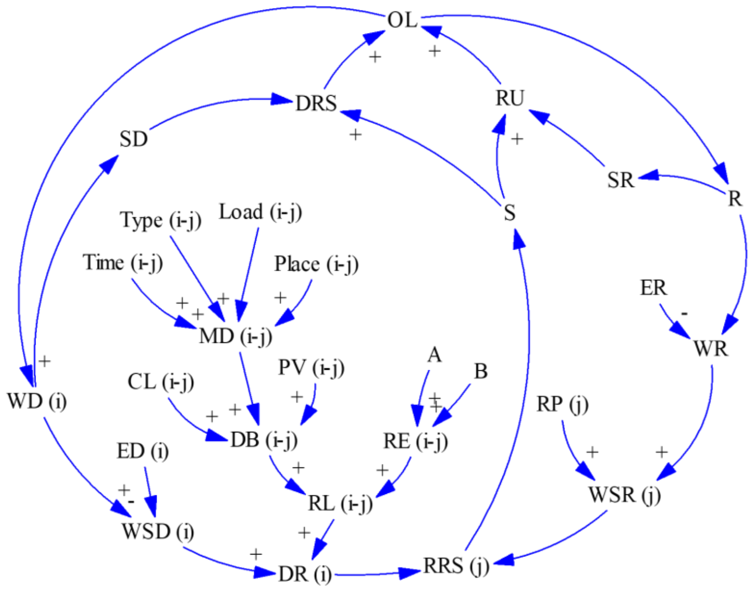


Figure 3: CLD of the business response process of RMPs.

Table I: Variable definitions and equations.

Variable (factor)	**Symbol**	**Equation**
Cargo source (demand resource/ demander)	*i*	*i* = C1, C2
Vehicle source (service resource/ supplier)	*j*	*j* = V1, V2
The increase in cargoes	*D*	WSD(C1) + WSD (C2)
Total number of cargoes	*SD*	INTEG (INTEGER(*D*))
Demander response success rate	*DRS*	ZIDZ (*S*, *SD*)
The increase in vehicles	*R*	*WR*
Total number of vehicles	*SR*	INTEG (INTEGER (*WR*))
Resource utilisation	*RU*	ZIDZ (*S*, *SR*)
Operation level of the platform	*OL*	WITH LOOKUP ((1/2) * (*RU*+*DRS*))
The increase in demander waiting for response	*WD*(C1)	RANDOM NORMAL (0, 1000, 500, 1, 100) * (1+0.3**OL*)
	WD(C2)	RANDOM NORMAL (0, 1500, 800, 10, 100) * (1+0.3**OL*)
Total number of demanders waiting for response	*WSD*(*i*)	INTEG (INTEGER(*WD*(*i*)-*ED*(*i*)-*DR*(*i*-V1)-*DR*(*i*-V2)))
The increase in demander that has responded	*DR*(*i*-V1)	IF THEN ELSE(*RL*(*i*-V1)>=*RL*(*i*-V2),IF THEN ELSE(*RL*(*i*-V1)>=0.2, IF THEN ELSE(*WSD*(*i*)-*ED*(*i*)<0, 0, INTEGER(*RL*(*i*-V1)*(*WSD*(*i*)-*ED*(*i*))), 0), 0)
	DR(*i*-V2)	IF THEN ELSE(*RL*(*i*-V2)>=*RL*(*i*-V1), IF THEN ELSE(*RL*(*i*-V2)>=0.2, IF THEN ELSE(*WSD*(*i*)-*ED*(*i*)<0, 0, INTEGER(*RL*(*i*-V2) * (*WSD*(*i*)-*ED*(*i*))), 0), 0)
The increase in demander exiting the system	*ED*(C1)	INTEGER (STEP (500*RANDOM NORMAL (0, 1, 0.2, 0.2, 10), 5))
	ED(C2)	INTEGER (STEP (800*RANDOM NORMAL (0, 1, 0.1, 5, 5),15))
Business (response) quality (i.e. the comprehensive evaluation by demanders based on decision attributes)	*DB*(C1-V1)	0.3 * *MD*(C1-V1) + 0.5 * *PV*(C1-V1) + 0.2 * *CL*(C1-V1)
	DB(C1-V2)	0.3 * *MD*(C1-V1) + 0.4 * *PV*(C1-*V*1) + 0.3 * *CL*(C1-V1)
	DB(C2-V1)	0.2 * *MD*(C1-V1) + 0.6 * *PV*(C1-V1) + 0.2 * *CL*(C1-V1)
	DB(C2-V2)	0.3 * *MD*(C1-V1) + 0.3 * *PV*(C1-V1) + 0.4 * *CL*(C1-V1)
Response efficiency	*RE*	0.5 * *A* + 0.5 * LN (15 * *B* + 1)
The level of service response	*RL*(*i-j*)	*DB*(*i-j*) * *RE*
Credit	*CL*(*i-j*)	RANDOM NORMAL (min, max, mean, stdev, seed)
Profit	*PV*(*i-j*)	RANDOM NORMAL (min, max, mean, stdev, seed)
Matching degree	*MD*(*i-j*)	*Place*(*i-j*) * *Time*(*i-j*) * *Type*(*i-j*) * *Load* (*i-j*)
Time compatibility	*Time*(*i-j*)	RANDOM NORMAL (min, max, mean, stdev, seed)
Type compatibility	*Type*(*i-j*)	1
Place compatibility	*Place*(*i-j*)	RANDOM NORMAL (min, max, mean, stdev, seed)
Load compatibility	*Load* (*i-j*)	1
The visibility of the response support information	*A*	0.3
The comprehensiveness of the response support information	*B*	0.3
Total number of demanders in response to service resources	*SDR*(*j*)	*DR*(C1-*j*) + *DR*(C2-*j*)
Increase in business response success	*RRS*(*j*)	INTEGER (IF THEN ELSE(*RDR*(*j*)< *WWR*(*j*), *RDR*(*j*), *WWR*(*j*)))
Increase in service resources waiting for a response	*WWR*(*j*)	INTEGER((*WSR*-*ER*) * *RP*(*j*))
Increase in service resources exiting the system	*ER*	INTEGER (STEP (1000*RANDOM NORMAL (0, 1, 0.1, 0.2, 0.3),10))
Total number of business response success	*S*	INTEG (NTEGER(*RRS*(V1*)* + *RRS(*V2)))
Total number of service resources waiting for response	*WSR*	INTEG(INTEGER(*WR*-*ER*-*WWR*(V1)-*WWR*(V2)))
Increased number of platform-matched resources	*WR*	INTEGER (RANDOM NORMAL (0, 3000, 1800, 100, 100) * (1 + 0.3 * *OL*))
Resource distribution probability	*RP*(*j*)	RANDOM UNIFORM (0, 1, 0.5)

To simplify the analysis of the influencing factors, we assumed: (i) The platform has two types of vehicle and goods sources, as listed in Table II. Cargo owners have similar requirements, and compete for the same vehicle sources. It used to represent the resource competition problem. (ii) Upon receiving a response from the demander, the supplier will accept it. This study did not consider cases where supplier refused to respond.

Table II: Vehicle and cargo classification.

Cargo	**Weight** /t	**Type**	**Vehicle**	**Load** /t	**Type**
C1	0.8	Ordinary cargoes	V1	0.8	Van
C2	0.8	Special cargoes	V2	1	Buggy

Then the initial CLD is detailed and transformed into the SD model of the business response process in Vensim, as shown in Fig. 4.

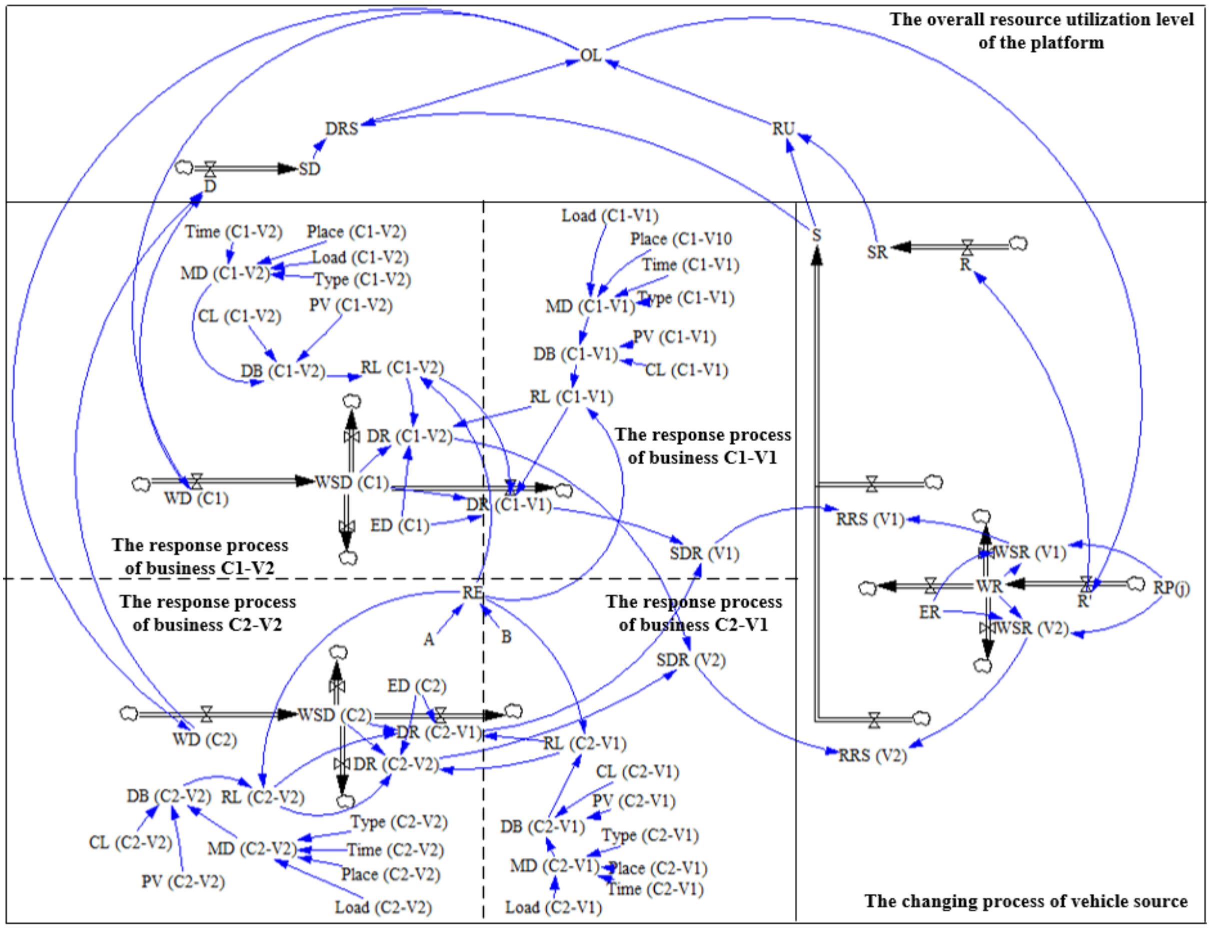


Figure 4: System dynamics model of the business response process.

The response process between the two types of cargo sources and the two types of vehicle sources results in four groups of response businesses: The response process of business C1-V1, the response process of business C1-V2, the response process of business C2-V1 and the response process of business C2-V2. The system dynamics model is divided into three parts: the response process of the four businesses, the changing process of vehicle source, and the overall resource utilisation of the platform.

The variable (factor) definitions and equations are listed in Table I. The equations and data were derived from research and references, and adjusted by comparison with the real system. Here, resource distribution probability (*RP*(*j*)) is represented by the proportion of a certain type of resources in the all resources at each moment.

4. SIMULATION AND DISCUSSION

After validating the model, the input factors that affect the observed variables were first obtained (Fig. 5) according to Fig. 3, including the decision attributes (compatibility, profit, etc.), the resource distribution probability, the visibility and comprehensiveness of the response support information. The visibility and comprehensiveness of the response support information are determined based on the development level of the platform. They are generally not adjusted in the operation. Therefore, these factors are divided into controllable and uncontrollable factors according to whether the platform is controllable, as shown in Fig. 5. This provides a direction to improve the business response stage. Therefore, the impacts of the controllable factors were investigated through simulation.

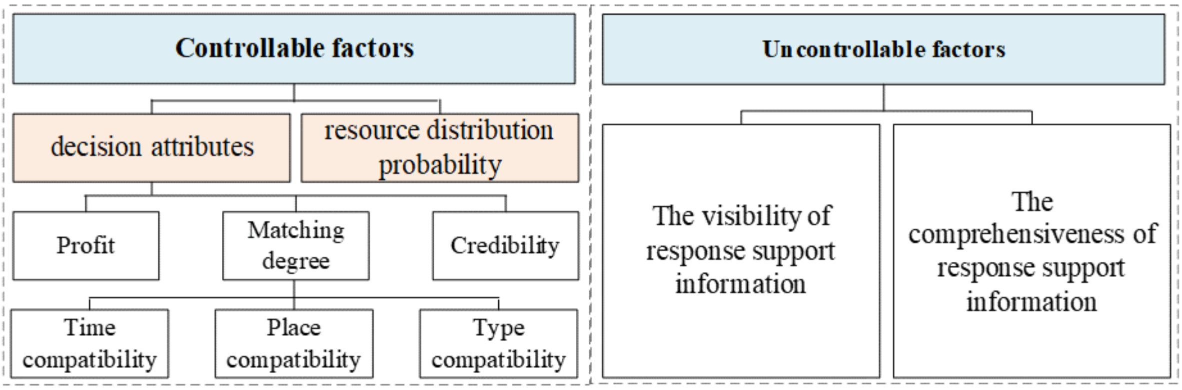


Figure 5: Factor affecting the observed variables.

The initial simulation parameters were set as follows: initial time = 0, final time = 365, time step = 1, and unit of time = day. The changing trend of the observed variables were analysed by comparing the basic situation with that after changing the parameters.

4.1 Simulation analysis of decision attributes

A single-factor simulation analysis was firstly conducted using the quality of response as the observation index. The simulation results revealed which factors had the highest impact on the quality of response. Subsequently, these key elements were used to discuss the impact of decision attributes on the overall resource utilisation of the platform.

Take business C1-V1 as an example (the simulation process for other business groups is similar). In the simulation, the compatibility of type, load, and volume were all uniformly set to 1 for C1-V1. Thus, only the compatibilities of time, location, credibility, and profit were investigated by increasing 0.1, as shown in Table III.

Table III: Parameter settings of C1-V1.

Scenario	Time	Place	Credit	Profit
Initial	0.5	0.3	0.6	0.3
Simulation of time compatibility	**+0.1**	0.3	0.6	0.3
Simulation of place compatibility	0.5	**+0.1**	0.6	0.3
Credit simulation	0.5	0.3	**+0.1**	0.3
Profit simulation	0.5	0.3	0.6	**+0.1**
Comprehensive simulation	**+0.1**	**+0.1**	**+0.1**	**+0.1**

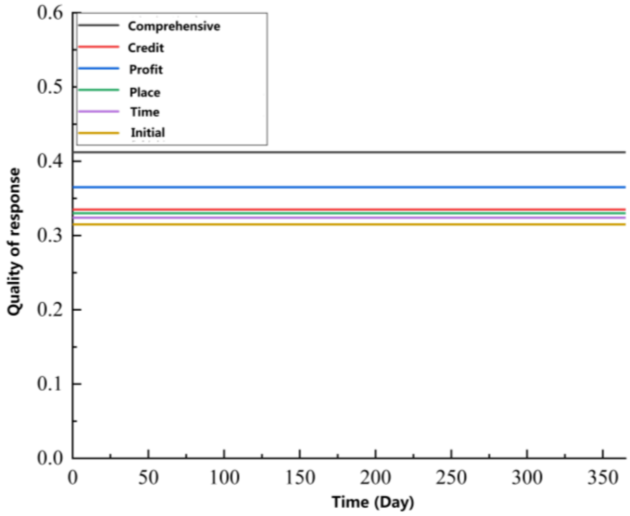
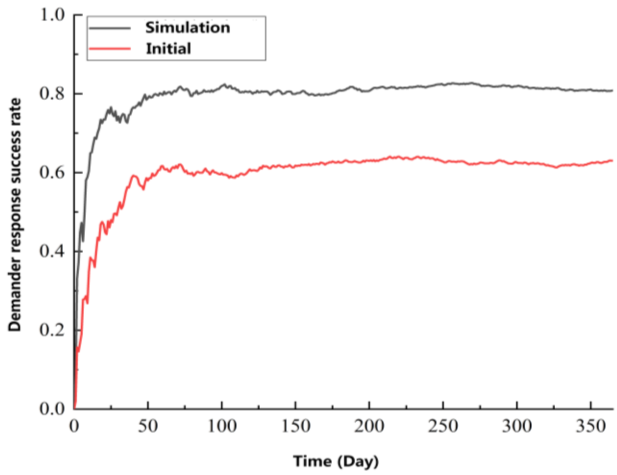


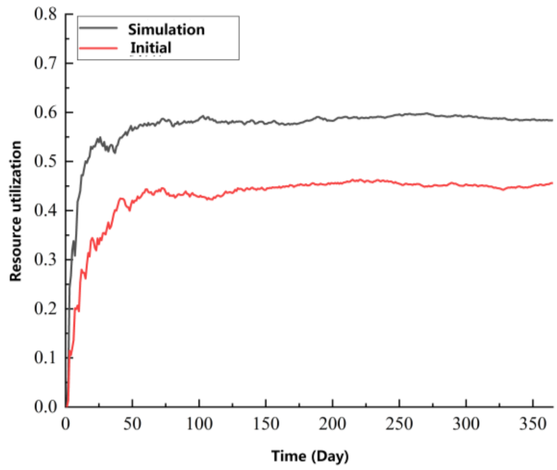
Figure 6: Changes in the quality of response.

Changes in the quality of response are as shown in Fig. 6. With the same change, the modelling results (Fig. 6) indicate that improving any the compatibility, credit, and profit produces a higher business (response) quality, which assists the demander in making a decision. Furthermore, the effect of simultaneously improving all the attributes was the most visible. This effect can be attributed to the fact that the judgment of a demander at any given moment is based on multiple factors. Thus, the simultaneous improvement of all decision attributes facilitates the decision-making process for the demander, whose result most meets the willingness of the demander. Furthermore, the profit brings the greatest improvement of the business response level. It shows a higher influential weight compared with any other single attribute. This means the demander is more concerned about the profits generated by resources. Furthermore, taking the comprehensive improvement of the decision attributes as the optimisation measure, the impact of the decision attributes on the overall resource utilisation of the platform is discussed below.

In the initial scenario, the distribution of the decision attributes of each business group was a random normal distribution within 0-0.5. After the comprehensive improvement of the decision attributes, the limits of the random normal distribution became 0.5-1. The changes in the demander-response success rate and resource utilisation are shown in Fig. 7.



a) Demander response success rate



b) Resource utilisation

Figure 7: Changes in observable indicators.

As shown in Fig. 7, the initial response success rate and the resource utilisation rate can only reach about 0.6 and 0.4, respectively; improving the decision attributes may increase the user response success rate and resource utilisation to a certain extent. The average success rate of the demander response of 365 days increases by 19.73 %, whereas the average resource utilisation rate increases by 14.23 %. It means that the resources with improved attributes are more in line with the decision-making response needs of the demander. Consequently, more resources are being utilised by the demander, thereby avoiding resource wastage and improving platform resource utilisation. Moreover, timely responses are more likely to prevent failure owing to missed response times, thereby increasing the success rate of user requests. However, this improvement is limited (the change curve in Fig. 7 finally tends to be horizontal) because when the amount of resources matched by the platform is limited, excessive demand response leads to competition.

The results above indicates that a significant improvement in each attribute can result in a corresponding improvement in resource quality, response success rate and resource utilisation. This implies that the platform can induce an improvement in quality, the transaction rate and resource utilisation by controlling business attributes, especially for insufficient resources and inferior resources. Further, it means that improving the accuracy of business matching, business expected profit, and business side credit are all effective measures to promote business response and resource utilisation. However, compared with ensuring the expected profit of the business and the credit of the business side, the effect of improving the accuracy of business matching is not outstanding. This means the matching algorithms and models currently intensively studied can improve the efficiency of business matching, but have limited effect on improving the utilisation of resources. In addition, the influence of each attribute is different. Therefore, in the design of matching models and algorithms, priority should be given to more accurately ensure the attribute requirements such as place, that is, it is suggested the matching model treats each business attribute differently, such as giving different weights.

At the same time, it should ensure the credit of business transaction parties. Therefore, the RMP needs to strengthen the evaluation and utilisation of business party credit, especially the responsible screening of high-quality business parties, which is essential to guarantee the transaction volume and healthy development of the platform. The results also mean that resources with high profit are more active in transaction. For inferior resources with low expected profit, it is suggested that the platform induce an improvement through profit incentives and punishments, such as providing subsidies to demanders responding to inferior resources or providing additional value-added services. Such measures guide the demanders to react to inferior resources and avoid resource wastage. This is consistent with reality.

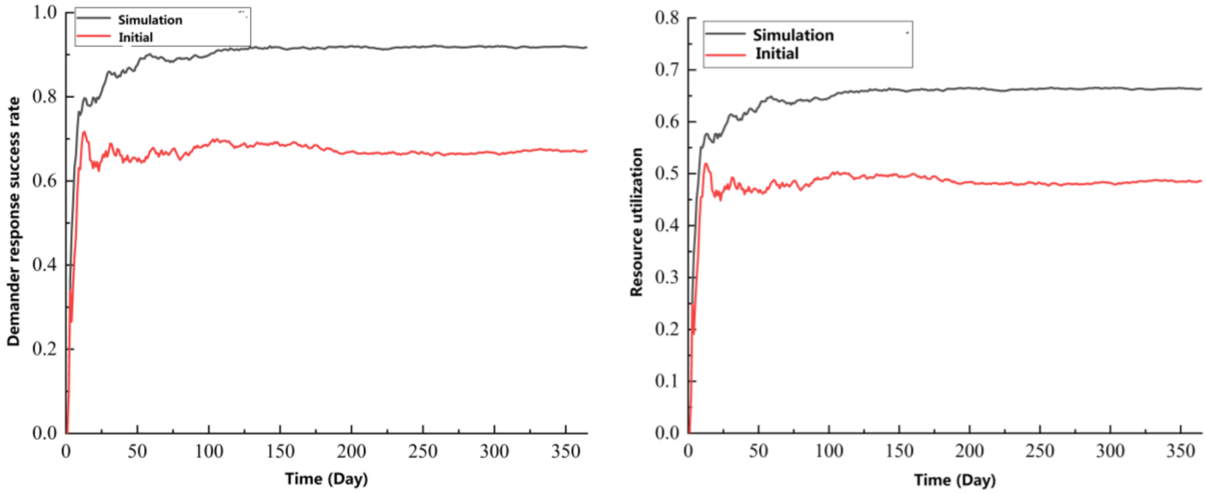
4.2 Simulation analysis of resource distribution probability

In the initial scenario, suppose the cargo owner and vehicle source V1 have a high response level, and the vehicle source distribution probability of V1 is a random distribution between 0-0.5. In the contrast scenarios, the response levels of the cargo owner and vehicle source V1 remain high, and the vehicle source distribution probability of V1 is a random distribution between 0.5-1.

The changes in the demander response success rate and resource utilisation are presented in Fig. 8 and Table IV.

Table IV: Changes in observable indicators.

Scenario	Average demander response success rate	Average resource utilisation
Initial	66.52 %	47.98 %
Simulation	89.52 %	64.58 %
Changes	+23 %	16.6 %



a) Demander response success rate b) Resource utilisation

Figure 8: Changes in observable indicators.

The simulation results demonstrate that the platform can effectively improve the overall resource utilisation by adjusting the resource distribution probability according to the demand response process, simultaneously address the response requirements of the demander largely. This is because the matching resources of the platform affect the decision response behaviour of the demander at a given time. Resources with higher quality (indicated by higher total decision attribute value of the resource at a specific time), exhibit better conformity with the decision response demand on the demander. Consequently, the decision response willingness of the demander is stronger. It implies through coordinating the resource business distribution such as control the number and order of matching businesses in each specific time window, the platform could guide the decision-making behaviour of the demander. Consequently, the platform can solve the problem of resource competition, and prevent decision-making competition. Furthermore, the average response success rate and resource utilisation rate increases by 23 % and 16.6 % (Table IV), respectively, which is higher than that of improving decision attributes. This means adjusting business distribution is more effective, but its cost is generally lower. Consequently, it suggests that adjusting business distribution should be the priority strategy for the platform to solve resource competition.

Moreover, the simulation assumed the demander is inclined to respond to the V1 vehicle source, and the platform is providing more V1 resources in response by increasing its probability. Theoretically, the introduction of more similar resources will increase competition, but the fact is reducing the competition among demands and improving the success rate of user responses. This may be more demand has the opportunity to trade. This shows that when coordinating business responses, the platform should focus on the demand situation, ensure the coordination of supply and demand responses, such that minimize resource competition to improve the success rate of the users' responses. Therefore, the platform would always monitor the agglomeration and distribution of demands, determine the development direction of special resources in real time with the maximum demand, and organise and control matching resources to guide user transactions. For example, carrying out specialized business resource supply in time division. In this manner, the platform can accurately introduce more high-quality resources to improve its business response level, promote the demand side to perform transactions on the platform, and ensure the long-term operation and development of the platform.

5. CONCLUSION

RMPs currently lack control over the actual business response of supply-demand, which increases resource competition in the process of business response, resulting in ineffective transactions and limited utilisation of resources (60% of resources may be wasted). This study utilised SD and constructed a SD model of the business response stage of RMPs to investigate the impact of business response on resource utilisation. Using the SD model, this study simulated and analysed how factors that can be controlled by the platform influence resource utilisation, and achieved the optimisation measurements. It enriches the research on RMPs. Furthermore, it provides a framework for applying SD to the matching resources.

Although the SD model takes the logistics information platform and four specific matching businesses as examples, assuming that the supplier will certainly accept the business response request of the demander, it cannot completely mimic the actual competition state, but it reproduces the response process of RMPs, and the influence laws obtained is suitable for all RMPs.

The decision attributes such as compatibility, credit and profit and the resource distribution have impacts on the user response, transaction success rate and the resource utilisation. Further, the profit attribute has a higher influential weight, and resource distribution is more influential than decision attributes. An improvement in each of these factors can bring a corresponding improvement in resource response quality, the resource utilisation and response success rate. This is conducive to the healthy development of the platform. Control of business distribution shall be the priority strategy for business completion. It is suggested that business response with platform regulation can achieve coordinated responses between supply and demand. Moreover, according to the impacts of expected profits, RMPs can implement incentives or punishments to guide and improve the decision-making behaviour of the demander, guide their response to inferior resources, and prevent resource competition caused by centralized decision-making. Resource distribution can also be reasonably coordinated according to business response at every moment to ensure coordinated responses between supply and demand. The above-mentioned optimisation strategies provide a solid theoretical foundation to implement resource scheduling and perfect functions of RMPs. Furthermore, the developed SD model provides a tool to predict actual impacts of adopted adjustment strategies like subsidy amount.

The simulation assumed the demand/service resources entering the platform are normally distributed. In fact, they may vary depending on the type of resource. Next, more distributions can be considered to investigate how coordination control can be used to optimise the platform. Secondly, in the future, we will develop and examine the resource scheduling of the matching platform from the perspective of this optimisation effect, in addition to the specific implementation path of coordination control on the platform.

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