Influencing Factors of Delivery Delay in the Cross-Border Supply Chain of Construction Materials in Dawan District Based on ISM-MICMAC

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Abstract. The construction of cross-border infrastructure in Guangdong, Hong Kong and Macao Greater Bay continues to advance, and the demand for cross-border transportation of engineering building materials continues to increase. The delivery efficiency of building materials has gradually become an important factor affecting project progress and project cost. Compared with the ordinary internal supply chain, the Dawan District Engineering building materials supply chain has the industrial characteristics of "large volume, high efficiency and strong construction dependence" of engineering building materials, as well as the institutional characteristics of cross cross-regional transportation, port supervision and Multi-Agent Coordination. Focusing on the problem of "delivery delay in the cross-border supply chain of construction materials in Dawan district", this paper identifies five influencing factors, including supplier management, logistics and transportation, customs clearance and supervision, cross-regional coordination, policy and external environment. And introduces the ISM-MICMAC method to analyze the hierarchical structure and driving mechanism among the factors. The research shows that cross-regional synergy factors and policy and external environmental factors are deep driving factors; customs clearance and regulatory factors have a linkage effect, while supplier management factors and logistics transportation factors are more represented as transmission links. Based on this, this paper puts forward some strategies, such as improving the cross-regional coordination mechanism, establishing the external risk early warning mechanism, promoting the coordination of customs clearance supervision, strengthening the supplier plan management and optimizing the cross-border logistics organization.

Keywords: GBA; Engineering building materials; Cross-border supply chain; Delivery delay; ISM-MICMAC

1. Introduction

The GBA is a national key strategic area. Major projects such as Qianhai, Hengqin and the northern metropolitan area of Hong Kong continue to advance, which puts forward higher requirements for the cross-border supply of engineering building materials. The outline of the development plan for the GBA proposes strengthening the interconnection of infrastructure and forming an infrastructure network with smooth connection and efficient operation. Relevant studies also pointed out that the logistics network of the GBA area has obvious cross-city connection characteristics, and the regional logistics organization is affected by factors such as spatial connection, traffic conditions and urban functional division [1]. In this context, cross-border delivery of engineering building materials is not only a logistics activity, but also related to the project progress, construction organization and regional supply chain coordination ability.

From the perspective of actual conditions, the supply capacity of basic building materials in Hong Kong and Macao is relatively limited. Some engineering materials such as cement, gravel, steel and prefabricated components rely on the supply of the Pearl River Delta, gradually forming a supply mode of "mainland production - Port Supervision - cross-border transportation - use in Hong Kong and Macao". According to the Hong Kong Development Council, Hong Kong will import about 3.1 million tons of cement in 2024, and the imported crushed stones for concrete and asphalt will mainly come from many quarries in Guangdong Province. At the same time, in 2023, Panyu customs supervised the export of about 700000 tons of building materials from Hong Kong and Macao, and the average daily output of about 3000 tons of building materials from Lianhuashan pass bank for

Hong Kong; In 2023, the number of inbound and outbound trucks of Hong Kong–Zhuhai–Macao Bridge exceeded 575600, and the freight volume reached 2.5976 million tons. These data show that the cross-border supply of engineering building materials in Dawan district has a realistic scale and cross-regional characteristics.

Cross-border delivery of engineering building materials is not simple point-to-point transportation, but a continuous system composed of demand planning, supplier stocking, logistics transportation, Port declaration and inspection, cross-border connection and engineering use.

Relevant studies have pointed out that whether the materials can be delivered to the construction site in time is closely related to the material plan, site reception, unloading arrangement and supply chain coordination [2]. In the cross-border scenario, this process is also affected by customs clearance regulations, channel operation and changes in the external environment. For example, the suspension of operations of some quarries in the mainland during the epidemic affected the supply of gravel in Hong Kong and the original project plan; Affected by the typhoon, the Zhuhai Highway port of HZM Bridge has also suspended the exit customs clearance service, and the main bridge has been temporarily closed. Therefore, the cross-border delivery delay of engineering building materials is not a single transportation speed problem, but the result of the joint action of the supply side, transportation side, customs clearance side, coordination side and the external environment.

Based on the above background, this paper takes the delivery delay of the cross-border supply chain of engineering building materials in Dawan district as the research object, identifies the influencing factors by combining the case data of the transportation of building materials for Hong Kong and Macao. And the operation of the HZM Bridge and introduces the ISM-MICMAC method to analyze its hierarchical relationship and driving mechanism. This paper aims to answer what are the influencing factors, how different factors interact, and which factors should be the focus of governance optimization. Theoretically, this paper is helpful to the research of the cross-border supply chain of supplementary engineering building materials; In practice, it can provide reference for the logistics organization, customs clearance coordination and supply chain stability improvement of cross-border projects in Dawan district.

2. Identification of Factors Affecting Delivery Delay

Based on case analysis and literature research, this paper identifies the influencing factors from the perspective of the whole supply chain process.

Cross-border delivery of engineering building materials involves demand planning, supplier stocking, logistics and transportation, port customs clearance, cross-border connection and project use; At the same time, the cross-border environment of Dawan district also makes it affected by regulatory rules, cross-regional coordination and changes in the external environment. Previous studies have pointed out that the logistics network in GBA has obvious regional connection characteristics, and the logistics operation is affected by factors such as traffic conditions, urban functional division and spatial connection [1]. Therefore, this paper classifies the influencing factors of delivery delay into five categories: supplier management factors, logistics and transportation factors, customs clearance and supervision factors, cross-regional coordination factors, policy and external environmental factors.

Supplier management factors mainly affect the front-end supply preparation, including stock capacity, production plan stability, order response speed and material supply guarantee ability. Engineering building materials are an important part of engineering project construction, and their logistics management level will directly affect the project schedule, cost and construction organization [3]. In the Dawan District scenario, the supplier's untimely goods preparation will not only affect the material delivery node, but also further affect the transportation arrangement, customs declaration and on-site reception.

Logistics transportation factors mainly affect the process of material space transfer. Engineering building materials are generally large in volume, weight and bath, and have high requirements for

vehicles, ships, loading and unloading facilities and transportation routes. The practice of building materials in Hong Kong and Macao shows that the Lianhuashan pass bank and the surrounding wharfs undertake important building materials distribution functions. If the transportation resources, loading and unloading connections, or route organization are insufficient, it is easy to cause waiting and cycle fluctuations.

Customs clearance and regulatory factors reflect the constraints of cross-border nodes, mainly including document preparation, inspection time, regulatory process and standard requirements. Cross-border supply chain research points out that customs clearance procedures will increase the time cost and coordination cost of the supply chain, and information sharing and collaborative governance will help reduce its impact [4,5]. Therefore, in the cross-border delivery of engineering building materials, the efficiency of customs clearance and supervision directly affects the transportation connection and arrival stability.

Cross-regional collaborative factors run through the whole process of the supply chain, including information sharing, Multi-Agent Coordination, planning convergence and emergency linkage. The cross-border supply chain of engineering building materials involves suppliers, logistics enterprises, customs, ports, construction units and project parties. If there is no timely connection between demand planning, goods preparation status, transportation arrangement and customs clearance information, it is easy to cause repeated waiting, plan conflict and idle resources. The study of supply chain disruption also shows that the complexity of the external environment and the lack of coordination among supply chain entities will magnify the risk of supply disruption [6].

Policy and external environmental factors mainly include temporary traffic control, extreme weather, public emergencies and changes in port operation status. Such factors are highly uncontrollable, but have a significant impact on transportation routes, customs clearance arrangements and supply stability.

Table 1. Influencing factor system of delivery delay in cross-border supply chain of engineering building materials.

Primary factor	primary coverage	Impact performance
Supplier management factors	Stocking capacity, production plan, order response, supply guarantee	Material delivery lags behind, affecting subsequent transportation and customs clearance
Logistics transportation factors	Transportation resources, route stability, loading and unloading connection, planning connection	Transportation waiting, poor connection, and lead time fluctuation
Customs clearance and regulatory factors	Document preparation, inspection time, regulatory process, standard difference	Port waiting, uncertain release, transportation plan adjustment
Cross regional synergy factors	Information sharing, Multi-Agent Coordination, plan connection and emergency linkage	Supply, transportation, customs clearance and construction demand dislocation
Policy and external environmental factors	Weather, traffic control, emergencies, port operation status	Cross border channels are limited, and the stability of the supply chain is reduced

Table 1 shows that the five factors are not isolated from each other. Supplier management and logistics transportation are closer to the implementation link. Customs clearance and supervision reflect the constraints of cross-border nodes. Cross-regional collaboration runs through the whole process. Policies and external environment reflect external uncertainty. It is necessary to further analyze the hierarchical relationship and driving mechanism between these factors.

3. Analysis of Influence Factors based on ISM-MICMAC

3.1. Method Logic and Variable Setting

This paper uses the ISM-MICMAC method to analyze the relationship between the factors affecting the delivery delay of the cross-border supply chain of construction materials in Dawan District. The data are mainly from policy documents, public information, case information and existing literature.

Among them, policy documents and public data are used to explain the realistic background of the cross-border supply of engineering building materials in Dawan District. Case information is used to analyze actual scenarios such as the transportation of building materials for Hong Kong and Macao. The channel operation of the HZM Bridge and port customs clearance, and existing literature, are used to support the identification of influencing factors and the judgment of the relationship between factors.

In terms of factor relationship judgment, this paper combines the case facts, literature conclusions and cross-border supply chain operation logic to set. For example, the lack of cross-regional collaboration will affect supplier response, transportation scheduling and customs clearance;

Changes in policies and external environment will affect the transport corridor, port operation and supply chain stability; Customs clearance and regulatory factors will further affect the logistics connection and delivery cycle. Therefore, this paper takes this as the basis for constructing a factor relationship matrix and carrying out ISM-MICMAC analysis.

The interpretative structural model (ISM) applies to transforming the relationship between complex factors into a hierarchical structure, and is used to identify deep root factors, intermediate conduction factors and surface result factors. The MICMAC method calculates the driving force and dependent force based on the reachability matrix, and is used to identify independent driving factors, linkage factors, dependent factors and independent factors [7,8]. In the study of supply chain risk and logistics capability, ISM-MICMAC is often used to reveal the transmission path and key drivers in a multifactor system [9,10]. Therefore, this paper uses this method to analyze the hierarchical relationship and driving mechanism between the delivery delay factors in the cross-border supply chain of construction materials in Dawan district.

This paper directly uses the five first-class factors identified above as the analysis variables, and sets "delivery delay" as the result node D. It should be noted that D is not a new influencing factor, but the result of the joint action of five types of factors. The number, name and meaning of each variable are shown in Table 2.

Table 2. ISM-MICMC analysis variables

Numble	Variable name	Meaning
S1	Supplier management factors	Supply preparation and order response
S2	Logistics transportation factors	Transportation resources, routes and connecting organizations
S3	Customs clearance and regulatory factors	Declaration, inspection, release and standard difference
S4	Cross regional synergy factors	Information sharing, subject coordination and emergency linkage
S5	Policy and external environmental factors	Weather, control, emergency and port operation
D	Delivery delay	Lead time fluctuation, transportation detention and unstable arrival

3.2. ISM Hierarchy Analysis

According to the case data and literature logic, this paper constructs the factor relationship matrix and obtains the reachable matrix through Boolean operation. ISM analysis aims to reveal the hierarchical relationship between the five influencing factors and delivery delay, to determine which

factors belong to the deep root, which factors belong to the intermediate transmission link, and which factors belong to the final result.

The analysis results are shown in Figure 1. The delivery delay of the cross-border supply chain of construction materials in Dawan district is not directly caused by a single link, but a systematic result formed by the gradual conduction of deep-seated factors. The cross regional synergy factor (S4) and the policy and external environment factor (S5) are at the bottom, indicating that insufficient information sharing, poor Multi-Agent Coordination, extreme weather, temporary control and port operation changes have a source effect, which will further affect the supplier's goods preparation, transportation organization and customs clearance, and ultimately lead to the instability of material arrival, the fluctuation of delivery cycle and the adjustment of construction plan.

Therefore, optimization should first focus on cross-regional coordination and external risk response. On the one hand, an information sharing mechanism covering the project party, suppliers, logistics enterprises, regulatory service subjects and construction units should be established to uniformly coordinate the demand plan, supply status, transportation arrangement, customs clearance progress and on-site reception, so as to reduce plan dislocation and communication costs. On the other hand, should establish a risk early warning mechanism for weather, port operation, traffic control and upstream supply changes, and configure backup suppliers, backup transportation routes and temporary storage nodes to improve the toughness of the supply chain. Christopher and Peck pointed out that the construction of supply chain resilience needs to pay attention to risk identification, collaboration and rapid response ability, which is consistent with the risk governance requirements of the cross-border supply chain of engineering building materials in Dawan district [11].

The supplier management factor (S1), logistics transportation factor (S2) and customs clearance and regulatory factor (S3) in the middle layer are the key links for the transmission of deep-seated factors to delivery delays, which affect the production and shipment of materials, cross-border transfer and port passage, respectively. Therefore, the optimization at the executive level should be combined with the deep-seated coordination mechanism to improve the stability of the supply side and the transportation side through rolling material demand planning, hierarchical management of key suppliers, transportation reservation and batch scheduling, and linkage between transportation planning and customs clearance planning.

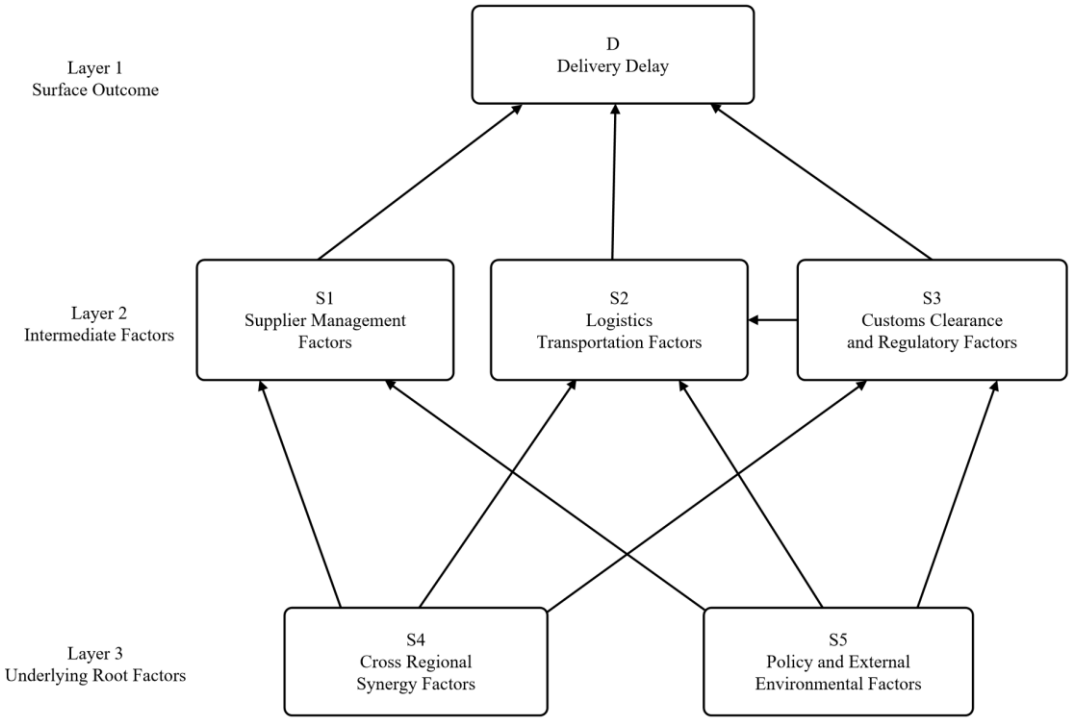


Fig. 1. ISM hierarchy of cross-border supply chain delivery delay of construction materials in Dawan District.

3.3. Micmac Driving Force Dependence Force Analysis

Based on the reachability matrix, this paper further calculates the driving force and dependent force of each variable and judges the action attribute of different factors in the system. Previous studies have shown that the ISM-MICMAC method is suitable for analyzing multi-factor systems such as supply chain risk, logistics capability and construction supply chain risk, and can identify key drivers and conduction nodes through driving forces and dependence forces [8,12]. Micmac analysis results are shown in Figure 2 and Table 3. Cross regional synergy factor (S4) and policy and external environment factor (S5) have high driving force and low dependence, which are independent driving factors; Customs clearance and regulatory factors (S3) have a certain driving force and dependence, which are linkage factors; The supplier management factor (S1) and logistics transportation factor (S2) are highly dependent and are dependent factors; Delivery delay (d) has the highest dependency and is the result node of system operation.

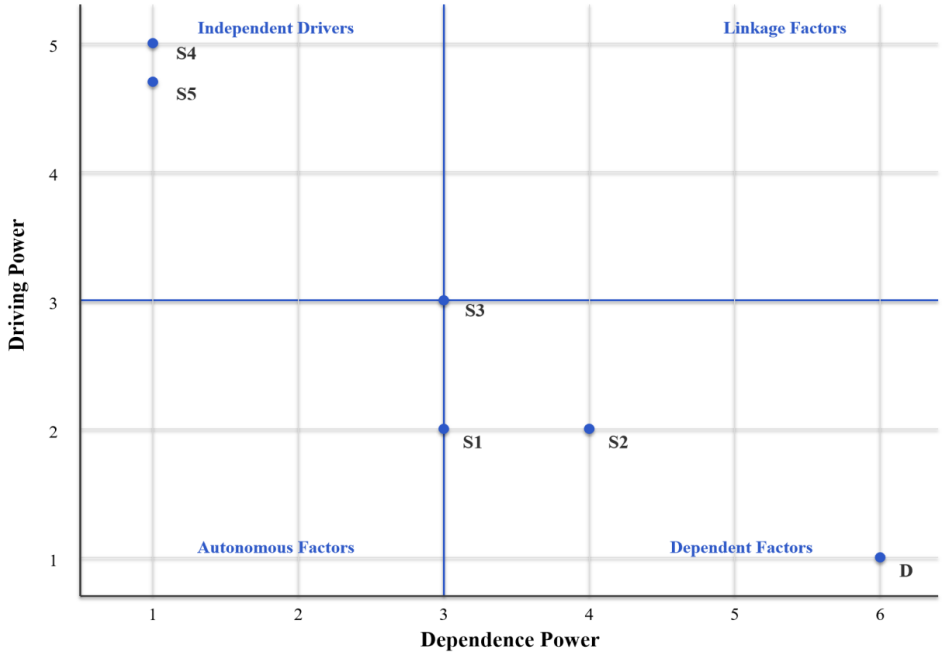


Fig. 2. Micmac driving force dependent force analysis diagram.

Figure 2 shows that S4 and S5 are located in the independent driving area with high driving force and low dependence, indicating that cross-regional synergy and policy and external environment are the source variables of delivery delay, which should be treated first. The two restrict supplier response, logistics organization and customs clearance efficiency mainly by affecting information sharing, subject coordination, transportation channels and port operations. Therefore, governance should be preceded by the construction of a coordination mechanism and external risk early warning.

Table 3. Micmac classification results.

Type	Number	Factorname	Managementimplications
Independent drivers	S4, S5	Cross regional synergy factors; Policy and external environmental factors	Deep driving, priority should be given to governance
Linkage factors	S3	Customs clearance and regulatory factors	Connecting the preceding and the following, affecting the stability of transportation and delivery
Dependent factors	S1, S2	Supplier management factors; Logistics transportation factors	Direct impact on delivery, but restricted by deep-seated factors
Result node	D	Delivery delay	Surface results after multiple factors

Table 3 further shows that the key to the delivery delay of the cross-border supply chain of construction materials in Dawan District lies not in a certain implementation link itself, but in the continuous impact of deep driving factors on the supply chain system. As independent driving factors, S4 and S5 indicate that cross-regional information sharing, subject coordination, emergency linkage, policy environment, weather, control and port operation status have a direct impact on supplier response, customs clearance efficiency and transportation stability.

In other words, the governance of delivery delay should give priority to the collaborative mechanism and external risks, rather than only remedy after the delay occurs.

S3 customs clearance and regulatory factors are in the linkage position, which shows that it is not only affected by the policy environment and the level of cross-regional coordination, but also will further affect the logistics connection and delivery cycle. The uncertainty of the customs clearance link will magnify the transportation waiting and plan dislocation, so it is an important node connecting the deep driving factors and the implementation link.

In contrast, although S1 supplier management and S2 logistics transportation have a direct impact on the delivery process, they are more constrained by S4, S5 and S3, which are highly dependent executive factors.

4. Conclusion

This paper focuses on the delivery delay of the cross-border supply chain of construction materials in Dawan district. Based on the realistic background and case data. It identifies five main influencing factors: supplier management, logistics and transportation, customs clearance and supervision, cross-regional coordination, policy and external environment, and uses the ISM-MICMAC method to analyze its hierarchical structure and driving mechanism. The research shows that the cross-border delivery delay of construction materials in Dawan district is not a single transportation efficiency problem, but a systematic result of supply preparation, transportation implementation, port supervision, regional coordination and external environment.

ISM analysis shows that cross-regional synergy factors and policy and external environmental factors are at the bottom of the model, which are the deep driving factors affecting delivery delay. The factors of supplier management, logistics transportation, customs clearance and regulatory factors are located in the middle layer, which are the main transmission links in the process of delay formation. And delivery delay is the surface result of multi-factor superposition. Micmac analysis further shows that cross-regional collaboration and the external policy environment have strong driving forces, customs clearance and regulatory factors have a linkage effect, while supplier management and logistics transportation factors are more restricted by deep factors.

Therefore, the treatment of cross-border delivery delay of engineering building materials should not only stay at the level of "accelerating transportation" or "urging suppliers" but should focus on improving cross-regional information sharing, external risk warning, customs clearance supervision coordination, supplier plan management and logistics transportation organization optimization from the perspective of system coordination.

There are still some limitations in this paper. Firstly, the research is mainly based on public data, case analysis and literature induction. The factor relationship matrix has not been further verified by large-scale questionnaires or expert interviews, and the conclusion is still exploring. Secondly, the case mainly focuses on the transportation of building materials for Hong Kong and Macao and the cross-border channel of the HZM Bridge. There may be differences in the influencing factors under different types of building materials, engineering types and transportation modes. The scope of application of the research conclusion still needs to be further expanded. Finally, this paper focuses on the structural relationship analysis and has not yet carried out a quantitative test on the importance of weight and action intensity of each factor.

Follow up research can be combined with expert scoring AHP, DEMATEL, Structural equation model or actual project operation data, further verify the relationship between influencing factors and

their action intensity, and carry out comparative analysis in combination with more cross-border engineering cases, so as to enhance the universality and practical guidance value of the research conclusion.

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