# Analysis on the Construction Path of Supply Chain Collaboration System for Small, Medium and Micro Enterprises

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***Abstract:*** *Small, medium and micro enterprises are generally faced with structural constraints such as resource fragmentation, information transmission distortion, and lagging collaborative response in the supply chain network, and the traditional collaboration model designed for large enterprises cannot be directly applied to them. To address this issue, this paper constructs a supply chain collaboration system for small, medium and micro enterprises from three levels: constituent elements, dynamic coupling mechanism, and embedding path. First, this paper defines the basic constituent elements of the collaboration system based on heterogeneous resource dependence, multi-level information transmission nodes, and transaction density thresholds. Second, this paper proposes a trigger-response sequence driven by orders, distributed coordination rules for inventory buffers, and a deviation correction path for the synchronization of logistics and capital flows, thereby forming a dynamic coupling mechanism. Finally, this paper designs a modular access method with lightweight digital interfaces, a trust accumulation model based on short-term reciprocity, and a node exit and substitution logic under a flexible collaboration framework as the embedding path. The above framework provides a systematic theoretical basis for small, medium and micro enterprises to achieve low-threshold and high-resilience supply chain collaboration.*

***Keywords:*** *small, medium and micro enterprises; supply chain collaboration system; dynamic coupling; trust accumulation; modular access*

## Introduction

Small, medium and micro enterprises, serving as a large number of nodes in the supply chain network, have their operational efficiency directly affecting the stability and response speed of the entire chain. However, these enterprises show significant differences from large enterprises in terms of resource endowment, information processing capability, and transaction relationship structure, which makes it difficult to directly adapt the existing key collaboration models. Constructing a supply chain collaboration system for small, medium and micro enterprises requires starting from basic issues such as resource dependence characteristics, information transmission distortion patterns, and transaction density distribution, and redesigning the trigger rules, buffer coordination mechanisms, and flow synchronization paths for collaboration. Meanwhile, technical barriers, lack of trust, and node instability constitute the practical obstacles for small, medium and micro enterprises to participate in collaboration, and there is an urgent need to develop lightweight access methods, quantifiable trust accumulation models, and flexible exit and substitution logic. Therefore, this study conducts an analysis from three dimensions, namely constituent elements, dynamic coupling mechanism, and embedding path, aiming to fill the gap in the supply chain collaboration theory for small, medium and micro enterprises regarding scale heterogeneity and operational constraints, and to provide necessary theoretical support for the system design in this field.

## 1. Constituent Elements of the Supply Chain Collaboration System for Small, Medium and Micro Enterprises

### *1.1 Heterogeneous Resource Dependence in Supply Chain Collaboration for Small, Medium and Micro Enterprises*

Small, medium and micro enterprises usually do not have the advantage of economies of scale in the supply chain network, and their resource endowment is characterized by decentralization, specialization, and localization. This heterogeneous resource structure determines that the construction of the collaboration system cannot directly copy the integration model of large enterprises, and it is necessary to identify the dimensions of resource complementarity among different enterprises. Specifically, the differences in technical parameters of production equipment, the gradient of throughput capacity of warehousing facilities, and the distribution of operational skills of human resources constitute the physical foundation of resource dependence. The effective matching of heterogeneous resources relies on the identification of capability gaps among collaborative nodes, that is, the correspondence between the resource redundancy of one party and the resource constraint of the other party. Any resource integration that deviates from this correspondence will lead to a loss of collaboration efficiency and may even trigger operational conflicts between nodes.

From the perspective of resource dependence theory, the stability of the supply chain collaboration system for small, medium and micro enterprises depends on the lock-in degree and substitution elasticity of heterogeneous resources. When a node's resources are highly specialized for a specific collaborative relationship, its exit cost increases, thereby enhancing the cohesion of the collaborative network. Conversely, if the resources have high generality, the dependence between nodes tends to become weak ties, and the collaboration system becomes more susceptible to external disturbances. Therefore, the resource dependence within the constituent elements does not pursue complete complementarity but requires the establishment of a threshold interval between specificity and flexibility. The upper and lower bounds of this interval are jointly determined by the asset specificity index and the transaction frequency of small, medium and micro enterprises, and any resource combination that falls outside this interval should be excluded from the collaboration framework[1].

### *1.2 Multi-Level Information Transmission Nodes in the Collaboration System*

Information transmission nodes serve as the basic units for data flow and state synchronization in the supply chain collaboration system for small, medium and micro enterprises. Each level of node corresponds to a participating enterprise or an internal functional unit, and its information processing capacity is limited by the enterprise's own digital maturity. In a multi-level structure, information is transmitted sequentially from the source node to the end node, and at each level of node, the information undergoes filtering, delay, or noise superposition. The widespread issue of information system heterogeneity among small, medium and micro enterprises makes it difficult to directly match the data formats and transmission protocols between nodes, thereby forming an accumulated effect of transmission distortion. The degree of distortion is positively correlated with the number of transmission levels. When the number of levels exceeds a critical value, the information received by the end node loses its decision-making reference value.

To reduce information attenuation in multi-level transmission, the collaboration system needs to set an upper limit on the number of levels of information nodes and establish redundant encoding rules for key nodes. Redundant encoding refers to the simultaneous transmission of the same information via two or more independent paths and the cross-validation at the confluence point. Small, medium and micro enterprises, constrained by resources, cannot bear the cost of redundant encoding across the entire network; therefore, they implement this mechanism only for the nodes located on the critical path of collaboration. The identification of the critical path is based on the transaction volume weight between nodes and the level of time sensitivity. In addition, the geographical distribution of information transmission nodes also affects the variance of transmission delay, and an excessively large variance will undermine the basic requirement of the collaboration system for real-time response. Accordingly, the spatial clustering degree of transmission nodes should serve as an input parameter for the design of the collaboration system.

### *1.3 Defining the Collaboration Relationship Threshold Based on Transaction Density*

Transaction density reflects the weighted combination of the order interaction frequency and the transaction amount per unit time among small, medium and micro enterprises. This indicator differs from simple transaction frequency, as its calculation requires the introduction of a normalization coefficient for the order amount and the reciprocal of the order interval time. In the low transaction density range, the interactions between enterprises are intermittent and irregular, making it difficult to form a stable collaborative expectation. As the transaction density increases, enterprises begin to make adaptive adjustments to each other's operational rhythms, such as sharing inventory information or aligning production schedules. The critical point at which the collaborative relationship shifts from loose coupling to tight coupling is defined as the first threshold, and interactions below this threshold should be classified as market-based transactions rather than collaborative relationships[2].

When the transaction density continues to increase and exceeds the second threshold, excessive reliance on a single collaborative partner will lead to lock-in risk and an imbalance in bargaining power. Small, medium and micro enterprises in the high transaction density range need to introduce third-party alternative nodes or diversify the order proportion to maintain the adjustability of the collaboration system. The specific value of the second threshold is jointly determined by the enterprise's capacity flexibility and the switching cost of alternative partners. Therefore, the effective definition of a collaborative relationship is not a unified density standard across the entire network but an interval range dynamically calculated for each pair of nodes. Any transaction density that falls outside this interval should trigger a reassessment of the collaborative relationship, including adjustments to the depth of information sharing, the division of inventory responsibilities, and the response priority for exception handling.

## 2. Dynamic Coupling Mechanism of the Supply Chain Collaboration System

### *2.1 Collaboration Trigger and Response Sequence Driven by Orders*

The starting point of the operation of the supply chain collaboration system for small, medium and micro enterprises is usually the generation and transmission of purchase orders. The product specifications, delivery window, and batch requirements in the order constitute the core signals that trigger collaborative behavior. After receiving an order, the upstream node needs to determine whether to enter the collaborative response state based on its own capacity occupancy rate and work-in-process inventory level. The determination of the response state depends on the matching degree between the order urgency index and the node's remaining capacity: if the order urgency index is higher than the node's preset threshold and the remaining capacity is sufficient, the node triggers a positive collaborative response and initiates the synchronous push of information to downstream nodes; otherwise, the node triggers a negative response, needs to return the capacity constraint parameters to the source node, and requests an order rescheduling. This trigger-response mechanism transforms the order from a mere transaction document into a dynamic control signal of the collaboration system[3].

The advancement of the response sequence follows the principle of backward derivation from time, which means that the starting time window of each upstream node is reversely deduced from the final delivery node. Small, medium and micro enterprises, due to their limited production flexibility, have a relatively narrow starting time window and impose high requirements on the punctuality of the preceding nodes in the sequence. In order to reduce sequence disturbances, each node needs to generate a confirmation receipt after completing its own production task, and this receipt contains the actual completion time and the deviation amount. When the deviation exceeds the allowable range, the subsequent nodes automatically trigger a sequence reconstruction and recalculate their respective starting times and buffer requirements. The adaptive adjustment capability of the response sequence determines the flow efficiency of orders in a complex network and also serves as the core feature that distinguishes the collaboration system from static production scheduling.

### *2.2 Distributed Coordination Rules for Inventory Buffers*

Inventory buffers serve to absorb fluctuations and isolate disturbances in the supply chain collaboration system for small, medium and micro enterprises. The distributed coordination rules require each node to manage its own buffer independently, but the capacity setting and replenishment rhythm of the buffer need to maintain parameter alignment with the upstream and downstream nodes. The basis for this alignment is the transmission delay distribution between nodes and the variance of demand fluctuations. When the delivery interval of an upstream node fluctuates significantly, the downstream node's buffer needs to increase its safety stock depth accordingly. Conversely, if the downstream node has high demand forecasting accuracy, the upstream node's buffer can be appropriately reduced. This parameter alignment does not rely on a central coordination authority but is achieved through the periodic exchange of buffer state vectors between nodes[4].

The buffer state vector includes the current inventory level, the quantity of materials in transit, and the estimated time of depletion. When the depletion time of a node is less than the replenishment lead time of its upstream node, the node sends an expedited replenishment request to the upstream node and simultaneously sends a potential stockout warning to its adjacent downstream nodes. The adjacent downstream nodes adjust their consumption rates or activate backup buffers based on the warning. The effectiveness of the distributed coordination rules depends on the response sensitivity of each node to changes in the buffer state, and this sensitivity is determined by the node's own reaction lag. Small, medium and micro enterprises, due to their low degree of warehouse automation, generally have a long reaction lag; therefore, they need to set a wider buffer threshold interval to compensate for the response delay. Any buffer state that exceeds the boundaries of the threshold interval should trigger an exception handling protocol between nodes, including the suspension of non-urgent order releases and the activation of emergency transfer channels.

### *2.3 Deviation Correction Path for Synchronization of Logistics and Capital Flows*

Logistics and capital flows naturally have a time mismatch in the supply chain collaboration system for small, medium and micro enterprises. Logistics moves unidirectionally from upstream to downstream, while capital flows usually move in the opposite direction, and the velocity functions of the two are different. The velocity of logistics is affected by transportation distance, loading and unloading efficiency, and warehouse queuing, while the velocity of capital flows is constrained by settlement cycles, document circulation, and credit terms. When the velocity of logistics exceeds that of capital flows, the downstream node has not yet completed the payment after receiving the materials, thus occupying the upstream node's working capital. Conversely, if the velocity of capital flows is too fast, the downstream node is required to pay before receiving qualified materials, thereby increasing its financial risk. The measure of the deviation is the time difference between the logistics arrival time point and the capital transfer time point, which is recorded as the synchronization deviation amount.

The correction path for synchronization deviation includes two types of mechanisms: payment node realignment and logistics rhythm adjustment. Payment node realignment refers to changing the original payment terms, which stipulate payment a fixed number of days after receipt of goods, into milestone-based payments according to the logistics status, such as payment upon shipment, payment during transit, and payment upon acceptance. Upon the completion of each logistics milestone, the downstream node releases the corresponding proportion of funds. Logistics rhythm adjustment means that the upstream node dynamically adjusts the shipment batch size and shipment interval based on the downstream node's payment credit record. Nodes with good credit records receive more compact shipment schedules, while nodes with abnormal credit records have their shipment intervals extended or are required to make advance payments. The two types of correction mechanisms can be used individually or in combination, and the specific choice depends on the ratio of the node's capital turnover rate to its inventory turnover rate. The closed loop of the deviation correction path requires that each capital transfer forms a traceable matching record with the corresponding logistics unit, and this record serves as the basis for updating credit parameters in subsequent transactions.

## 3. Embedding Path of the Supply Chain Collaboration System for Small, Medium and Micro Enterprises

### *3.1 Modular Access Method of Lightweight Digital Interfaces*

The information infrastructure of small, medium and micro enterprises generally features limited computing resources and prominent software heterogeneity. The design of lightweight digital interfaces needs to strip away the heavy modules in traditional supply chain systems that do not match the scale of these enterprises, and retain only three core functions: order status synchronization, inventory level notification, and abnormal event broadcasting. Each type of function is encapsulated as an independent interface module, and the modules interact with each other through a standardized data dictionary. The definition of the data dictionary does not rely on specific commercial software but is based on industry-general material coding rules and transaction units of measurement. The modular access method allows small, medium and micro enterprises to choose to enable all or part of the modules according to their own business complexity. For the modules that are not enabled, the adjacent nodes in the collaboration network perform logical conversion on their behalf and then reintegrate them[5].

The parameter configuration during the access process follows the zero-code principle, which means that the interface adaptation is completed by filling in a configuration file rather than writing program code. The configuration file contains three elements: the node identifier, the bill of materials mapping table, and the response timeout threshold. The node identifier is used for network routing, the bill of materials mapping table resolves the differences in coding systems between different enterprises, and the response timeout threshold defines the switching condition under which the interface enters a waiting or retry state when no feedback is received. When a new node joins the collaboration network, it only needs to broadcast the three elements of its configuration file to the adjacent nodes without requiring global synchronization. This access method reduces the technical threshold for small, medium and micro enterprises to participate in the collaboration system while maintaining the loosely coupled characteristics of the network structure. Furthermore, the broadcast of the configuration file adopts a differential update strategy, meaning that a node only broadcasts the fields that have changed compared to its previous configuration, thereby reducing the amount of redundant transmission in the network and making it suitable for access scenarios of small, medium and micro enterprises with limited bandwidth resources.

### *3.2 Trust Accumulation Model Based on Short-Term Reciprocity*

Trust in the supply chain collaboration system for small, medium and micro enterprises is not a preset moral attribute but a quantifiable variable that is gradually accumulated through reciprocal behaviors in transaction history. The trust accumulation model takes the outcome of a single collaborative behavior as the basic measurement unit, and each interaction generates a reciprocity coefficient, the value of which is the ratio of the actual delivery quality to the promised delivery quality. Delivery quality includes three dimensions: the punctuality rate, the qualified rate, and the information accuracy rate. The weight of each dimension is determined by the two transacting parties through parameter negotiation before the interaction. A reciprocity coefficient greater than 1 indicates that the delivery exceeds expectations, while a coefficient less than 1 indicates that the delivery falls short of expectations. The update rule for the trust value adopts the decay-weighted moving average method, meaning that the reciprocity coefficient of recent interactions is assigned a higher weight, and the weight of historical interactions decays exponentially over time.

The characteristic of short-term reciprocity is reflected in the fact that the trust value is calculated based only on the recent limited number of interaction windows, and the window length is determined by the transaction frequency of the node. Nodes with high-frequency transactions adopt a shorter window length to respond quickly to changes in the counterparty's behavior; nodes with low-frequency transactions adopt a longer window length to smooth out occasional fluctuations. When the trust value of a node falls below a preset lower limit, the collaboration network automatically reduces its information sharing level and moves it from the real-time synchronization list to the polling query list. After the trust value recovers to the upper limit, the information sharing level is adjusted back accordingly. This model does not rely on external credit rating agencies but operates entirely based on the direct interaction records between nodes, making it suitable for collaboration scenarios of small, medium and micro enterprises that lack public credit information. Furthermore, a penalty coefficient is introduced in the calculation process of the trust value to handle malicious default or information concealment behaviors. The value of the penalty coefficient is positively correlated with the degree of information asymmetry in the default behavior, thereby restraining nodes from engaging in opportunistic behaviors after accumulating trust through short-term high-frequency transactions.

### *3.3 Node Exit and Substitution Logic Under the Flexible Collaboration Framework*

The supply chain collaboration system for small, medium and micro enterprises faces situations where a node is unable to continue participating due to capacity fluctuations, capital constraints, or equipment failures. The flexible collaboration framework requires that the exit behavior of each node follows the principle of predictability, that is, before exiting, the node sends an exit intention signal to its adjacent nodes and attaches a time series of its remaining service capacity. The exit intention signal includes a classification of exit types: planned exit and unplanned exit. A planned exit corresponds to a node's proactive adjustment of its business scope or seasonal shutdown, and its exit process gradually reduces the interaction volume according to a predetermined schedule. An unplanned exit corresponds to a sudden capacity interruption and requires the immediate activation of the substitution process. The distinction between the two types of exit is based on whether the node sends the signal three transaction cycles in advance[6].

The core of the substitution logic is the dynamic maintenance of a candidate set of backup nodes. Each node in the collaboration network maintains a list containing at least two backup nodes, and the selection of backup nodes is based on their resource similarity and geographical proximity. Resource similarity is calculated by matching the node's production equipment models and process parameters, and geographical proximity determines the incremental transportation cost after substitution. When an unplanned exit occurs for the original node, the adjacent nodes simultaneously send substitution requests to all candidate nodes in the backup node list, and each request contains the historical order parameters and time window constraints of the original node. The candidate node that first confirms acceptance obtains the substitution qualification, and the remaining candidate nodes receive cancellation notices. After the substitution is completed, the topology of the collaboration network undergoes local reconnection, and the trust value of the new node is initialized as the trust value of the original node before its exit multiplied by a discount coefficient, and this coefficient is determined by the degree of information loss during the substitution process.

## Conclusion

Starting from the resource structure, information transmission characteristics, and transaction density distribution of small, medium and micro enterprises, this paper defines the constituent elements of the supply chain collaboration system, then constructs a dynamic coupling mechanism consisting of order-triggered response, distributed inventory coordination, and flow synchronization deviation correction, and proposes three embedding paths: lightweight digital interfaces, short-term reciprocal trust accumulation, and flexible exit and substitution. This theoretical framework reveals the core logic that distinguishes the supply chain collaboration of small, medium and micro enterprises from the integration model of large enterprises, namely a loosely coupled structure based on heterogeneous resource complementarity, local information redundancy, and threshold-based relationship management. Future research can be extended in the following directions: first, exploring the differentiated value rules of parameter thresholds in the collaboration system for small, medium and micro enterprises across different industries; second, combining the trust accumulation model with distributed ledger technology to verify its performance in tamper resistance and automated execution; third, investigating the cascading failure propagation mechanism in multi-level collaboration networks to further optimize the response efficiency of the flexible exit and substitution logic.

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