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

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Abstract: *Small and medium-sized enterprises are generally less organised, so they are more likely to have problems with resource fragmentation, abnormal flow of information, slow collaborative response in the supply chain network, etc., and the traditional collaboration model for large enterprises cannot be directly applied to them. Therefore, the supply chain collaboration system for small and medium-sized enterprises and micro enterprises in this paper will be based on the three levels of constituent elements, the dynamic coupling mechanism and the embedding path. Given that there are many various resources and different thresholds for transaction density at all levels, the basic components of the collaboration system are introduced in this paper. Second, according to the above order, this paper will present the trigger-response sequence and put forward distributed coordination rules for inventory buffers, as well as a deviation correction path for the synchronisation of logistics and capital flows to build a dynamic coupling mechanism. Finally, this paper puts forward a modular access method with a lightweight digital interface, 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 can offer some general theoretical support for small and medium-sized enterprises and micro-enterprises in building low-threshold and high-resilience supply chain collaborations.*

Keywords: *Small and Medium-Sized Enterprises (SMEs), Supply Chain Collaboration System, Dynamic Coupling, Trust Accumulation, Modular Access.*

Introduction

Small and medium-sized enterprises are one of the many links in the supply chain network, and their operating efficiency directly affects the stability and responsiveness of the whole chain. However, these enterprises are not large-scale; they have limited funds and weak information processing capabilities, and the structure of their transaction relationships is different from that of large enterprises. The first problem that needs to be addressed in the construction of a supply chain collaboration system for small, medium and micro enterprises is the basic issue of resource dependence, distortion in the transmission and distribution of information about transaction density, and then the trigger rules, buffer coordination mechanisms and flow synchronization paths for collaboration should be redesigned. At the same time, there are practical problems such as technical barriers, lack of trust and node instability that hinder the participation of small, medium and micro enterprises in collaboration, and there is an urgent need to develop lightweight access methods, quantifiable trust accumulation models and flexible exit and substitution logic. Thus, the three contents of this paper will be the components, the dynamic link mode and the integration path. To solve the problem of the lack of a supply chain collaboration theory for small and medium-sized enterprises in all circumstances and at all times, this paper hopes to provide some theoretical support for system design in this regard.

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 and medium-sized enterprises generally do not have the advantage of economies of scale in

the supply chain network, and their resources are dispersed, specialised and localised. Given that the available resources are very diverse, the construction of the collaboration system should not be directly copied from the integration model of large enterprises; instead, we need to determine the dimensions of resource complementarity among all these enterprises. Technical parameters of the production equipment, the gradient of throughput capacity for the warehousing facilities, and the distribution of operating skills among the workforce are the material basis of resource dependence. To make full use of all the resources, we need to know the strengths of all the parties involved and determine whether the surplus of resources on one side can cover the shortage of resources on the other side. If the combined resources do not meet the above requirements, cooperation will be ineffective, and there will be operation conflicts among the nodes.

According to the theory of resource dependence, the stability of the supply-chain collaboration system for small, medium and micro enterprises is determined by the extent of lock-in and substitution elasticity of heterogeneous resources. If a node has the resources for a certain type of collaboration, then its exit cost will be relatively high, and thus the cohesion of the collaborative network will also be relatively strong. At the same time, if the nature of the resources is too general, the interdependence among the nodes will be that of weak ties, and the collaboration system will be more susceptible to external shocks. Therefore, there is no full coverage of the resource dependence of the constituent elements; rather, to some extent, there should be an overlap in specificity and flexibility. The upper and lower bounds of this interval are the asset-specificity index and the combined transaction frequency of small, medium and micro enterprises; any resource combination outside this range should not be included in the collaboration framework[1].

1.2 Multiple-Level Information Transmission Nodes in the Collaboration System

The basic units of data flow and state synchronisation in the supply chain collaboration system for small, medium and micro enterprises are information transmission nodes. Each level of a node is a participating enterprise or an internal functional department, and the information processing capacity is limited by the digital level of the enterprise. In a multi-level structure, the information is carried from the source node to the end node in several stages, and at each level of a node, there may be filtering, delay or the addition of noise. There is a problem of information system heterogeneity among small, medium and micro enterprises, and it is difficult to directly match the data formats and transmission protocols of the nodes; thus, there is an accumulated effect of transmission distortion. The Degree of Distortion is positively correlated with the number of transmission stages. If the number of levels is too large, there will be no decision reference value at the end node for the information.

To reduce the attenuation of information in multi-level transmission, the collaboration system should set an upper bound on the number of levels of information nodes and establish redundant encoding rules for key nodes. Redundant encoding is the transmission of the same information along two or more independent paths, and cross-validation is performed at the point of convergence. SMEs have limited funds and cannot afford to duplicate the encoding work for all the nodes in the network; therefore, this method is only used for nodes that are on the critical path of cooperation. The Identification of the Critical Path is based on the transaction volume weight of the nodes and the degree of time sensitivity. The position of the information transmission node will also affect the variance of transmission delay, and if this variance is too large, the basic requirement of real-time response for the collaboration system will not be met. Therefore, the degree of spatial clustering of the transmission nodes will be used as an input parameter in the Design of the collaboration system.

1.3 Set the Collaboration Relationship Threshold According to Transaction Density

Transaction density is the weighted sum of the frequency of order interaction and the amount of transactions per unit time for small, medium and micro enterprises. This index is not only the number of transactions but also needs to be normalised by a coefficient for the order amount and the reciprocal of the order interval time. The number of transactions is small, the enterprises have not worked together for a long time, and a stable cooperative model has not been formed. With the increase in the size of their businesses, some companies have begun to integrate all aspects of their operations and share inventory data and production plans. The first threshold is the point at which the cooperative relationship moves from loose coupling to tight coupling; interaction below this threshold should be treated as a market transaction and not a cooperative relationship[2].

As the number of transactions has been rising steadily and both thresholds have been reached,

depending too much on a single cooperative partner will result in lock-in risk and an imbalance of bargaining power. Small and medium-sized enterprises that have carried out many transactions need to add third-party alternative nodes or distribute the proportion of orders to ensure the flexibility of the cooperation system. The actual amount of the second threshold will be determined by the company's capacity flexibility and the switching costs of other partners. Therefore, a good definition of a collaborative relationship is not a single density norm for the entire network but rather a range of intervals that vary according to different pairs of nodes. Any transaction density outside this range will be considered a reason not to continue with the cooperative arrangement, and therefore we will reduce the scope of information sharing, redistribute inventory responsibilities, and lower the priority of handling exceptions.

2. Dynamic Coupling Mechanism of the Supply Chain Collaboration System

2.1 Cooperation Trigger and Response Sequence Driven by Orders

Generally speaking, the start of operation for the supply chain collaboration system of small and medium-sized enterprises (SMEs) is the generation and transmission of purchase orders. The first few reasons for cooperation are the product's specifications, delivery time and the batch size of the order. The upper node will decide whether to enter a joint-response mode based on its own utilisation rate of capacity and work-in-progress inventory after receiving the order. The response state will depend on how well the order urgency index matches the remaining capacity of the node; if the order urgency index exceeds the predefined threshold for the node and there is sufficient remaining capacity, a positive collaborative response will be triggered, synchronous information push will be sent to the downstream nodes, and otherwise, a negative response will occur, the capacity constraint parameters will be returned to the source node, and order rescheduling will be requested. Therefore, the order is no longer merely a record of the transaction but also an active instruction for the collaboration system[3].

The progress of the response sequence is based on backward derivation from time; that is to say, the starting time window of each upstream node is determined in reverse order from the final delivery node. Small and medium-sized enterprises have relatively low production flexibility, so their start time window is relatively short, and they have high demands for the punctuality of the preceding nodes in the sequence. To keep things orderly, after finishing its own production, each node needs to issue a confirmation receipt, and this receipt should include the actual completion time and the deviation amount. If it is out of range, the next nodes will automatically start sequence reconstruction and adjust their start times and buffer sizes accordingly. The adaptability of the response sequence will affect the flow efficiency of orders in a complex network, and it is also one of the main attributes of the collaboration system that set it apart from fixed production schedules.

2.2 Distributed Coordination Rules for Inventory Buffers

Inventory buffers can absorb the shock of fluctuations and buffer the supply chain cooperation system of small and medium-sized enterprises (SMEs) from disturbances. The distributed coordination rule is that each node independently manages its own buffer, but the size of the buffer capacity and the replenishment interval should be coordinated with the parameters of the upstream and downstream nodes. The basis of this matching is the distribution of transmission delay at the nodes and the variance of demand fluctuations. If the delivery time of the upstream node is not uniform, then the buffer at the downstream node needs to be relatively large. If the forecast accuracy of the demand at the downstream node is high, then the buffer at the upstream node can be reduced. Periodically change the buffer state vector to align the parameters of the nodes, and a central coordination unit will not be needed[4].

The three parts of the buffer state vector are the current stock, the amount of materials in transit, and the predicted time to depletion. If the depletion time of a node is less than the replenishment lead time of the upstream node, then an expedited replenishment request will be sent to the upstream node, and at the same time, a possible stockout warning will be issued for the adjacent downstream nodes. The next lower node will reduce consumption or use the backup buffer according to this alarm. The degree of the effect of the distributed coordination rule depends on how quickly each node can respond to changes in the buffer status, and this response speed is limited by the reaction delay of the node itself. SMEs and small businesses have generally been at a lower level of warehouse automation, have a slower response speed, and thus need to set a larger buffer threshold interval to account for response delay. If the buffer state of any one exceeds the upper limit of the threshold interval, then an exception handling process

will be started in the nodes to stop the release of non-urgent orders and enable emergency transfer channels.

2.3 Deviation Correction Path for Synchronization of Logistics and Capital Flows

Logistics and capital flows are naturally out of sync in the collaboration system of small, medium and micro enterprises. Logistics moves in the direction of upstream to downstream, but capital generally flows in the opposite direction, and their velocity functions are not the same. Logistics speed is influenced by the distance of transport, the efficiency of loading and unloading, and warehouse queuing; at the same time, the speed of capital flow is limited by settlement cycles, document circulation and credit terms. When the speed of logistics is higher than that of capital flows, the downstream node has not yet finished paying after receiving the materials, and thus its working capital is tied up at the upstream node. At the same time, if the speed of capital flow is too high, the downstream node will have to pay before receiving the qualified materials, and thus its financial risk will be relatively high. The size of the deviation is the time difference between the arrival of the goods and the capital transfer time, and this is recorded as the synchronization deviation amount.

The two ways to correct for the synchronisation error are to move the payment node and change the logistics cycle. Realigning the payment node is to alter the original payment terms, which are fixed in the form of 'N days after goods are delivered', and change them to milestone-based payments according to the logistics status, such as payment upon shipment, payment during transit, and payment upon acceptance. At each time in the logistics process, the next party will release an instalment of the funds. Logistics rhythm adjustment is to change the size and frequency of the shipment batch at the upper end according to the credit history of the lower end. Nodes with good credit will be given a shorter shipment period, and those with poor credit will have their shipment intervals extended or be required to pay in advance. The two kinds of correction mechanisms can be used alone or together, and the choice depends on the ratio of a node's capital turnover rate to its inventory turnover rate. The closed-loop of the deviation correction path should ensure that each capital transfer is traceable and linked to the corresponding logistics unit, and this record will be used to update the credit parameters of the next transaction.

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

3.1 Modular Access Method for Lightweight Digital Interface

Generally speaking, the information infrastructure of small and medium-sized enterprises has relatively low computing power and is very diverse in software. The Design of the light digital interface should not have a large module of the traditional supply chain system that is not suitable for the scale of these enterprises, and only keep the three core functions: order status synchronization, inventory level notification, and abnormal event broadcasting. All the functions are in different interface modules, and these modules are connected to each other via a common data dictionary. The definition of the data dictionary does not need special commercial software; rather, it should be based on the general material coding rules of the industry and transaction unit measures. Modular access is available for all sizes of enterprises, and all or some modules can be selected according to the actual needs of the company. Modules that are not enabled will have the adjacent nodes in the collaboration network carry out logical conversion for them and then integrate them[5].

The parameter configuration at the access stage is zero-code; that is to say, interface adaptation is carried out by filling in a configuration file rather than writing program code. The three parts of the configuration file are the node ID, the bill of materials mapping table and the response timeout. Node ID is used for network routing; the Bill of Materials mapping table normalises the various coding systems of different enterprises, and the response timeout threshold sets the switching condition after no feedback has been received, which is to enter a wait or retry state. When a new node is added to the collaboration network, only the three items in its configuration file need to be broadcast by the adjacent nodes; whole-network synchronisation is not required. Therefore, it will be convenient for small and medium-sized enterprises, as well as micro-enterprises, to use the collaboration system and maintain the loosely coupled nature of the network. In addition, the broadcast of the configuration file is differential; that is to say, a node only needs to broadcast the parts of the configuration that have been changed since the last time, reducing the amount of repeated transmission in the network and making it

suitable for access scenarios of small, medium and micro enterprises with limited bandwidth.

3.2 Trust Accumulation Model Based on Short-Term Reciprocity

Trust in the supply chain collaboration system of small and medium-sized enterprises and micro-enterprises is not an innate trait of morality but rather an index of mutual behaviour in transaction history. The smallest unit of measurement in the trust accumulation model is the outcome of a single cooperative act, and each interaction has a reciprocity coefficient; this value is the ratio of the actual delivery quality to the promised delivery quality. The three contents of delivery quality are the proportion of on-time delivery, quality rate and information accuracy. The weights of all the items will be set in advance by the two parties to be dealt with. A reciprocity coefficient of 1 or more means that the delivery has met or exceeded expectations; otherwise, if it is less than 1, then it has failed to meet expectations. The update rule for the trust value is a decay-weighted moving average; that is to say, the reciprocity coefficient of recent interactions is given more weight, and the weight of historical interactions decreases exponentially with time.

The attribute of short-term reciprocity is that the trust value is based only on a small number of recent interaction windows, and the length of the window is determined by the transaction frequency of the node. Nodes that are frequently traded have a small window size and need to respond quickly to changes in the behaviour of the counterparty; nodes that are traded infrequently can have a large window size and are more tolerant of fluctuations. If the trust value of a node is lower than the preset lower bound, then the collaboration network will reduce the amount of shared information and move the node from the real-time synchronization list to the polling query list. If the level of trust is too high, some or all of the information will not be disclosed. It does not need to refer to external credit rating agencies and, instead, can use the direct interaction data of nodes to evaluate the creditworthiness of small and medium-sized enterprises (SMEs) and micro-enterprises (micro-enterprises) that lack public credit information. A penalty coefficient is added to the calculation of the trust value for malicious default or information concealment behaviour. The higher the penalty coefficient, the more serious the penalty for failing to repay the debt will be, and thus it is less likely that a party, having trusted the counterparty based on many small and frequent transactions, will act opportunistically.

3.3 Node Exit and Substitution Logic in the Flexible Collaboration Framework

One node in the supply chain cooperation system of the small and medium-sized enterprise has been closed due to changes in capacity, lack of funds or equipment failure. The flexible cooperation framework needs to know when each node will leave; that is to say, before leaving, a node should inform its neighbouring nodes that it plans to leave and provide a time series of the remaining service capacity. The two kinds of exit intentions are a planned departure and an unplanned one. A planned exit is a company's voluntary reduction in the scope of business or a seasonal closure, and at this time, contact will be gradually reduced according to a prearranged plan. An unscheduled departure is a reduction in capacity, so we need to begin the replacement work promptly. The two kinds of exits differ in that the node sends the signal three transaction cycles earlier[6].

The first goal of the substitution logic is to have an updated list of available backup servers. Each node in the collaboration network has a list of at least two backup nodes, and the choice of these backup nodes is based on the resource similarity and geographical proximity of the nodes. Resource similarity is employed to match the model and process parameters of production equipment at different nodes, and the extra transportation cost of substitution will be influenced by the distance between them. If the original node suddenly goes offline, all adjacent nodes will immediately send substitution requests to the candidate nodes in the backup node list, and each request will carry the historical order parameters and time window constraints of the original node. The first candidate node that confirms acceptance will be given the substitution qualification, and cancellation notices will be sent to the other candidate nodes. After the substitution is carried out, the local topology of the collaboration network is reconnected, the trust value of the new node is set to the trust value of the original node multiplied by a discount coefficient, and this coefficient is determined by the degree of information loss during the substitution process.

Conclusion

According to the structure of resources, the features of information transmission and distribution for

transaction density in small, medium and micro enterprises have been studied; in this paper, the constituent elements of the supply chain collaboration system are defined, a dynamic coupling mechanism of order-triggered response, distributed inventory coordination and flow synchronization deviation correction are established, and three embedding paths are put forward: lightweight digital interfaces, short-term reciprocal trust accumulation and flexible exit and substitution. Based on the above theory, the main reasons for cooperation among small, medium and micro enterprises (SMEs) in their supply chains differ from the integrated model of large enterprises; that is, there is a loose coupling structure, heterogeneous resource complementarity, local information redundancy and threshold-based relationship management. First, we will learn about all the different rules for the parameter threshold values in the collaboration systems of small, medium and micro enterprises across all industries. Second, we will integrate the trust accumulation model with distributed ledger technology, and then we will investigate how tamper-proof and automatic the execution is. Thirdly, we will continue to study the causes of the spread of cascading failures in multi-level collaboration networks and improve the response speed of the flexible exit and substitution mechanism.

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