Inter-Business Trading Structure Model with Agent-Based Simulation and Its Application to Real Data

Taisei Mukai * and Takao Terano *

Abstract: This paper proposes an inter-business trading structure model with agent-based simulation. The proposed model can deal with the two kinds of dynamic changes: (1) supply and demand volumes and the resulting production lead time, and (2) the combination of both decentralized and centralized inter-business structure. The model is applied to analyzing recent rapid market changes of Japanese firm data. The data is taken from the TDB (Teikoku Databank) business trading database, which contains firm information with four million trading items, business volumes and relations over many years. Using this information, we focused on changes in the trading of firms involved in the Japanese software industry. The experimental results applied to real data suggest that the dynamic structural changes determined by the model have a critical role in various cases of performance of Japanese software industry firms in the TDB database.

Key Words: decentralized structure, inter-business structure, inter-business trading network, agent-based simulation.

1. Introduction

In the areas of firms having dealings with software development and surrounding firms, many firms have been vertically integrated continuing dealings with particular partners in the past. Recently, however, business conditions have changed, just as observed in the development of smartphones and web apps, for example, firms change partners quickly. In order to observe such changes in business conditions, we can effectively use the database provided by Teikoku Databank1 (TDB). This database contains information more than four million dealings, including items transacted, business volumes, and firms information.

To increase profit while adapting to the ever-changing business environment, it is desirable for firms to have a dynamic trading structure where business partners can be freely changed according to their change in needs [1]–[3]. This study defines such an inter-business trading structure as a decentralized inter-business trading structure (a decentralized structure, or centralized structure in Figs. 6–9 shown later).

However, the inter-business trading data provided by the TDB show some cases where sales destinations (client) are limited to only one in the case that all business partners change every year as the decentralized trading structure. It also shows many cases where profit increased after the business partners are limited to one ((5) in Table 1). Additionally, the percentage of the sales reaches 30% or more ((6) in Table 1).

In such cases, the dynamic trading structure is not limited to the inside of the software industry, but it is related to the out of the most of the other industries. This study defines an exclusive trading structure where the client is limited to only one as an inter-business centralized trading structure (a centralized structure, or centralized structure in Figs. 6–9).

Previous studies have failed to clearly explain how a centralized trading structure is generated within a dynamic trading structure that can be confirmed in such data, and how profit and sales can be increased. Through this study, therefore, we are going to (1) propose an agent model for explaining cases with a centralized trading structure within the decentralized trading structure, and (2) evaluate our simulation results with the actual data. These two factors serve as the contributions made by this study.

Our proposed inter-business trading structure model introduces a centralized structure in the decentralized structure in a form that not only to increase profit but also to respond to increases/decreases in business volumes. Since the inter-business relationship serves as a mechanism that produces a centralized structure based on the decentralized structure, the proposed inter-business trading model is referred to as a decentralized/centralized trading structure model (“Cent in Decent structure” in Figs. 6–9).

In this paper, Section 2 describes related studies, Section 3 overviews the proposed model, Section 4 explains how the evaluation was done, Section 5 describes the study results, and Section 6 summarizes this paper.

2. Related Studies

Inter-business trading structures include the decentralized structure and the centralized structure, which were described in Section 1 [4]. The following subsections describe that these related studies have individually been made and developed and that models that can be evaluated by simulation have yet to be developed.

2.1 Related Studies on the Inter-Business Decentralized Trading Structure

Some studies on the inter-business decentralized trading structure focus on the selection of business-to-business partners. For example, studies on supply chains or supply networks have focused on fixed alliance networks in the past. Recently, however, these studies focus on those that select part-

1 The TDB dataset is provided by Teikoku Databank, Ltd. http://www.tdb.co.jp/english/company/index.html.
Table 1: Sales contribution ratios for the decentralized trading structure within the centralized trading structure. (Note: A centralized structure means a trading relation where there is only one client; 3,451 firms exist in all software industries (having dealings within two consecutive years from 2013).)

| Provider | Client |
|----------|--------|
| 575      | 560    |
| 155      | 92     |
| 110      | 42     |
| 118      | 71     |
| 91       | 33     |
| 43.0%    | 1.2%   |
| 38.4%    | 1.1%   |

2.2 Related Studies on the Inter-Business Centralized Trading Structure

Studies related to the inter-business centralized trading structure include those focusing on intermediaries in inter-business trading, such as corporate brokers. In many cases, analysis of intermediaries is based on network analysis [11]. Such analysis examines the advantages and the disadvantages in network locations; therefore, it is not a simulation study. A study on the broker’s characteristics based on the game theory [12] serves as a simulation study; however, the trading structure is impossible to change. The proposed model can be adaptive to environmental changes by handling the centralized structure amid changes in the trading structure. There exist a wide variety of centralized structure patterns. Recently, technological advancement based on the Internet has accelerated disintermediation, forming a simple, centralized structure. Based on this concept, this study examines the fundamental model with two simple inter-business structures. A model, which is capable of handling both decentralized and centralized structures, has been proposed [13]. Additionally, buffering for dealing with changes in trading volumes within the centralized structure has been examined. In these studies, however, any simulation was not conducted based on actual data. In our study, we conduct simulation by utilizing actual data, and this study serves as a developmental study for these previous related studies.

3. Proposed Model

The inter-business decentralized/centralized trading structure model proposed by this study is an agent model for explaining cases where the centralized structure is generated within the decentralized structure. This section develops descriptions in order. Section 3.1 describes the relationships between environment and firms and behavioral rules for firms, and two structures based on this consideration. Section 3.2 describes the decentralized trading structure, and Section 3.3 describes the centralized trading structure. Section 3.4 describes the proposed model where two characteristics are integrated, Section 3.5 describes the relationships between the model and data, and Section 3.6 describes the simulation procedures.

3.1 Relationships between the Business Environment and Firms

In the business environment, only several firms exist, firms (agents) have the purpose of increase profit by selling what they produce, one item, to their clients. These firms act while changing their dealings with their partners sequentially in order to select a more potentially profitable business item, while procuring necessary resources for production at a lower cost from other firms and producing the item, so as to sell the item to firms that purchase it at a higher price (Fig. 1). Individual firms have their own characteristics, differing in the following three points: (1) the produced item, (2) production capacity per step, and (3) the type of resources necessary for production and their ratios. However, they produce their items in accordance with the same behavioral rules (on the right of Fig. 2). The rule in a firm agent is acted once at each time step. Figures 3 and 4 are the details of the behavior rule in Fig. 2. And the equations in Fig. 4 are used in after part (Procurement process, Production process, and Sales process and Account process) of the firm agent behavior rule in Fig. 2. The following subsection explains the behavioral rules for firms.
3.1.1 Environment recognition process

The environment recognition process (on the right of Fig. 2) searches three options, items, clients, and providers, and creates a candidate set for each of these options. Here, these three options are searched under the conditions shown on the left side of Fig. 3. In the search item option, if a player finds a high cost (price) item which compares with his previous item in the market, he takes the item which he expects to sell higher into the task candidate. In the search client option, if a player finds a firm which intends to buy a high cost (price) resource compared with his previous trade in the market, he takes the firm into the client candidate. In the search provider option, if a player finds a firm which intends to sell a low cost (price) resource compared with his previous trade in the market, he takes the firm into the provider candidate set. All searches are conducted based on the item relationship list (Item-Item list). This list will be described in Section 3.5. Items are searched by comparing them with the current items and other firms’. Firms definitely have items that they handle. If there are no firms for trade, these options are searched in comparison with the average of item categories.

3.1.2 Firm selection process

The firm selection process (on the right of Fig. 2) determines items, clients, and providers. Following the item change flow on the right of Fig. 3, items to be produced are determined from the options based on the item change ratio. Within each set of options, clients and providers that meet the conditions of orders and available production capacity are selected in descending order according to the client change ratio. Clients and providers can be considered as a relative dealing; thus they are determined at one time. Here, providers determine clients by confirming orders. Once clients are determined, Firms then invite potential providers to order necessary items (task announce (TA), on the lower right of Fig. 3). Sometimes, clients and providers are not determined. Ordering is conducted by drawing order volumes, costs, and temporary turnaround time. As described above, firms serve as sellers as well as buyers, while they can freely change their items to produce and clients. This point corresponds to the inter-business decentralized trading structure focused on by this study. This structure is created by scaling the framework of the division model [14] which is an agent model where items can be selected.

3.1.3 Evaluation phase

Since other processes in the rule are used for evaluation; these are summarized below. The evaluation indexes consist of the profit and the lead time. These indexes serve to measure the trading volumes by confirming that profitable items are selected and produced in changes in needs and are promptly responded to changes in demands. A desirable condition is a high profit with a short lead time. The behavioral rules of firm agents have the following four processes to calculate the profit and the lead time (in the lower right of Fig. 2, and Fig. 4).

In the procurement process (upper left of Fig. 4), a firm agent receives the required resources from several contracted providers. From the stock produced by the providers, the firm agent receives the number of resources that are determined based on the resource sales process of the providers. There is no distinction in resources of the same type provided.
In the production process (lower left of Fig. 4), the firm agent uses the required resources to produce its own items as the production resources. The amount of several required resources necessary for producing one production resource is dependent on the ratio determined by the list of relationships between items. Within its own production capacity, the firm agent produces the maximum amount that can be achieved as long as stocks last (e.g., it produces the minimum value of production per unit of resource required for production). If resources B, C, and D are required for production of resource A at the ratio of 2, 3, and 4, and stocks of necessary resources are 6, 9, and 8, the calculation is \((6/2 = 3, 9/3 = 3, \text{and } 8/4 = 2)\), then only 2 of resource A will be produced.). Firms that do not need supply can produce while consuming only the production cost. The order propagation stops at such a firm having no need for procuring, while in turn, it becomes the basis of resource propagation (on the right of Fig. 5).

In the sales process (upper right of Fig. 4), the firm agent sells the resources produced. If multiple clients exist, these resources are split by the ratio of contracted trading volume. The out of volume that reaches the upper limit determined by the contract remains in stock.

In the accounting process (lower right of Fig. 4), the cost that corresponds to the sales volume (contracted cost times sales volume divided by contracted trading volume) is sequentially exchanged between sellers and buyers, while the profit is calculated. Where resources cannot be produced because of a shortage of resources or where resources are produced in small quantities, the profit can impact negatively.

\[
Profit(t) = Min(t) - Pcost - Mout(t).
\]

Here, \(Min\) indicates the sales price, \(Mout\) indicates the provider cost, and \(Pcost\) indicates the production cost.

Where all the trading volumes that were contracted at the time of order have been sold, the lead time is calculated. Trading is not always a one-time event.

\[
LeadTime = Off - Ost.
\]

Here, \(Off\) indicates the order completion time and \(Ost\) indicates the order start time.

The inter-business structure in the proposed model is determined when orders are propagated, while the evaluation index is calculated by the resource propagation (Fig. 5). This resource propagation model is similar to a manufacturing industry style, while it is calculated based on the concept of selling services or resources by the piece. Therefore, this calculation is close to a person-month calculation or a depreciation calculation. Items that are observed from the software industry actually include various industries, such as manufacturing, wholesale, insurance, and recycling. This structure is close to the supply chain structure. A previous study has indicated that a high-performance supply chain can adapt to changes in the market and can respond to demands promptly, and component firms share a mutual interest [15]. The evaluation indexes that satisfy these points are calculated based on this process.

3.2 Inter-Business Decentralized Trading Structures

The inter-business decentralized trading structure is a structure where firms can freely trade (decentralized firms in Fig. 1). As previously described, each individual firm agent acts under the following conditions: (1) items are searchable and selectable, (2) clients are searchable and changeable, and (3) providers are searchable and changeable. Search destinations are all firm agents, except for the user itself.

3.3 Inter-Business Centralized Trading Structures

The inter-business centralized trading structure focused on by this study is a structure where a certain target firm trades with the provider exclusively when the firm detects an increase in trading volumes from the client (centralized firms in Fig. 1). Firm agents as providers act under the following conditions: (1) items are unchangeable, (2) clients are unchangeable, and (3) providers are searchable and changeable. Those providers that have the centralized structure cannot sell to other firms because of exclusive dealing, while they can respond to additional orders placed by clients. Therefore, they can immediately respond to an increase in trading volumes of clients, reducing search cost and lead time. However, they cannot update to better items and clients. This causes a trade-off by preventing other firms from updating to providers with lower cost.

3.4 Proposed Decentralized and Centralized Trading Structure Model

The inter-business decentralized trading structure that was defined in Section 3.2 is modeled as a form that generates a centralized structure described in Section 3.3. This model focuses on the point that firm agents can quickly deal with increases in trading volumes by conducting exclusive trading with providers when they capture increases in trade volumes from his client. Success or failure of exclusive dealing is determined by the ratio \(P(x)\) in the select providers, which is given to the potential providers shown on the right of Fig. 3. This ratio is anything as long as it is an ascending function according to the assumption. Then the sigmoid function was adopted. The setting of this sigmoid function occurs a centralized structure with a moderate response to trading volume, according to the previous research [13]. Conducting exclusive dealing with the provider determined by this ratio can form a centralized structure. This structure is maintained during the ordering period, while making it possible to conduct additional dealings within a range where production is available, enabling the trading volume to be increased. When exclusive dealing is canceled with ordering completion, this structure returns to the decentralized structure. Figure A.1 in Appendix describes the summarized concept of the proposed model.
In the simulation experiment, the inter-business trading networks dynamically change as the decentralized structure. Sales partners and suppliers change in time series. The temporal trading structure is determined when orders are propagated in details. Furthermore, the centralized structure occurs under the dynamic trade structure in the combined model.

3.5 Relationships between the Model and Data

This study focuses on a case where there are changes in production items, clients, and providers as the case with the decentralized trading structure. By using the actual data for determining these production items, clients, and providers, the baseline is set by using actual data as the decentralized structure. This baseline is compared and evaluated with the proposed decentralized and centralized trading structures. The following three factors shown below are taken from the data to determine the decentralized structure (on the right of Fig. 2). The available data list has two firms that traded as the seller and supplier and their trade amount, and each firm has a business category assumed as the main business item of a firm. These are reorganized as follows:

- List of relationships between items (Item-Items list);
- Change rates between items (Item-Item probability table);
- Change rates between firms (Firm-Firm probability table).

The list of relationships between items contains items that are necessary for producing a certain item. Based on this list, firm agents search environments to find options for items, clients, and providers. For those options found, items are changed based on the change probabilities between items. However, this change takes place at the end of the order that is currently in process. As for changing clients and providers, firm agents search in descending order of partners having items with a higher probability for changing partners, while they have a dealing if they find partners that meet the condition. This condition is whether the production volume (volume/t per cost/period) is achieved or not. Upon ordering, the client notifies the potential provider of the price (cost), the trading volume (volume), and the production period (t). Here, the turnaround time is not strictly observed, because prediction is not an issue of concern. The change rate between items of firms (from item i to item j) is expressed as the equation shown below. If no items to deal, TCrate is 0.

\[ TCrate_{ij} = \frac{NewTask_{ij}}{NewTask_{ij} + Task_{ii} + NonTask_{i}}. \]

Here, TCrate_{ij} indicates the rate of change from item i to item j, NewTask_{ij} indicates the number of new changes made from item i to item j, Task_{ii} indicates the number of item i retained next year, and NonTask_{i} indicates the number of item i that is reduced next year.

The change rates between firms are expressed as the equation below, based on the firm’s rate of establishing a new client (from firm i to firm j).

\[ P_{xxij} = \frac{New_{xxij}}{New_{xxij} + Old_{xxij} + Non_{xxij}}. \]

Here, the subscript \( xx \) indicates that there is no dealing, the subscript \( xxiij \) indicates that there are dealings of the subscript \( ij \) next year from the previous year with no dealings, \( P_{xxij} \) indicates the establishment rate of new dealings, \( New_{xxij} \) indicates the number of new dealings, \( Old_{xxij} \) indicates the number of dealings retained, and \( Non_{xxij} \) indicates the number of dealings canceled.

3.6 Simulation Procedures

Simulation provides a firm agent in the top node at the sampling with orders, sorts firm agents randomly every period, and executes the behavioral rules in the sorting order (Fig. 1). Inter-business trading networks dynamically appear or disappear depending on the propagation or completion of orders. When all firms complete their actions, the dealing step moves to the next step, while this process is repeated subsequently. The completion condition intentionally stops at the 50th step. In the present study, the following process is repeated: when the top node completes placing an order, the next order is placed at the top node.

4. Simulation

The purpose of this simulation is to understand, from the behavior of each firm agent, why inter-business transactions observed from the software industry position toward the supply direction generates a centralized trading structure. This simulation is conducted by comparing the centralized trading structure with the baseline, the decentralized trading structure, after which the proposed decentralized and centralized trading structure model is compared with the evaluation index, the profit, and the lead time. When positive results, the increase in profit and the reduction in the lead time, are simultaneously observed in the proposed model case, business transactions of individual firm agents having the centralized structure are confirmed. Here, it is insufficient to merely confirm a faster lead time. Next, the effectiveness of the centralized structure is examined by comparing the sales contribution ratios of the agents having the centralized structure with the actual data cases. After confirming that the centralized structure functions well, the reasons why the centralized structure is a better structure are considered. The evaluation procedure is shown below: (1) Conduct the agent-based simulation; (2) Confirm improved cases where two evaluation indexes are simultaneously positive; (3) Confirm the behavior of individual firm agents having the centralized structure; (4) Compare the actual data cases and sales contribution ratios. The following subsections describe the initial settings, simulation steps, simulation scenario and data used.

4.1 Initial Settings

Agent IDs consist of firms that are sampled from the actual data of the TDB database. Upon sampling, additionally, the firm’s characteristics, the item production ability per period, the item production cost, and resources necessary for items are assigned. The production ability is created based on the normal distribution. The production cost is calculated inversely from sampling. Refer to Table A.1 in Appendix for the details about predetermined parameters. The next subsection describes the details about sampling.

4.2 Sampling of Firms

Inter-business trading structures are explored to sample firm agents. The following procedures define the sampling steps.
1. Choose three firms randomly that are categorized as in the software industry
2. Setting this as the base point, explore firms with a depth of five toward the supply direction, obtain 581 firms
   - At the same time, aggregate the list of relationships between items and obtain 117 items
3. Delete the inter-business trading structures when sampling
4. Assign the production cost for each firm

The cost, spent on a firm’s production, is comprised of the production cost and the cost of the required resources. This cost is calculated by sales minus profits of each firm at sampling. This cost is then further distributed at 1 to 2 rate to the production cost and the cost of the required resources. This is based on the approximate sales cost ratio in the information and communication industry. The cost of the required resources is further divided proportionally with the number of required resources gathered from the list of relationships between items.

\[
P_{\text{cost}} = \frac{1}{3} (\text{Sales} - \text{Profit}),
\]

\[
R_{\text{cost, item}} = \frac{2}{3} \left( \frac{\text{Sales} - \text{Profit}}{\text{Number, item}} \right).
\]

Here, \(P_{\text{cost}}\) indicates the production cost, Sales indicates the sales volume, Profit indicates the profit earned, \(R_{\text{cost, item}}\) indicates the required resources cost per item, and \(\text{Number, item}\) indicates the number of required resources per item produced.

### 4.3 Simulation Scenario

The experiment prepares different simulation scenarios that change a trading volume which a top firm accepted as an order. It is because the centralized structure function in the combined model assumes to deals with a trading volume. We will find a scenario where the proposed model is effectively better than the decentralized trading structure model (baseline) in the same scenario. This is the evaluation procedure (2) described in Section 4. The trading volume is set to normal, three times normal, and five times normal increase case. The normal is the amount that can be handled in roughly one year. Each scenario consists of 50 times simulation with the same setting. In the multiple scenarios, the order volume after the second order at the top node is tripled. This process is taken because of removing the influence of the particular movement triggered by the initial order placed. The point of timing for multiple orders is at the completion of the initial order.

### 4.4 Data Used

In this study, we used the trading section in the credit report provided by Teikoku Databank, Ltd. and corporate profile information in COSMOS2 by associating them with firm IDs. The data used here contains information between January of 2013 and January of 2014. The number of business transactions in 2014 is 4,672,871. In the software industry, 3,451 firms exist (which conduct transactions between 2013 and 2014 having required values for calculation). See Section 3.3 for the details on how to use data. Both the item change rates and the trading change rates are listed in a 117 × 117 table. The items handled by the proposed model are categorized into the firm’s small classification category.

### 5. Simulation Results and Consideration

The simulation results are shown in the time-series charts of the evaluation indexes, the profit, and the lead time. The results were evaluated as the average of calculations conducted 50 times, and the final period of the cumulative chart became the overall evaluation. To show that there were no sudden changes in the final period, raw movements across the experimental period are also shown for your reference. Figures 6 and 7 show the simulation results of the normal scenario. The multiple-time scenarios were placed after the average \(T = 10\) of all 50 simulation sessions. Figures 8 and 9 show the three-time increase scenario. Since the result of the five-time scenario tended not to be much different from the result of the three-time scenario, we, therefore, focused on the triple case. In the three-time scenario, we confirmed the evaluation index status assumed by the proposed model. In other words, the proposed model’s profit tended to expand for the decentralized structure which serves as the baseline; at the same time the lead time tended to be reduced. In addition, the dotted line in the lower side of each figure shows all partners trade with the centralized structure in the proposed model, That is, all partner selection uses the fixed \(P(x) = 1.0\). It is for reference.

Next, from the simulation results with the highest sales, we extracted and confirmed the changes in the centralized structure of each firm agent (Fig. 10). This figure shows all the providers for the firm having the ID 720 while listing this provider’s items. This agent with the ID 720 conducts centralized dealings with multiple providers after an increase in the sales volume between the simulation steps \(T = 2\) and 3.

Here, providers can sell items only to the firm with the ID 720, while especially those encompassed with blue frames conduct multiple transactions with the ID 720 simultaneously. The ID 720 is able to use the idle production capacity of the providers applying the centralized structure only for its own procurement activity. This shows that the proposed model functions in an expected manner. These transactions are sequentially open at \(T = 7\), corresponding to the increase and decrease of transactions.

Table 2 shows how much those firms that apply the centralized structure even once contributed to the overall trading volume (sales) when the profit and the lead time produced a positive result. These results were evaluated by the sales contribution ratio of the actual data in Table 1. The actual data does not include the trading volume. Therefore, we consider the contribution rate of the centralized structure in sales as a trading volume.

Table 2 shows the top 10% of the simulation results both with high sales and short lead times picked out of the results from all 50 simulation sessions. The result confirms approximately 36% of the sales contribution ratio. If this ratio reaches about 70%, the lead time goes down almost to the lowest level.

The sales contribution ratios of the sales of the case (4) and the sales of the case (1) are shown in Table 1, where the actual data was analyzed. In cases where providers applying the decentralized structure changed for two consecutive years, approximately 38% of the sales contribution ratio was confirmed for the decentralized structure in cases where the centralized structure was applied by providers in the following year of the year when sales were increased. The simulation we conducted

---

2 EDIUNET (http://industry.ediunet.jp/).
Fig. 6 Time-series profit charts. The bottom is a cumulative chart, where the profit of the decentralized and centralized structures increases positively when compared to that of the decentralized structure. Max-Min indicates the maximum value connected with the minimum value of each period during 50 simulation sessions. The same applies hereafter.

Fig. 7 Time-series lead time charts. The bottom is a cumulative chart, where no significant difference is observed. Synchronized with Fig. 6.

Fig. 8 Time-series profit charts where orders were tripled. Orders were tripled after the average $T = 10.3$ (because orders were tripled after the initial order completion). The bottom is a cumulative chart. The proposed model’s profit tends to increase when compared to the base line. The profit is lowest when only the centralized structure is applied.

Fig. 9 Time-series lead time charts where orders were tripled. Orders were tripled after the average $T = 10.3$. The bottom shows a cumulative chart. The proposed model’s lead time tends to be reduced when compared to the base line. This is also the case with positive profits (Fig. 8).
showed the results that were close to this ratio. While, the contribution ratio in these cases, where the clients changed for two consecutive years while similarly applying the centralized structure, was about 1%. This paper does not commit this real case as not important.

In addition, although this point is not indicated in the Table 1, the profit increased in all the cases where the clients and the providers changed for two consecutive years while applying such a centralized structure. This situation corresponds to the case where the proposed model functioned well.

In the case where the proposed combined model works, the search cost is reduced in the centralized structure because of an exclusive trade. It is reflected in the lead time. The profit is raised by duplicating this structure at the same time. In other words, the emergence of this model is not the occurrence of a network, but the effective formation of the centralized trading structure in the decentralized trading structure. This effect of the emergence is supported by the simulation results validated with the real data.

These results show that in the inter-business trading structures, some cases are quite profitable although there is a centralized trading structure with restrictions. This is because prompt responses to an increase in trading volumes, based on the centralized structure with the providers, serve to maintain the profit structure. However, this depends on the profit structure when the centralized structure is applied. On the other hand, the centralized structure interferes with the selection of better providers by other firms. This could make the overall profit drop. This phenomenon can also be observed in Fig. 8, where all transactions were conducted in the centralized structure (dotted lines).

As shown here, by carefully examining the simulation results, it is possible to consider the situation on the model which is not clarified in the case of actual data.

6. Conclusion

In this study, we focused on a centralized structure that is observed by tracing inter-business trading within the actual data from the software industry toward the procuring direction. We then created an agent model to understand why this structure is generated and can achieve positive profits. For evaluation, we compared the simulation results with the actual data cases. The model we created in this study had a form where the decentralized trading condition that allows firms to freely engage in business transactions, and the centralized trading structure that connects exclusive transactions with providers were generated.

Our attempt confirmed the following two findings: (1) When a firm increases trading volume with clients, it responds to an increase in the trading volumes with providers based on the centralized structure. At that time, the firm reduces the lead time by maintaining the exclusive trading structure and at the same time increases profits. This finding could be confirmed only by conducting the agent-based simulation. (2) The proposed model handles only one item as a product, and clients change quickly. Since many firms handle multiple items, this type of model cannot always apply correctly to every case. However, we also confirmed from actual data that such cases surely exist in a consistent form. We still need to carefully examine each individual actual case regarding the details of what is suggested by the proposed model. Further studies are required in this area. In addition, we cannot apply the proposed model as it is in industries where a number of products are handled. Agentification of multi-items handled by firms will enable us to expand the proposed model as a general inter-business model, and we can have expectations for developing the proposed model primarily as an economic model. We will work on this as a future issue in further studies.

Acknowledgments

This work was supported in part by Center for TDB Advanced Data Analysis and Modeling, Tokyo Institute of Technology.

References

[1] W.H. Davidow and M.S. Malone: The Virtual Corporation: Structuring and Revitalising the Corporation for the 21st Century, Harper Collins, 1992.

[2] J.P. Davis, K.M. Eisenhardt, and C.B. Bingham: Optimal structure, market dynamism, and the strategy of simple rules, Administrative Science Quarterly, Vol. 54, No. 3, pp. 413–452, 2009.

[3] I. Kaneko and K. Imai: A network view of the firm, 1st Hitotsubashi-Stanford Conference, 1987.

[4] T.W. Malone: Modeling coordination in organizations and markets, Readings in Distributed Artificial Intelligence, pp. 151–158, Elsevier, 1988.
Appendix Complement of the Simulation

| ODD Elements | Description |
|--------------|-------------|
| Basic principles | Divisitional model [14]: a model that can adapt to changes in the environment and change work (production item(task)) |
| Emergence | Improvement of average profit meter, average lead time meter of all agents with centralized structure |
| Adaptation | Improve profit, lead time under renewal of items and clients, providers, to meet environmental changes (type of item, trade volume of item) |
| Objectives | Confirm whether the function of the decentralized and centralized structure is effective against the baseline and can deal with the trade volume. |
| Learning | Double loop learning: item and partner update if the ratio of sales is continuing to rise, it will be learning, but if it breaks, it returns to the original. |
| Prediction | Changed candidate of item and partners by improving compared to the previous term |
| Sensing | Searching task(item), Clients, Providers |
| Interaction | Order flow, Resource flow, Money flow between firms |
| Stochasticity | Relationships between items in initial setting, Agent setting (production capacity, order of action) |
| Collectives | Cascading occurrence of centralized structure, Blinking order chain |
| Observation | Profit, Lead Time, No. of centralized structure, No. of output resource. |

Table A.1 Other simulation parameters in Section 4.1.

| Parameter | Value |
|-----------|-------|
| Firm’s production capacity (dispersed to a certain degree for variety in sampling) | N(230, 50) × 0.9995 × 0.9 |
| The normal distribution is damped with the sampling depth. | |
| Initial order price | Cost = Rcost / Alist task |
| Propagated with this equation at the item announcement TA. | |
| Order trading volume | 600. Drawn to the top node at sampling. |
| The initial order is not achieved approximately within two periods at the fastest rate. |
| Divided with the number of required resources at TA. | |
| Order period | Normal distribution N(10, 2) |
| Set longer, with consideration of search, ordering, and acceptance. No damping at TA. | |
| Order cancellation | 12 steps. Cancelled if nothing is delivered in 12 steps. |
| Sigmoid coefficient α, β | 1.0, 5.0. Refer to a previous study [13]. |
| No. of items | 117 by sampling |
| No. of agents | 581 by sampling |
| No. of simulation sessions | 50 |
| No. of simulation periods | 50 |

Taisei Mukai
He received his B.E. and M.E. degrees from the University of Electro-Communications, Japan, in 2011 and 2013, and his Ph.D. degree from Tokyo Institute of Technology, Japan, in 2018. He is currently a Researcher of the Department of Innovation Research in the Tokyo Institute of Technology. His research interests include distributed artificial intelligence, natural language processing, and machine learning.

Takao Terano (Member)
He is currently a Researcher of the AIST-Tokyo Tech Real World Big-Data Computation Open Innovation Laboratory (RWBC-OIL). He received the B.E. and M.E. degrees from the University of Tokyo in 1976 and 1978. He received the Ph.D. from Tokyo Institute of Technology in 1991. During 1978 and 1989, he was the research scientist at the Central Research Institute of the Electric Power Industry. He had been a professor in the Department of Computer Science, School of Computing, Tokyo Institute of Technology in 2004–2018. His research interests include genetic algorithm-based machine learning, case-based reasoning, analogical reasoning, cooperative agents, computational organization theory, and knowledge system development methodology.