Strategic Supplier Network for Supplier Selection

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***Abstract*— Based on changing market conditions and pressure to different companies, the companies need to find strategic supplier network with the help of value network to increase more competencies and advantages. Supplier network optimization not only plays a key role to find cooperative network, but also increases more competencies across supply network. However, traditional supplier optimization for choosing direct suppliers no longer meet the requirements of strategic supplier network. There exists a link between supplier network and supplier selection. Thus, in order to satisfy the requirements of different evaluation criteria and business decision, this study proposes strategic supplier network for supplier selection. In-depth combined pattern mining is considered first to find the first-level or direct strategic suppliers. Then extend the whole supplier network, with the help of value network, graph theory and evaluation criteria, the strategic supplier network satisfied the needs of supply network is generated. After that, by using strategic supplier network, companies can select the most suitable suppliers.**

***Index Terms*— supply network, supplier optimization, data mining, value network, graph theory**

I. Introduction

Changing market conditions are forcing companies into an increasingly competitive landscape. At present, most companies are trying to identify their core competencies in order to optimize partners, especially suppliers, related to business processes toward supply network.

A supply network is a pattern of temporal and spatial processes carried out at facility nodes and over distribution links, which adds value for customers through the manufacturing and delivery of products [1]. Harland [2] showed that supply strategy has been developed from the externalisation of operations strategy into inter-organisational supply networks, extending the work on supply chain management into larger, more complex network systems. Supply network strategy is concerned with the improvement of supply performance across supply networks [3].

Actually, a supply chain is a special instance of supply network in which raw materials, intermediate materials and finished goods are procured exclusively as product through a chain of processes that supply one another [1]. Accordingly, in supply chain, collaboration with partners is considered an essential element of success, because the competitiveness of a company is delivering products to end users. Such collaboration is achieved by systematic interfaces among business partners, to the overall purpose of increasing customer satisfaction [4].

Nowadays, the main and basic challenges in supply chain are to plan a strategy to manage the resources and meet the demands, to select the suppliers that will deliver the goods and services that are required to build the product, to manufacture the product. Therefore, in order to enable success in supply chain, suppliers are often applied to improve the entities competitiveness and to increase customer satisfaction. However, traditional relationships no longer suffice to maintain business advantages, partnering with strategic suppliers has become a key factor to the success of supply chain.

In general, most companies, especially for manufacturing enterprises, suppliers are consisted of supplier network. Supplier network composed of multiple-levels suppliers is an essential component for supply network. Thus, the optimization of supplier network is necessary for the formation of strategic supply network. However, in academy, most of the approaches or models (e.g. [5], [6]) related to supplier optimization and selection mainly focus on the first level suppliers. In industry, current enterprise resource planning (ERP) systems build the fundamentals for the management and controlling of supply networks, but there is a lack of functionality of competent partners. In other words, Supplier relation management systems mainly focus on direct supplier relations.

Thus, developing a suitable approach to optimize supplier network toward strategic supply network is a challenging task. In addition, some researchers concerned on key supplier selection using data mining technique. For instance, Lin et al. [7] employed association rule mining of data mining and set theory to find key suppliers. Xu and Lin [8] integrated association rule mining with analytical hierarchy process (AHP) to find key suppliers. Furthermore, Albani et al. [9] proposed a approach of evaluating and rating of strategic supplier networks based

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on an entire value network[1], providing the base for supplier networks selection.

Accordingly, considering the perspective of overall organization business model and supply network strategy, this study aims to optimize supplier network toward strategic supply network based on previous work done in the area ([9], [11], [12]). To be more specific, first, find the first-level or direct strategic suppliers with the help of in-depth combined pattern mining. Second, evaluate and rank potential supply networks, extended from the first-level or direct strategic suppliers, through methods such as value network, graph theory. Finally, generate supplier network satisfied the requirements of strategic supply network.

The remainder of this paper is organized as follows. Section II summarizes relevant approaches or models of supplier selection. In-depth combined pattern mining employed for choosing the first-level or direct strategic suppliers is introduced in section III. Section IV presents functionality of strategic supplier network model. Toward strategic supply network, a mechanism for identification and evaluation of supplier network is outlined in section V. Finally, conclusions and future work are provided.

II. Supplier Selection and Optimization

In this section, the importance of supplier selection and optimization, methods or models for supplier selection, and criteria for supplier evaluation and selection are briefly described separately.

A. The Importance of Supplier Selection and Optimization

The supply chain represents all activities associated with the movement and transformation of raw materials to finished goods, from primary suppliers, to assemblers and through retailers to the end users. Managing a company's sources of materials, components and services are vitally important. For companies that spend a high percentage of their sales revenue on parts and material suppliers, and whose material costs represent a larger portion of total costs, saving from suppliers are of particular importance.

In recognizing the importance of successful supply chains, one of the competencies essential to supply chain success is an effective purchasing function [13]. Ellram and Carr [14] concluded that purchasing function plays a key role in corporate strategic success through the selection and development of suppliers that can support the firms long-term strategy and competitive positioning. As companies become more dependent on suppliers, the direct and indirect consequences of poor decision-making get more severe. So the process of supplier selection and optimization is one of the most critical activities of a company in today's competitive business world.

[1]Value networks spanning multiple tiers are created to better fulfill specific customer requests provided customized products on time in the right quality and for a competitive price [10].

B. Supplier Selection Approaches

Supplier selection is a multi-attribute decision making problem. How to choose capable suppliers is an imperative issue in the management of modern business organization. As such, many researchers devoted their efforts to developing supplier selection methodologies. On the one hand, some of them treat supplier selection as an optimization problem. Different solution methodologies have been proposed, raging from linear programming (e.g. [15]) to non-linear programming (e.g. [16]). On the other hand, researchers from business emphasize philosophical issues and focus on developing qualitative principles to guide management decision making. To business researchers, AHP is one of popular methods for supplier selection and optimization. AHP reflects the natural tendency of human mind to sort elements of a system into different levels and to group like elements in each level [17]. It is favored as generic multi criteria decision-making methodology. Furthermore, to a lesser extent, outranking method is also used to select suppliers. Whether AHP or outranking is applied, one must determine the approach and criteria used to measure supplier performance. Therefore, the prerequisite for effective supplier selection is to determine appropriate effective criteria based on a specific business strategy.

However, while strategic thinking cannot provide quantitative solutions, a mathematically optimal solution has no meaning if it does not match a firm's business strategy. Actually, a suitable method for strategic supplier selection should handle both quantitative and qualitative criteria. For example, Ghodsypour and Brien [18] proposed an integrated method that use the AHP and linear programming to deal with both qualitative and quantitative criteria, where strategic fit between product characteristics and supplier performance is emphasized.

C. Criteria for Supplier Evaluation and Selection

Supplier evaluation and selection are the most critical activities of a company in today's competitive business world. Criteria for choosing potential supply partners require continuous consideration and reconsideration from potential and actual partners.

Usually, different criteria may be applied to suppliers. The relative importance of the criteria depends on the strategies of companies. From a strategic perspective, this indicates that the dimensions of cost, flexibility, quality, service and delivery are not to be traded-off against one another but need to be simultaneously prioritized. Furthermore, Goffin et al. [19] pointed out that the priorities among supplier selection criteria are different to concrete company in actual situation. Thus, the priorities of criteria are likely to be influenced in the supplier selection decision according to the actual situation of the industrial environment.

III. First-Level or Direct Strategic Supplier Selection

This section discusses in-depth combined pattern mining implemented on the first-level or direct strategic supplier selection.

A. Data Mining

Data mining or knowledge discovery has emerged to be one of the most vivacious areas in information technology during the last two decades. Usually, data mining combines the statistic and artificial intelligence to find out the rules that are contained in the data, letters and figures [20]. In addition, Data mining comprises a number of techniques, such as clustering, classification, association rules, prediction, regression, and neural networks.

B. Association Rule Mining

In the study of data mining applications, especially in the context of business environment, many techniques are designed for individual problems, in order to generate interesting pattern or knowledge for the decision making. Association rule mining is one of the popular approaches employed to discover useful knowledge.

Association rule, a quite widely data mining technique, is used to search through an entire set for rules of revealing the nature and frequency of relationships or association between data entities. The basic terminologies of association rule, Support, Confidence are introduced in the original work described by Agrawal and Scrikant [21]. Support and Confidence, are two major indices, which have useful applications to evaluate the association rules. For example, consider rule AR: if A then B. Suppose that AR has 25% Support and 60% Confidence. It expresses that 25% of records contain A and B. This also means that in 25% of total records, AR is valid. Additionally, it expresses 60% of records that contain A, contain B as well.

C. In-depth Combined Pattern Mining

Usually, real-world data mining is a complex problem-solving system. however, traditional association rule mining cannot generate actionable knowledge effectively. Cao and Zhang [22] noted that the involvement of domain experts and their knowledge can assist in developing highly effective domain-specific data mining techniques and can reduce the complexity of the knowledge-producing process in the real world. Furthermore, a new combined pattern mining named in-depth combined pattern mining, was proposed by Xu and Lin [23]. i.e., with the help of algorithms of data-centered pattern mining such as association rule mining and ubiquitous intelligence, more interesting and actionable patterns can be generated through in-depth combined pattern mining. More details related to in-depth combined pattern mining can be seen [8] and [24].

Accordingly, toward the optimization of supplier network, the first-level strategic supplier selection can be obtained through in-depth combined pattern mining. To be more specific, expert domain knowledge applied through AHP is used as domain intelligence, and association rule mining is employed as data intelligence. The combination of AHP and association rule mining is adopted to find the first-level or direct strategic suppliers.

IV. Functionality for Modeling Strategic Supplier Network

Supplier relationship management provides methods, processes and tools to support different phases of a direct supplier relationship, e.g. identification, evaluation, qualification, and if necessary termination [25]. Using these functions in practice, supplier management are widely limited in direct supplier. The function of traditional supplier management cannot satisfy the needs of strategic supply network. The following parts first describe the general function of traditional supplier relationship management, and then illustrate the functionality of modeling strategic supplier network.

A. Function of Supplier Relationship Management

The traditional functions of supplier relationship management are shown below [26].

- Purchasing and souring. Purchasing and souring is the process of developing a corporate strategy and executing it by finding qualified sources to fulfill supply needs, negotiate purchase agreements, manage contracts and evaluate supplier performance.
- Operational procurement. Operational procurement is the process of buying direct materials and services (those used in production) or indirect materials and services (those used for maintenance, repair, and operations).
- Supplier collaboration. Supplier collaboration combines activities and tasks necessary to communicate and collaborate with suppliers.

B. Model of Strategic Supplier Network

Supplier network can be built after the direct strategic suppliers are determined. In other words, with respect to the increasing importance of value networks we postulate the extension of the traditional frame in supplier relationship management to supplier network scope, thus traditional supplier management is further developed toward strategic supplier network management. Accordingly, based on previous research [12], strategic supplier network model is illustrated in Figure 1.

V. Identification and Evaluation of Strategic Supplier Network

To model the strategic supplier network in a structured way, at first, the product related to the first-level or direct strategic suppliers will be searched and evaluated. Then

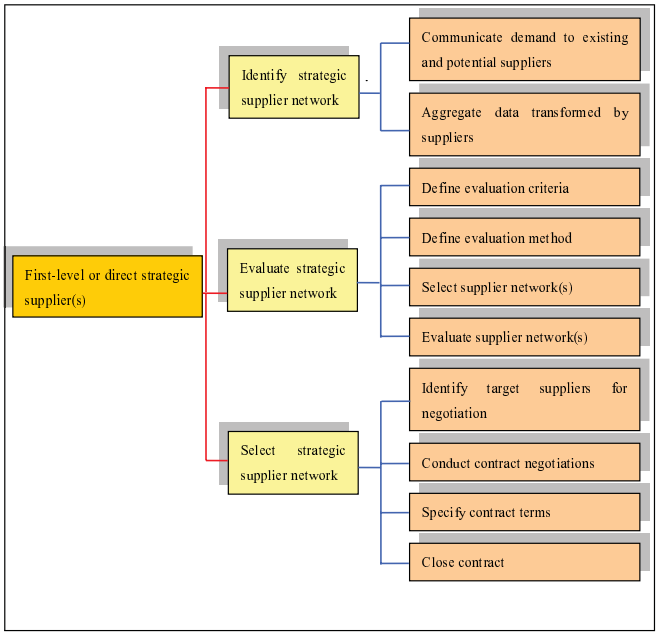

Figure 1. Strategic supplier network model

these suppliers will check whether they can fulfill the demand internally and if not sent out subsequent demands to their respective suppliers. Accordingly, the supplier network will be formed. Furthermore, in order to find strategic supplier network, evaluation criteria and methods satisfied business objective, evaluation approach toward strategic supplier network and a numerical example are introduced separately in this section.

A. Evaluation Criteria and Methods for Business Objective

In order to evaluate the strategic supplier network process, criteria and approaches should be defined according to different criteria. To a supply network [26], criteria and methods satisfied business objective are listed below.

Working with small and concise network. Business model should consider the criteria of number of operation nodes. The approach can be shown as follows:

- Count number of nodes;
- Identify minimum number of nodes;
- Select supply network.

Reducing cost of purchasing. Purchasing cost should be considered based on the cost of source in business model. The method can be generalized as follows:

- Calculate sum of source per node;
- Summate costs for all nodes up to the root node.

Reducing procurement lead time. The method can be summarized as follows:

- Identify paths within supply network;
- Calculate overall delivery and transport time per path;
- Select supply network combined with total delivery time.

Ensuring product quality. Factor of Product quality should be considered in business model. The approach can be outlined as follows:

- Count number of bad deliveries;
- Select supply network with highest quality factor in equal conditions.

Ensuring the liability of procurement lead time. Business model should consider the procurement lead time liability. The approach can be reviewed as follows:

- Count number of liable time deliveries;
- Calculate procurement lead time liability factor;
- Select supply network combined with procurement lead time liability.

Supplier network belongs to supply network. Thus, the evaluation criteria and methods for supply network can be applied to supplier network.

B. Evaluation Approach toward Strategic Supplier Network

Evaluation criteria and methods satisfied business objective have discussed above. Accordingly, facing to supplier networks, methods of evaluation and optimization should be considered to generate strategic supplier network. Jungnickel [27] noted that supply network can be treated as direct routed trees consisting of nodes representing companies and edges representing flow of information and goods. A graph G represented as a set of nodes V and a set of edges E:

$$G = (V, E) \tag{1}$$

Furthermore, supplier network is one of parts in supply network. Thus, supplier network can also be regarded as direct trees consisting of nodes representing suppliers and edges representing flow of information and product or

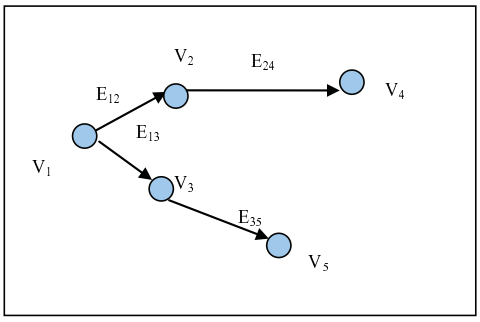

Figure 2. Example of a supplier network

parts of product. In Figure 2, V_a denotes the nodes and E_b denotes the edges.

Here use the number of nodes $N_v(G)$ and edges $N_e(G)$ simply count the number of nodes and edges in supplier network respectively. The following equations shows the method:

$$N_v(G) = |V(G)| \tag{2}$$
$$N_e(G) = |E(G)| \tag{3}$$

After that, the evaluation of supplier network may be based on a single business objective but could also be a combination of business objective owing to the different organization needs. This paper describes the business object of supplier network with weighted criteria and suggests a ranking process in order to select strategic supplier network. The supplier network can be viewed as weighted direct tree. In particular, the value of a criterion with no weight is supposed to be 1. Actually, the weight value of criteria can be obtained through questionnaires coming from domain experts.

While calculating purchasing cost $C(G)$ is assumed that there is a cost element related to a node CNv_i and a cost element which is related to an edge CEe_j. The weights of CNv_i and CEe_j are $WCNv_i$, $WCEe_j$ respectively. The cost of purchasing is the sum of all these cost elements ($\forall$ i, j: $i \in V$, $j \in E$):

$$C(G) = WCNv_i \times CNv_i + WCEe_j \times CEe_j \tag{4}$$

Therefore, total cost purchasing $C_f(G)$ of supply networks can be shown as follows:

$$C_f(G) = \sum C(G) \tag{5}$$

Furthermore, overall delivery time DEe_m and transport time DEe_n per path in the supplier network decide the procurement lead time $T_u(G)$. The time of total delivery time per path is ($\forall$ m, n, u: m, $n \in V$, $u \in E$):

$$T_u(G) = DEe_m + DEe_n \tag{6}$$

The procurement of lead time of paths $T(G)$ can be calculated ($\forall$ u: $u \in$ N) as follows:

$$T(G) = \sum T_u(G) \tag{7}$$

Thus, overall transport time $T_f(G)$ achieved is shown in equation (8):

$$T_f(G) = \sum T(G) \tag{8}$$

In the context of evaluation and optimization of supplier network, product quality describes the ability of a supplier to deliver good products. Accordingly, good products are defined as products which are accepted for further usage while bad products are not usable and which need to be replaced. In most cases, replacing products directly affect procurement lead time negatively as well [26]. Therefore, it is necessary that the number of bad products is as low as possible. In order to use product quality as a criterion for evaluating strategic supplier network, product quality factor Q is introduced. Q refers to the relationship between two nodes and is based on historical data deliveries.

In addition, owing to the procurement lead time used as a criterion for the evaluation and optimization of supplier network, consider the product quality, a certain node can not be able to adhere to the procurement lead time originally forecasted. Accordingly, it is necessary to know the liability of the procurement lead time considering strategic supplier network. Thus, the procurement lead time liability factor P is introduced. This factor indicates the ratio number of deliveries within the forecasted procurement lead time to the total number of deliveries. P also refers to the relationship between two nodes and is computed for analyzing historical data of deliveries. P and Q factors are shown as follows:

$$P = NDPLT/ND \tag{9}$$
$$Q = NGPD/ND \tag{10}$$

- Number of deliveries within procurement lead time: $NDPLT$;
- Number of deliveries: ND;
- Number of good product deliveries: $NGPD$.

Accordingly, the ranking of supplier network $R_i(G)$ can be calculated through the following repeated process:

$$R_i(G) = C(G)/C_f(G) + T(G)/T_f(G)) \tag{11}$$
$$+(1-P) + (1-Q) \tag{12}$$

$$R_i(G) = C(G)/C_f(G) + T(G)/T_f(G)) \tag{13}$$
$$+2 - (P+Q) \tag{14}$$

Finally, the minimum ranking value of supplier network is chosen as final strategic supplier network. In particular, if the value of $R_i(G)$ is equal, the priority of factors will be employed for the optimization of supplier network. i.e.,

TABLE I.
PARTS PROVIDED BY FIRST-LEVEL SUPPLIERS

Part No.	Suppliers	Part No.	Suppliers
P_1	S_2S_6	P_2	$S_2S_4S_6$
P_3	$S_1S_2S_4$	P_4	$S_2S_3S_5$
P_5	$S_1S_2S_5$	P_6	S_2S_3

TABLE II.
SHIPMENT RECORDS

Shipment No.	Parts
1	$P_1P_2P_4P_6$
2	$P_2P_3P_5P_6$
3	$P_1P_3P_5P_6$
4	$P_4P_5P_6$
5	$P_1P_2P_5P_6$
6	P_5P_6
7	$P_2P_5P_6$
8	$P_1P_2P_4P_5P_6$
9	$P_4P_5P_6$
10	$P_3P_5P_6$

$$R_i(G) = W_1 \cdot (C(G)/C_f(G)) + W_2 \cdot (T(G) \quad (15)$$
$$/T_f(G)) + W_3 \cdot (1-P) + W_4 \cdot (1-Q) \quad (16)$$

where W_i denotes the weight of factors.

C. A Numerical Example

Take a manufacturer as a simple example to illustrate the approach proposed. Shipment records covering shipping number and parts provided by the first-level suppliers shown in TABLE I. There are six parts (P_1, P_2, P_3, P_4, P_5 and P_6) and six direct suppliers (S_1, S_2, S_3, S_4, S_5 and S_6). This example assumes that individual direct supplier can supply more than one part.

Furthermore, there are ten records in shipment table (see TABLE II). In-depth combined mining is employed to further find the direct strategic suppliers. The processes of finding the direct strategic suppliers are shown as follows:

- Assume the ranking order of suppliers[2] is S_2, S_3, S_1, S_6, S_5 and S_4.
- Suppose Minimum-support=9. Frequent partsets are listed as TABLE III. Thus, final two frequent partset is $\{P_5, P_6\}$.
- With the help of the ranking value of suppliers, the ranking value of S_5 is not high. Thus, S_5 is not involved in the final direct strategic supplies. Accordingly, the final strategic supplier sets are $\{S_1, S_2\}$, $\{S_2, S_3\}$.

In this example, S_1, S_2 and S_3 can supply all the parts. Thus, S_1, S_2 and S_3 can consist the supplier network (as shown in Figure 3).

To S_1, there has supply network S_{1N1} and S_{1N2}, where include factors $C_{1N1}(G_1)$, $T_{1N1}(G_1)$, $P_{1N1}(G_1)$, $Q_{1N1}(G_1)$, $C_{1N2}(G_1)$, $T_{1N2}(G_1)$, $P_{1N2}(G_1)$ and $Q_{1N2}(G_1)$. Suppose the values are 8000, 600, 0.9, 0.8, 10000, 700, 0.9, 0.7 separately. According to equations (13-14), $R_1(G_1)$=1.2 and $R_2(G_1)$=1.5. Thus, S_{1N1} is the chosen supplier network.

To S_2, there has supply network S_{2N1} and S_{2N2}, where include factors $C_{2N1}(G_1)$, $T_{2N1}(G_1)$, $P_{2N1}(G_1)$, $Q_{2N1}(G_1)$, $C_{2N2}(G_1)$, $T_{2N2}(G_1)$, $P_{2N2}(G_1)$ and $Q_{2N2}(G_1)$. Suppose the values are 7000, 500, 0.9, 0.7, 12000, 900, 0.9, 0.8 separately. According to equations (13-14), $R_1(G_2)$=1.1 and $R_2(G_2)$=1.6. Thus, S_{2N1} is the chosen supplier network.

To S_3, there has supply network S_{3N1} and S_{3N2}, where include factors $C_{3N1}(G_1)$, $T_{3N1}(G_1)$, $P_{3N1}(G_1)$, $Q_{3N1}(G_1)$, $C_{3N2}(G_1)$, $T_{3N2}(G_1)$, $P_{3N2}(G_1)$ and $Q_{3N2}(G_1)$. Suppose the values are 16000, 600, 0.7, 0.7, 14000, 900, 0.8, 0.6 separately. According to equations (13-14), $R_1(G_3)$=1.5 and $R_2(G_3)$=1.7. Thus, S_{3N1} is the chosen supplier network.

Finally, the optimization results of supplier network should be S_{1N1}, S_{2N1} and S_{3N1}.

[2]In real life applications, methods such as AHP and ANP can be employed to rank the suppliers.

TABLE III.
FREQUENT PARTSETS

Frequent 1-partsets		Frequent 2-partsets	
Part	Support	Part	Support
P_1	4	P_5P_6	9
P_2	5		
P_3	3		
P_4	4		
P_5	9		
P_6	10		

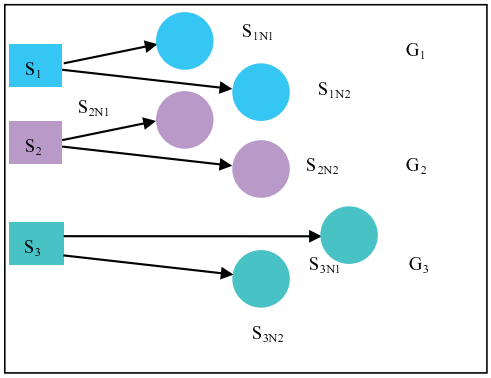

Figure 3. Supplier network

VI. CONCLUSION AND FUTURE WORK

To conclude, based on preparatory work done in the area of supplier network optimization, this study proposes strategic supplier network for supplier selection.

The main novel points and merits of the proposed approach are in three fold: First, the domain of supplier selection is extended to supplier network while introducing supply network perspective. Second, value network and graph theory are adopted to increase the competency and advantage of the optimization of supplier network.

Third, both technique and business interestingness are involved during the optimization process.

In addition, there exists two drawbacks in this study. On the one hand, the case of first-level or direct supplier cannot satisfy the needs of companies is not involved. On the other hand, although the proposed approach is illustrated with a numerical example, additional work is to verify its effectiveness which should be applied in real environments in later research.

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