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# 볼록 자원소비함수, 일반적인 납기와 거부 옵션을 갖는 적시 단일공정 스케줄링 문제*

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# A Just-in-time Single-machine Scheduling Problem with Convex Resource Consumption Functions, Generalized Due Dates and Rejection*

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We consider two just-in-time scheduling problems in a single-machine environment, where the due dates are not job-dependent but position-dependent. A job can be rejected or accepted, and the processing time of the accepted jobs can be reduced according to a decreasing convex function of the resource consumption amount. Some cost occurs for rejecting jobs and reducing the processing times of the accepted jobs. The performance measure of the accepted jobs is the total benefit of the just-in-time jobs. The first objective is to maximize the total benefit minus the total rejection cost with a constraint on the total resource consumption cost, and the second is to maximize the total benefit minus the sum of the total rejection and the total resource consumption costs. We show that the first problem is weakly NP-hard, and polynomially solvable if the benefit and the rejection cost of each job are identical. Furthermore, we show that the second problem is polynomially solvable by reducing it to the shortest path problem.

***Keyword*** : Single-Machine Scheduling, Just-In-Time, Convex Resource Consumption Function, Generalized Due Dates, Rejection

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# 1. Introduction

Consider a single-machine scheduling problem such that the due date is not job-specific but position-specific. Note that such due date is referred to as a *generalized due date* (GDD). The performance measure is the total benefit of the *just-in-time* (JIT) jobs that are completed exactly at the assigned due date. Two options are considered to improve the performance measure. The first is to reject some jobs, which incurs the rejection cost. Note that the rejection can be interpreted as the outsourcing, defined as a business practice in which services or job functions are farmed out to a third party. The second is to reduce the processing time of the accepted job by using the additional resource, which incurs the resource consumption cost. Note that in our problem, the processing time of each job is inversely proportional to the power of the resource consumption amount.

Our problems can be formally stated as follows. Let $J=\{1,2,...,n\}$ be the set of the jobs. For $j\in J$, each job $j$ has a workload $w_j$, a benefit $v_j$, a rejection cost $o_j$ and the processing time that can be calculated as

$$p_j(u_j)=\left(\frac{w_j}{u_j}\right)^k,$$

where $u_j$ is a resource amount consumed to job $j$ and $k>0$ is a given value. Under the GDD policy in our model, a due date $d_i$ is assigned to the job positioned $i$th for $i\in\{1,2,...,n\}$. Let $\Delta_i=d_i-d_{i-1}$ for $i\in\{1,2,...,n\}$, where $d_0=0$ for consistency of notation. For simplicity, assume that

$$d_1\le d_2\le\cdots\le d_n.$$

Under the rejection option in our problem, some jobs can be rejected, which occurs some cost. Let $\sigma=(O;\pi,u)$ be a schedule such that

· $O$ is the set of the rejected jobs;

· $\pi=(\pi(1),\pi(2),...,\pi(l))$ is the sequence of the accepted jobs in $I=J\setminus O$, where $l=|I|$;

· $u=(u_j)_{j\in I}$, where $u_j>0$ is the resource amount consumed to an accepted job.

To ensure that the schedule is well defined, assume that in $\sigma=(O;\pi,u)$,

· All jobs in $I$ should become the JIT jobs, which implies that the non-JIT jobs should be rejected;

· A cost $o_j$ occurs for each job $j\in O$, while a benefit $v_j$ and a cost $u_j$ occur for each job $j\in I$;

· Job $\pi(i)$ in $I$ has a due date $d_i$ for $i\in\{1,2,...,l\}$ while the jobs in $O$ do not have the due date.

Let $\sigma^*=(O^*;\pi^*,u^*)$ be an optimal schedule and $I^*=J\setminus O^*$. For $j\in I$, let $S_j(\sigma)$ and $C_j(\sigma)$ be the start and the completion times of job $j$ in $\sigma$, respectively. Then, it is observed that if job $j$ in $I$ is sequenced $i$th in $\sigma$, then

$S_j(\sigma)=d_{i-1}$ and $C_j(\sigma)=d_i$.

Note that if $S_j(\sigma)\ne d_{i-1}$, then in $\sigma$, $S_j(\sigma)>d_{i-1}$ due to $C_{\pi(i-1)}(\sigma)=d_{i-1}$. Then, we can decrease the value of $u_j$ by increasing the value of job $p_j(u_j)$ without infeasibility or the decrease of the objective value. Two objectives are considered in our problems. The first is to maximize the total benefit minus the total outsourcing cost while the total resource consumption cost should not exceed a given budget. The second is to maximize the total benefit minus the sum of the total outsourcing and the total resource consumption costs. Thus, our problems can be formulated as follows:

$$max\, z_1(\sigma)=\sum_{j\in I}v_j-\sum_{j\in O}o_j$$

$$s.t.\ \sum_{j\in I}u_j\le B,$$

where $B$ is a given budget for the total resource consumption cost, and

$$max\, z_2(\sigma)=\sum_{j\in I}v_j-\sum_{j\in O}o_j-\sum_{j\in I}u_j\ .$$

Let the first and the second problems be referred to as Problems P1 and P2, respectively.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. In Section 3, we prove the weak NP-hardness and the polynomiality of Problems P1 and P2, respectively. Finally, Section 4 presents concluding remarks and future works.

## 2. Literature Review

In this section, we first review four research fields related with our problem, and then introduce the papers simultaneously considering more than two research fields. Since our machine environment is a single-machine, we focus on the a single-machine case.

The research on a scheduling problem to maximize the weighted number of the JIT jobs was initiated from the work by Lann and Mosheiov (1996). They proved the polynomiality of a single-machine case. See (Kovalyov et al., 2007; Sung & Vlach, 2005) for the parallel-machine case (Choi & Yoon, 2007; Shabtay & Bensoussan, 2012) for the various shop cases. The research on scheduling with controllable processing times was initiated from the work by Vickson (1980) (see Janiak et al., 2007; Shabtay & Kaspi, 2006) for the comprehensive surveys). Since the processing time in our problem is calculated as a convex function, we focus on the research with convex resource consumption functions. For simplicity, let the problem to minimize the sum of the criterion and the total resource consumption cost be referred to as Type 1, and the constrained version as Type 2. Choi & Chung (2021) considered three single-machine cases with bounded convex resource consumption functions and the makespan (or the total completion time) criterion. They proved the polynomiality for Types 1 and 2 of two criterions except Type 2 of the second objective. Shabtay & Kaspi (2004) introduced some polynomially solvable cases, and developed a dynamic programming algorithm and some heuristics for Type 2 of a single-machine case with the total weighted completion time criterion. Choi & Chung (2022) proved the NP-hardness and introduced the polynomially solvable case for Types 1 and 2 of two single-machine cases with the late work criterion. See (Monma et al., 1990) for the project scheduling case, Choi & Lee (2022), Shabtay & Kaspi (2006) for the parallel-machine case, and (Cheng & Janiak, 2000; Choi & Park, 2022a, 2022b; Engels et al., 2003) for the flow shop case. The research on scheduling with GDD was initiated from the work by Hall (1986). Hall (1986) and Hall et al. (1991) established the computational complexity for the problems with various performance measures (e.g., the maximum lateness, the total weighted tardiness and the weighted number of tardy jobs), except a single-machine case to minimize the total weighted tardiness, which later was proven to be NP-hard in (Srikandarajah, 1990; Yuan, 1992) and strongly NP-hard in Gao & Yuan (2016). Choi & Park (2018) established the computational complexities for the various single-machine cases to minimize the weighted number of early and tardy jobs. The objective to minimize the total earliness plus the total tardiness in a single-machine case was considered in (Choi et al., 2019; Choi et al., 2022; Gao & Yuan, 2015; Hall et al., 1991). Hall et al. (1991) proved the weak NP-hardness of the case with identical due dates, while Gao & Yuan (2015), and Choi et al. (2019) proved the strong NP-hardness so even for the case with identical intervals between the consecutive due dates. For simplicity, let GDD with identical intervals between the consecutive due dates be periodic due date (PDD). See (Choi et al., 2022; Hall, 1986; Hall et al., 1991; Kim et al., 2020) for the various shop case. The literature on scheduling with rejection was initiated by Bartal et al. (2000). They developed the approximation algorithm for Type 1 of a parallel-machine case with the makespan criterion. Cao & Zhang (2007) and Zhang et al. (2009) considered Type 1 of a single-machine case with release times and the makepsan criterion. In Cao & Zhang (2007), the complexity was proven to be NP-hard and an approximation algorithm was developed, while in Zhang et al. (2009), the exact complexity was established to be weakly NP-hard and an FPTAS was provided. Sengupta (2003) considered the weak NP-hardness and developed a FPTAS for Type 1 of a single-machine case with the maximum lateness criterion. Engels et al. (2003) considered the weak NP-harndess and provided an FPTAS for Type 1 of a single-machine case with the total weighted completion time criterion. Lee & Sung (2008) proved the NP-hardness for Type 2 of a single-machine case with the total completion time criterion. See Choi & Chung (2011) for the flow shop case.

Henceforth, we introduce the papers considering simultaneously at least two fields among four fields of JIT jobs, GDD, resource consumption functions and rejection. First, Gerstl & Mosheiov (2017, 2021) considered a single-machine scheduling problem with GDD and rejection. In Gerstl & Mosheiov (2017), they proved the NP-hardenss developed the heuristics for Type 1 of the case with the maximum tardiness (or the total tardiness) criterion. In Gerstl & Mosheiov (2021), they proved the weak NP-harness for Type 2 of the case with the total late work criterion. They showed that the problem is weakly NP-hard. Choi et al. (2020) proved NP-hardness for Type 2 of the identical parallel-machine scheduling problems with GDD, linear resource consumption functions and the number of the JIT criterion. Choi (2022), Karhi & Shabtay (2018), and Shabtay & Steiner (2011) considered the single-machine scheduling problem with convex resource consumption functions and rejection. In Choi (2022), he proved the NP-hardenss for Types 1 and 2 of the cases with the makespan criterion. In (Karhi & Shabtay, 2018; Shabtay & Steiner, 2011), they proved the NP-hardness and developed an FPTAS for the case to minimize the sum of the makespan and total rejection cost while the total resource consumption cost should not exceed a given budget.

To our best knowledge, the scheduling problem considering simultaneously the JIT jobs, GDD, the convex resource consumption functions and rejection has not yet been found.

Table 1. Papers with at Least Two of Four Fields

| Papers | JIT | GDD | Cov. | Rej. |
|---|---|---|---|---|
| Gerstl & Mosheiov (2017, 2021) | | O | | O |
| Choi et al. (2020) | O | O | O | |
| Choi (2022), Karhi & Shabtay (2018), Shabtay & Steiner (2011) | | | O | O |
| P1 & P2 | O | O | O | O |

* Cov. : convex resource consumption cost function
* Rej. : Rejectoion

# 3. Results

## 3.1 Optimality Condition

In this section, we introduce an optimality condition that holds in Problems P1 and P2.

**Lemma 1**: If $\{a,b\} \subseteq I^*$ and $w_a < w_b$, then $C_a(\sigma^*) - S_a(\sigma^*) \leq C_b(\sigma^*) - S_b(\sigma^*)$.

**Proof**: Suppose that

$$C_a(\sigma^*) - S_a(\sigma^*) > C_b(\sigma^*) - S_b(\sigma^*) \qquad (1)$$

Then, we can construct a new schedule $\overline{\sigma} = (\overline{O}; \overline{\pi}, \overline{u})$ by letting

$$(S_j(\overline{\sigma}), C_j(\overline{\sigma})) = \begin{cases} (S_b(\sigma^*), C_b(\sigma^*)) & for\, j = a \\ (S_a(\sigma^*), C_a(\sigma^*)) & for\, j = b \\ (S_j(\sigma^*), C_j(\sigma^*)) & for\, j \in J \setminus \{a,b\} \end{cases};$$

and

$$\overline{u}_j = \begin{cases} w_a(C_b(\sigma^*) - S_b(\sigma^*))^{-\frac{1}{k}} & for\, j = a \\ w_b(C_a(\sigma^*) - S_a(\sigma^*))^{-\frac{1}{k}} & for\, j = b \\ u_j^* & for\, j \in J \setminus \{a,b\}. \end{cases}$$

Note that $u_a^* = w_a(C_a(\sigma^*) - S_a(\sigma^*))^{-\frac{1}{k}}$ and $u_b^* = w_b(C_b(\sigma^*) - S_b(\sigma^*))^{-\frac{1}{k}}$. Then, it is observed that $z_1(\overline{\sigma}) = z_1(\sigma^*)$ and $z_2(\overline{\sigma}) \geq z_2(\sigma^*)$, and by (1), we have

$$\sum_{j \in I^*} u_j^* > \sum_{j \in \overline{I}} \overline{u}_j,$$

which implies that $\overline{\sigma}$ is a feasible schedule. By these observations, Lemma 1 holds. ■

## 3.2 Problem P1

In this section, we show that Problem P1 is weakly NP-hard and polynomially solvable for the case with identical benefit and rejection cost, that is $v_j = v$ and $o_j = o$ for $j \in J$.

**Lemma 2**: Problem P1 is NP-hard.

**Proof**: We prove it by a reduction from the partition problem, which can be stated as follows: Given the integers in $N = \{a_1, a_2, ..., a_g\}$ with $\sum_{j=1}^{g} a_j = 2A$, is there a set $Q \subset N$ with $\sum_{j \in Q} a_j = A$?

Given an instance of the partition problem, we can construct an instance of Problem P1 with $g$ jobs such that $w_j = v_j = a_j$ and $o_j = 0$ for $j \in \{1,2,...,g\}$. Furthermore, let $d_i = i$ for $i \in \{1,2,...,g\}$, and $B = A$. Henceforth, we show that there exists a solution to the partition problem if and only if there exists a feasible schedule $\sigma$ with $z_1(\sigma) \geq A$.

($\Rightarrow$) Suppose that there exists a solution $\overline{Q}$ to the partition problem with $\sum_{j \in \overline{Q}} a_j = A$. Then, we can construct a schedule $\overline{\sigma} = (\overline{O}; \overline{\pi}, \overline{u})$ by letting $\overline{I}$ be the set of the jobs corresponding to the integers in $\overline{Q}$ and $\overline{O} = \{1,2,...,g\} \setminus \overline{I}$, and $\overline{u}_j = a_j$ for $j \in \overline{I}$. Then, we have

$$p_j(\overline{u}_j) = 1 \text{ for } j \in \overline{I}.$$

Thus, construct $\overline{\pi}$ by arbitrarily assigning jobs in $\overline{I}$ to the first $|\overline{I}|$ intervals $[d_{i-1}, d_i]$ for $i \in \{1,2,...,|\overline{I}|\}$. Then, since

$$\sum_{j \in \overline{I}} \overline{u}_j = \sum_{j \in \overline{Q}} a_j = A,$$

$\overline{\sigma}$ is a feasible schedule, and

$$z_1(\overline{\sigma}) = \sum_{j \in I} v_j = \sum_{j \in Q} a_j = A.$$

($\Leftarrow$) Suppose that there exists a feasible schedule $\hat{\sigma} = (\hat{O}, \hat{\pi}, \hat{u})$ with $z_1(\hat{\sigma}) \geq A$,

which implies that

$$\sum_{j \in \hat{I}} v_j = \sum_{j \in \hat{I}} a_j \geq A \qquad (2)$$

It is observed that by the GDD policy, the jobs in $\hat{I}$ are assigned to the first $|\hat{I}|$ interval $[d_{i-1}, d_i]$ for each $i \in \{1,2,...,|\hat{I}|\}$, which implies that

$$\hat{u}_j \geq a_j \text{ for } j \in \hat{I}. \qquad (3)$$

By (2) and (3), we have

$$\sum_{j \in \hat{I}} \hat{u}_j \geq A. \qquad (4)$$

Then, by the feasibility of $\hat{\sigma}$,

$$\sum_{j \in \hat{I}} \hat{u}_j \leq A. \qquad (5)$$

By (4) and (5), we have

$$\sum_{j \in \hat{I}} \hat{u}_j = A. \qquad (6)$$

By (2), (3) and (6),

$$\sum_{j \in \hat{I}} a_j = A. \qquad (7)$$

Thus, let $\hat{Q}$ be the set of integers corresponding to the jobs in $\hat{I}$. Then, by (7), $\hat{Q}$ becomes a solution to the partition problem. ■

**Lemma 3**: Problem P1 can be solved in pseudo-polynomial time.

**Proof**: We prove it by reducing Problem P1 to the restricted shortest path problem (RSPP), which can be stated as follows. Given a graph $G = (N, E)$ with a node set $N = \{1,2,...,n\}$ and an edge set $E = \{(j,j') \mid i \in N \text{ and } j \in N\}$, each edge $(j,j')$ in $E$ has a length $c_{j,j'}$ and a cost $t_{j,j'}$. The objective is to find a path from nodes 1 to $n$ whose total length is minimized while the total cost is less than or equal to a given budget $B$. It has been known from (Hassin, 1992) that the RSPP can be solved in pseudo-polynomial time. Without loss of generality, assume that

$$w_1 \leq w_2 \leq \cdots \leq w_n.$$

Suppose that $|I^*| = l$ in $\sigma^*$. Let $(\pi^*(1), \pi^*(2), ..., \pi^*(l))$ be the permutation such that

$\{\Delta_1, \Delta_2, ..., \Delta_l\} = \{\Delta_{\pi^*(1)}, \Delta_{\pi^*(2)}, ..., \Delta_{\pi^*(l)}\}$

and

$$\Delta_{\pi^*(1)} \leq \Delta_{\pi^*(2)} \leq ... \leq \Delta_{\pi^*(l)}. \qquad (8)$$

Let $N(0,0)$ and $N(l+1, \cdot)$ be the source and the terminal nodes, respectively. For $0 \leq i \leq \min\{l,j\} \leq j \leq n$, let $N(i,j)$ be the node representing that job $j$ is the $i$th accepted job. For $i < l$ and $j < j'$, let $N(i,j)$ be connected to $N(i+1,j')$ with length $\sum_{g=j+1}^{j'-1} o_g - v_{j'}$ and cost $w_{j'}(\Delta_{\pi^*(i+1)})^{-\frac{1}{k}}$. For $i = l$, let $N(i,j)$ be connected to $N(l+1, \cdot)$ with length $\sum_{g=j+1}^{n} o_g$ and cost 0. The objective is to find the path from $N(0,0)$ to $N(n+1, \cdot)$ to minimize the total length while the total cost is less than or equal to $B$. Note that this reduction can be done in polynomial time. Note that $i < j$ in each edge $(N(i,j), N(i+1,j'))$, which implies that by (8), the job with the less workload is assigned to the smaller interval. Based on Lemma 1, this guarantees that the path corresponding to an optimal schedule for the case with $|I^*| = l$ exists in the constructed graph.

Then, we can obtain an optimal schedule by solving the case with $|I^*| = l$ for each $l \in \{0,1,...,n\}$ and choosing the schedule with the smallest objective value. Thus, Lemma 3 holds. ■

**Theorem 1**: Problem P1 is weakly NP-hard.

**Proof**: It holds immediately from Lemmas 2 and 3. ■

**Lemma 4**: If $a \in I^*$, $b \in O^*$, $v_a = v_b$ and $o_a = o_b$, then $w_a \le w_b$.

**Proof**: Suppose that $w_a > w_b$. Then, we can construct a new schedule $\overline{\sigma} = (\overline{O}; \overline{\pi}, \overline{u})$ by letting

$$\overline{I} = I^* \setminus \{a\} \cup \{b\} \text{ and } \overline{O} = J \setminus \overline{I};$$

$$(S_j(\overline{\sigma}), C_j(\overline{\sigma})) = \begin{cases} (S_j(\sigma^*), C_j(\sigma^*)) & for\, j \in \overline{I} \setminus \{b\} \\ (S_a(\sigma^*), C_a(\sigma^*)) & for\, j = b \end{cases};$$

and

$$\overline{u}_j = \begin{cases} u_j^* & for\, j \in \overline{I} \setminus \{b\} \\ \dfrac{w_b}{w_a} u_a^* & for\, j = b. \end{cases}$$

Then, it is observed that $z_1(\overline{\sigma}) = z_1(\sigma^*)$ and by $w_b / w_a < 1$, we have

$$\sum_{j \in \overline{I}} \overline{u}_j < \sum_{j \in I^*} u_j^* \le B,$$

which implies that $\overline{\sigma}$ is a feasible schedule. By these observations, Lemma 4 holds. ■

**Theorem 2**: Problem P1 is polynomially solvable if the benefit and the rejection cost of each job are identical, that is, $v_j = v$ and $o_j = o$ for $j \in J$.

**Proof**: Without loss of generality, assume that $w_j \le w_{j+1}$ and $\Delta_j \le \Delta_{j+1}$ for $j = 1, 2, ..., n-1$. Then, based on Lemmas 1 and 4, we can construct the following algorithm to find an optimal schedule for the case with $v_j = v$ and $o_j = o$ for $j \in J$.

Step 1: Set $j = 1$, $I^* = I = \varnothing$, $O^* = O = J$, $\pi = \pi^* = \varnothing$ and $z^* = 0$.

Step 2: Let $I = I \cup \{j\}$, $O = O \setminus \{j\}$, $\pi = (\pi, j)$ and $u_j = w_j \Delta_j^{-\frac{1}{k}}$, where $(\pi, j)$ is a sequence of the jobs in $I$ constructed by positioning job $j$ after the last job in $\pi$.

Step 3: If $u_j > B$, then return $(O^*; \pi^*, (u_j^*)_{j \in I^*})$ and STOP, while otherwise let $B = B - u_j$.

Step 4: If $\sum_{j \in I} v_j - \sum_{j \in O} o_j \le z^*$, then return $(O^*; \pi^*, (u_j^*)_{j \in I^*})$ and STOP, while otherwise, let $I^* = I$, $O^* = O$, $\pi^* = \pi$, $u_j^* = u_j$, $z^* = \sum_{j \in I} v_j - \sum_{j \in O} o_j$ and $j = j + 1$.

Step 5: If $j = n + 1$, then return $(O^*; \pi^*, (u_j^*)_{j \in I^*})$ and STOP, while otherwise, go to Step 2.

Note that this algorithm can be done in $O(n)$. Thus, Theorem 2 holds. ■

### 3.3 Problem P2

In this section, we show that Problem P2 is polynomially solvable.

**Theorem 3**: Problem P2 is polynomially solvable.

**Proof**: We prove it by reducing Problem P2 to the shortest path problem (SPP), which can be stated as follows. Given a graph $G = (N, E)$ with a node set $N = \{1, 2, ..., n\}$ and an edge set $E = \{(j, j') \mid i \in N \text{ and } j \in N\}$, each edge $(j, j')$ in $E$ has a length $c_{j, j'}$. The objective is to find a path from nodes 1 to $n$ whose total length is minimized. It has been known from (Ahuja et al., 1990) that the SPP can be solved in polynomial time. Without loss of generality, assume that

$$w_1 \le w_2 \le \cdots \le w_n.$$

Suppose that $|I^*| = l$ in $\sigma^*$. Let $\pi^{*l} = (\pi^*(1), \pi^*(2), ..., \pi^*(l))$ be the permutation such that

$$\{\Delta_1, \Delta_2, ..., \Delta_l\} = \{\Delta_{\pi^*(1)}, \Delta_{\pi^*(2)}, ..., \Delta_{\pi^*(l)}\}$$

and

$$\Delta_{\pi^*(1)} \le \Delta_{\pi^*(2)} \le ... \le \Delta_{\pi^*(l)}. \tag{9}$$

Let $N(0,0)$ and $N(l+1, \cdot)$ be the source and the terminal nodes, respectively. For $0 \le i \le \min\{l, j\} \le j \le n$, let $N(i, j)$ be the node representing that job $j$ is the $i$th accepted job. For $i < l$ and $j < j'$, let $N(i, j)$ be connected to $N(i+1, j')$ with length $-v_{j'} + \sum_{g=j+1}^{j'-1} o_g + w_{j'} (\Delta_{\pi^*(i+1)})^{-\frac{1}{k}}$.

For $i = l$, let $N(i, j)$ be connected to $N(l+1, \cdot)$ with length $\sum_{g=j+1}^{n} o_g$. The objective is to find the path from $N(0,0)$ to $N(n+1, \cdot)$ to minimize the total length. Note that this reduction can be done in polynomial time. Note that $i < j$

in each edge $(N(i,j), N(i+1,j'))$, which implies that by (9), the job with the less workload is assigned to the smaller interval. Based on Lemma 1, this guarantees that the path corresponding to an optimal schedule for the case with $|I^*| = l$ exists in the constructed graph.

Then, we can obtain an optimal schedule by solving the case with $|I^*| = l$ for each $l \in \{0,1,...,n\}$ and choosing the schedule with the smallest objective value. Thus, Theorem 3 holds. ■

## 4. Concluding Remarks

We consider two just-in-time single-machine scheduling problems with generalized due dates, convex resource consumption functions and rejection. Some cost occurs if jobs are rejected or the processing times of the accepted jobs is reduced. The performance measure of the accepted jobs is the total benefit of the just-in-time jobs. The first objective is to maximize the total benefit minus the total rejection cost while the total resource consumption cost is less than or equal to a given budget. The second is to maximize the total benefit minus the sum of the total rejection and the total resource consumption costs. We prove the weak NP-hardness and polynomiality of the first and the second problems, respectively. Furthermore, we show that the first problems is polynomially solvable if the benefit and the rejection cost of each job are identical.

For future research, it would be interesting to first develop good heuristics for the first problem, and consider the problem to maximize the number of the just-in-time jobs while the sum of the total resource consumption cost and the total rejection cost should not exceed a given budget, or to maximize the number of the just-in-time jobs while the total resource consumption cost and the total rejection cost should not exceed theirs own given budgets, respectively.

## REFERENCES

[1] Ahuja, R. K., Mehlhorn, K., Orlin, J., & Tarjan, R. E. (1990). Faster algorithms for the shortest path problem. *Journal of the ACM*, 37, 213-223.

[2] Bartal, Y., Leonardi, S., Marchetti-Spaccamela, A., Sgall, J., & Stougie, L. (2000). Multiprocessor scheduling with rejection. *SIAM Journal on Discrete Mathematics*, 13, 64-78.

[3] Cao, Z. G. & Zhang, Y. Z. (2007). Scheduling with rejection and nonidentical job arrivals. *Journal of Systems Science and Complexity*, 20, 529-535.

[4] Cheng, T. C. E. & Janiak, A. (2000). A permutation flow-shop scheduling problem with convex models of operation processing times. *Annals of Operations Research*, 96, 39-60.

[5] Choi, B. C. (2022). A single-machine scheduling problem with convex resource consumption functions and rejection. *Journal of the Korean Society of Supply Chain Management*, 22, 11-18.

[6] Choi, B. C. & Chung, J. B. (2011). Two-Machine flow shop scheduling problem with an outsourcing option. *European Journal of Operational Research*, 213, 66-72.

[7] Choi, B. C. & Chung, Y. (2021). Single-machine scheduling problem with bounded convex resource consumption functions. *Journal of The Korean Operations Research and Management Science Society*, 46, 1-9.

[8] Choi, B. C. & Chung, Y. (2022). A single-machine scheduling problem with the controllable processing times and the late work criterion. *Journal of The Korean Operations Research and Management Science Society*, 47, 35-44.

[9] Choi, B. C. & Lee, J. H. (2022). Parallel machine scheduling problems with convex resource-dependent processing times. *Yonsei Business Review*, 59, 1-19.

[10] Choi, B. C., Min, Y. H., Kim, K. M., & Park, M. J. (2022). Scheduling with generalized and periodic due dates under single- and two-machine environments. *Optimization Letters*, 16, 623-633.

[11] Choi, B. C., Min, Y. H., & Park, M. J. (2019). Strong NP-hardness of minimizing total deviation with generalized and periodic due dates. *Operations Research Letters*, 47, 433-437.

[12] Choi, B. C. Min, Y. H., Park, M. J., & Kim, K. M. (2022). A single machine scheduling with generalized and periodic due dates to minimize the total deviation. *Discrete Applied Mathematics*, 314, 31-52.

[13] Choi, B. C. & Park, M. J. (2018), Just-In-Time scheduling with generalized due dates and identical due date

intervals. *Asia-Pacific Journal of Operational Research*, 35(6).

[14] Choi, B. C. & Park, M. J. (2022). Two-machine flow shop scheduling with convex resource consumption functions. Optimization Letters. https://doi.org/10.1007/s11590-022-01934-1.

[15] Choi, B. C. & Park, M. J. (2022). Two permutation flow shop scheduling models with makespan criterion and convex resource consumption functions. *Journal of Scheduling* (submitted to Journal of Scheduling).

[16] Choi, B. C., Park, M. J., & Min, Y. H. (2020), A just-in-time scheduling problem with generalized due dates and controllable processing times. *Journal of the Korean Society of Supply Chain Management*, 20, 17-23.

[17] Choi, B. C. & Yoon, S. H. (2007). Maximizing the weighted number of just-in-time jobs in flow-shop scheduling. *Journal of Scheduling*, 10, 237-243.

[18] Engels, D. W., Karger, D. R., Kolliopoulos, S. G., Sengupta, S., Uma, R. N., & Wein, J. (2003). Techniques for scheduling with rejection. *Journal of Algorithms*, 49, 175-191.

[19] Gao, Y. & Yuan, J. (2015). Unary NP-hardness of minimizing the total deviation with generalized or assignable due dates. *Discrete Applied Mathematics*, 189, 49-52.

[20] Gao, Y. & Yuan, J. J. (2016). Unary NP-hardness of minimizing total weighted tardiness with generalized due dates. *Operations Research Letters*, 44, 92-95.

[21] Gerstl, E. & Mosheiov, G. (2017). Single machine scheduling problems with generalised due-dates and job-rejection. *International Journal of Production Research*, 55, 3164-3172.

[22] Gerstl, E. & Mosheiov, G.(2021). Minimizing total late work on a single machine with generalized due-dates. *European Journal of Operational Research*, 293, 837-846.

[23] Hall, N. G. (1986). Scheduling problems with generalized due dates. *IIE Transactions*, 18, 220-222.

[24] Hall, N. G., Kubiak, W., & Sethi, S. P. (1991). Earliness-tardiness scheduling problems, II: deviation of completion times about a restrictive common due date. *Operations Research*, 39, 847-856.

[25] Hall, N. G., Sethi, S. P., & Srikandarajah, S. (1991). On the complexity of generalized due date scheduling problems. *European Journal of Operational Research*, 51, 100-109.

[26] Hassin, R. (1992). Approximation schemes for the restricted shortest path problem. *Mathematics of Operations Research*, 17, 36-42.

[27] Janiak, A., Janiak, W., & Lichtenstein, M. (2007). Resource management in machine scheduling problems: A survey. *Decision Making in Manufacturing and Services*, 1, 59-89.

[28] Karhi, S. & Shabtay, D. (2018). Single machine scheduling to minimise resource consumption costs with a bound on scheduling plus due date assignment pernalities. *International Journal of Production Research*, 56, 3080-3096.

[29] Kim, K. M., Choi, B. C., Min, Y. H., & Park, M. J. (2020). Two-machine ordered flow shop with generalized due dates. *Asia-Pacific Journal of Operational Research*, 37, 1950032.

[30] Kovalyov, M. Y., Ng, C. T., & Cheng, T. C. E. (2007). Fixed interval scheduling: Models, applications, computational complexity and algorithms. *European Journal of Operational Research*, 178, 331-342.

[31] Lann, A. & Mosheiov, G. (1996). Single machine scheduling to minimize the number of early and tardy jobs. *Computers and Operations Research*, 23, 765-781.

[32] Lee, I. S. & Sung, C. S. (2008). Single machine scheduling with outsourcing allowed. *International Journal of Production Economics*, 101, 623-634.

[33] Monma, C. L., Schrijver, A., Todd, M. J., & Wei, V. (1990). Convex resource allocation problems on directed acyclic graphs: Duality, Complexity, Special cases, and Extensions. *Mathematics of Operations Research*, 15, 736-748.

[34] Sengupta, S. (2003). Algorithms and approximation schemes for minimum lateness/tardiness scheduling with rejection. *Lecture Notes on Computer Science*, 2748. 79-90.

[35] Shabtay, D. & Bensoussan, Y. (2012). Maximizing the weighted number of just-in-time jobs in several two-machine scheduling systems. *Journal of Scheduling*, in5, 39-47.

[36] Shabtay, D. & Kaspi, M. (2004). Minimizing the total weighted flow time in a single machine with controllable

processing times. *Computers and Operations Research*, 31, 2279-2289.

[37] Shabtay, D. & Kaspi, M. (2006). Parallel machine scheduling with a convex resource consumption function. *European Journal of Operational Research*, 173, 92-107.

[38] Shabtay, D., Kaspi, M., & Steiner, G. (2007). The no-wait two-machine flow shop scheduling problem with convex resource-dependent processing times. *IIE Transactions*, 39, 539-557.

[39] Shabtay, D. & Steiner, G. (2007). A survey on scheduling with controllable processing times. *Discrete Applied Mathematics*, 155, 1643-1666.

[40] Shabtay, D. & Steiner, G. (2011). A bicriteria approach to minimize the total weighted number of tardy jobs with convex controllable processing times and assignable due dates. *Journal of Scheduling*, 14, 455-469.

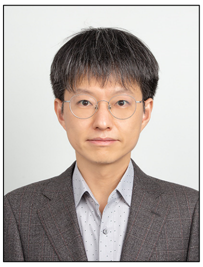
[41] Srikandarajah, S.(1990). A note on the generalized due dates scheduling problem. *Naval Research Logistics*, 37, 587-597.

[42] Sung, S. C. & Vlach, M. (2005). Maximizing weighted number of just-in-time jobs on unrelated parallel machines. *Journal of Scheduling*, 8, 453-460.

[43] Vickson, R. G. (1980). Choosing the job sequence and processing times to minimize total processing plus flow cost on a single machine. *Operations Research*, 28, 1155-1167.

[44] Yuan, J. J. (1992). The NP-hardness of the single machine common due date weighted tardiness problem. *Systems Science and Mathematical Science*, 5, 328-333

[45] Zhang, L. Q., Lu, L. F., & Yuan, J. J. (2009). Single machine scheduling with release dates and rejection. *European Journal of Operational Research*, 198, 975-978.



**최 병 천**

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# 중국 유기농 식품 공급사슬 관리에서 투명성 개선을 위한 블록체인 기술 수용 행동*

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# Blockchain Technology Adoption Behavior to Improve Transparency in Organic Food Supply Chain in China

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The adoption of information technologies using the innovation diffusion theory (IDT) and technology acceptance model (TAM) has been studied several decades. However, there are still limited researches on organic food firms by applying blockchain technology. This study proposes an extended TAM by integrating external environmental characteristics, IDT and TAM. Based on 156 valid questionnaires collected from managers of Chinese organic food enterprises, the analysis results of structural equation model (SEM) indicate that the behavior intention to use (BIU) blockchain technology is influenced by five factors. External pressure, relative advantage, compatibility, and complexity positively impact on perceived usefulness (PU). Also, external pressure, compatibility, and complexity positively influence on perceived ease of use (PEU). The findings of this research validate the utility of information technology (IT) theories in explaining the adoption of blockchain technology in Chinese organic food organizations. The insights of this research are of practical importance to organic food practitioners and policymakers.

***Keyword*** : Blockchain technology, Supply chain management, Organic food supply chain, TAM, IDT

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## 1. Introduction

In recent years, the sales of organic food have shown a significant growth due to a rising awareness of healthy foods among the public. Although organic food was introduced relatively late in China compared with Western countries, supportive policies and economic strategies have made a significant expansion of organic foods.

In the past few years, there have been several obstacles to the expansion of the organic goods market resulting from the frequent occurrence of unethical practices in the certification process including fraud and scandals (Manning & Kowalska, 2021; Thanujan et al., 2022). The supply chain management (SCM) for organic foods requires the adoption of more cutting-edge models and methods to solve challenging problems. New information technologies for SCM have captured the interest of both scholars and practitioners. To build transparent SCM, decision-makers might incorporate the concept of blockchain technology (Lekha et al., 2021). One example of blockchain technology being applied in the Chinese organic food supply chain is Hema Xiansheng, a Chinese retail company that provides fresh organic food to customers through both online and offline channels. Hema Xiansheng uses blockchain technology to transparently manage every step of the process, from production to distribution. A transparent supply chain performs a variety of functions, including facilitating information exchange among supply chain participants, boosting communication about food quality, supporting product differentiation, and increasing the efficiency of logistical operations and business processes (Trienekens et al., 2012).

According to previous research, blockchain technology notably enhances information transparency within the supply chain and allows stakeholders in the supply chain to share information each other (Treiblmaier & Garaus, 2023). However, there is still an issue on the degree to which potential users would accept emerging technologies. Studies in the literature are mostly concentrated on the technical aspect of blockchain. Corporate blockchain adoption behavior is not well studied in most research. Some particular industry traits are not included in earlier multi-industry studies on this topic. This study proposes the subsequent set of research questions (RQs) to measure how willing the organic food supply chain is to adopt blockchain technology:

RQ1: What are the key drivers that have led to the adoption of blockchain technology in the organic food supply chain?

RQ2: What are the crucial factors that will influence the adoption of blockchain technology in the supply chain for organic foods?

The level of user acceptance is a prerequisite for implementing blockchain technology. The literature review on technology adoption shows that researchers in the field not only rely on IDT by Rogers (1995) and the TAM by Davis (1989), but also consider numerous environmental factors. These factors may compel companies to learn more about blockchain technology. This can help companies overcome numerous uncertainties by making innovations and reducing the perceived barriers to adoption. The purpose of this study is to examine the impact of environmental characteristics and innovation characteristics on an organic food firms when applying blockchain technology in the near future. The empirical results validate the theoretical framework for researchers and offer practical insights for practitioners who developing and implementing blockchain technology.

## 2. Literature Review

The TAM is widely used to forecast and illuminate end-users' behavior and system utilization. It is one of the fundamental theories in view of its strong theoretical underpinnings. The environmental characteristics and innovation characteristics are suggested to support theory for investigating how motivational drivers affect TAM constructs. A theoretical framework that extends the TAM is proposed in this research.

### 2.1 Blockchain Technology

Financial services and cryptocurrencies like Bitcoin are two of the most common uses of blockchain technology (Tapscott & Tapscott, 2017). After initially used in Bitcoin, blockchain technology is shown in cryptographic algorithms and peer-to-peer networks. Although blockchain technology was originally developed to underpin Bitcoin, it has now permeated different areas such as logistics, food supply, and transportation (Koh et al., 2020).

The blockchain, according to Tapscott & Tapscott (2017), is the most likely technology to alter business in the ensuing ten years. The food business, in particular, values the advantages that result from blockchain technology (Tsolakis et al., 2021).

The blockchain is a tool that defends transparency but does not actually offer it. Blockchain as a service is developing to provide fundamental supporting infrastructure. The BaaS integrates cloud computing, IoT, and blockchain technologies to enable businesses to develop tailor-made applications. It ensures supply chain transparency and traceability (Song et al., 2022). IBM and Microsoft appear to be at the forefront in the offering of blockchain infrastructure services (Singh & Michels, 2018). Since 2016, JD.com and IBM have collaborated to deploy blockchain in the logistics industry (Joo & Han, 2021).

## 2.2 Blockchain Technology-Based Food SCM

The SCM is one of the areas that this innovative technology can anticipate to generate significantly benefits. Christopher (2016) claims that SCM is “the management of upstream and downstream interactions between suppliers and customers in order to offer higher customer value at less cost to the supply chain as a whole”. Since blockchain can simplify complicated interactions between network participants and resolve inconsistent data, the entire supply chain network would be impacted by using blockchain technology, which would improve operations efficiency (Queiroz & Wamba, 2019). By applying blockchain technology, social sustainability might be improved, and supply chain hazards could be reduced (Chaudhuri et al., 2021).

Blockchain technology has the ability to lessen the “ripple effect”. It defines how risks spread further along the food supply chain and determines how network planning and structural design criteria are made (Dolgui et al., 2018). The food companies may employ blockchain technology to ensure food traceability and connect participants in the distribution chain. It assures that information cannot be changed without their permission (Niknejad et al., 2021).

As the emphasis on food quality, safety, and freshness grows, in particular organic food industry is coming under growing pressure to meet these requirements. If their organic products are revealed not being organic, supply chain partners may face serious consequences. The United States has advocated the adoption of blockchain technology for tracking the organic goods supply chain since 2020 (Van Hilten et al., 2020).

## 2.3 IDT

The IDT is a theory connected to technological innovation research (Gillenson & Sherrell, 2002). The framework that explains how and at what rate a new technology spreads, and elements that help users adopt the technology, known as “IDT” (Holland, 1997). The traditional innovation diffusion theory has evolved over more than 60 years to become a go-to theory assisting in the puzzle-solving of any innovation, including blockchain. Rogers (1995) defined diffusion as “the process by which an innovation is disseminated through certain channels over time among the members of a social system.” In general, only 10-15% of people initially adopt new technology (Holland, 1997).

Rogers (1995) compiled a substantial corpus of articles on IDT, highlighting the necessity to consider the perceived qualities of innovations (i.e. trialability, observability, complexity, compatibility, and relative advantage). As suggested by Chong et al. (2009), the trialability is a characteristic that has frequently been left out of IT innovation research. When studying new IT innovations, IDT-based models do not include observability due to the same limitation within the enterprise (Agi & Jha, 2022; Chong et al., 2009). This research benefits from the innovative attributes set in the IDT including relative advantage, compatibility, and complexity, assist to explain the varying acceptance rates of blockchain technology.

## 2.4 TAM

There is a fairly extensive body of researches on adoption models. Various models have arisen during the past few years including theory of planned behaviour (Ajzen, 1991), theory of reason action (Fishbein et al., 1975), TAM (Davis, 1989), and TAM 2 (Venkatesh et al., 2003). In information system researches, the TAM has received a lot of attention, because it offers trustworthy instruments with strong measuring qualities, emphasizes system use, and is grounded on empirical research despite of its minimalism (Pavlou, 2003).

Davis (1989) created the TAM, which is mostly used to represent and forecast users' adoption of information technology, based on the rational behavior theory. He expected that the use of this model can effectively predict users' behavior toward adopting an information system and identify key factors affecting their willingness to use technology. The TAM contends that both PEU and PU are two outside factors that affect how people actually use internet technologies (Pavlou, 2003). Some recent studies have effectively used the TAM to examine how blockchain-related technologies are accepted and deployed. Under the TAM, Nuryyev et al., (2020) studied the determinants of medium-sized tourist and hospitality firms' use of cryptocurrency payment.

### 2.5 Extending IDT and TAM

A single model can neither adequately capture user behavior towards technology in all situations nor reflect adoption behavior. While investigating how new technologies are adopted, the IDT and TAM complement one another in several ways (Lee et al., 2011). According to earlier researches, these two theories might be integrated to provide a model that is more accurate than using each of them independently (Wu & Wang, 2005). However, it is crucial to broaden these models to employ additional important elements when using them to examine the adoption of blockchain technology.

As stated by Oliveira & Martins (2011), Although the IDT emphasizes the innovation's characteristics, it is well acknowledged that a variety of external contextual factors have an impact on how organizations choose to use information technology. Klaas et al. (2010) suggest that organizational size can be measured through factors such as human capital and enterprise scale. Meanwhile, Iacovou et al. (1995) demonstrate that Organizations' adoption of new technologies may be influenced by various factors, such as their partners, regulations, and competition. Therefore, it is crucial to examine context-specific factors in the firm-level adoption of technology. This approach will aid in developing a more thorough understanding of the elements that affect how companies adopt new technology. The determinants of enterprises' adoption of blockchain technology in the organic food supply chain can be divided into five contributing factors, innovation and environmental characteristics.

## 3. Theoretical Model and Research Hypotheses

This research aims to investigate the inclination towards adopting blockchain technology for managing organic food supply chains by extending the IDT and TAM. To determine the PEU, PU, and BIU, five factors (external pressure, organizational size, relative advantage, complexity, and compatibility) are investigated. Based on the literature review on the research framework and related concepts, the research hypotheses about the relationship between the constructs are proposed.

### 3.1 External Pressure

Kwon et al. (2021) stated that organizations function within a social system comprised of various units that serve distinct objectives, such as clients, vendors, rivals, and other parties. This highlights the interconnectedness and interdependence of different components within the business environment. Therefore, in a business setting, external pressure from these different units may have a social impact and prompt the commercial use of the new technology.

Numerous researchers have investigated the impact of external pressure on the making innovation. For instance, Zhu et al. (2003) claimed that external pressure on firms to accept innovations might come from customer preparedness and competitors' adoption of those innovations. External pressure affects decision-makers' willingness to adopt innovation (Kwon et al., 2021). Consequently, the following hypotheses are developed:

H1-1: External pressure positively influences the PU of blockchain technology.
H1-2: External pressure positively influences the PEU of blockchain technology.
H1-3: External Pressure positively influences the BIU of blockchain technology.

### 3.2 Organization Size

The examination of organizational size as a structural variable in organizations has been extensively studied and analyzed various aspects such as innovation, R&D expenditures, and market power (Mabert et al., 2003). In comparison with smaller firms, larger organizations have a higher success rate when deploying new technology. This is attributed to the fact that larger organizations typically have more employees, larger capital, and higher profit margins. However, small and medium-sized enterprises (SMEs) face limitation of their ability to invest in technology due to resource constraints and weak innovation capabilities (Bracci et al., 2022).

DeLone (1981) emphasized the importance of organizational factors for the successful implementation of innovation. Therefore, larger organizations are expected to have a higher PU and PEU of the technology, and a stronger BIU to adopt it compared with smaller ones. The following hypotheses are developed:

H2-1: Organizational size positively influences the PU of blockchain technology.
H2-2: Organizational size positively influences the PEU of blockchain technology.
H2-3: Organizational size positively influences the BIU of blockchain technology.

## 3.3 Relative Advantage

According to Rogers (1995), the idea of relative advantage refers to the degree to which an innovation outperforms its predecessor in terms of economic value and impact. Blockchain is a disruptive technology that can create numerous opportunities, particularly in improving transparency (Rajnak & Puschmann, 2021). It is widely used in supply chains to generate and disseminate unique records and data among partners, with the goal of enhancing information openness and accessibility (Agi & Jha, 2022).

A relative advantage is also discovered to be a predicator of technological adoption (Brandon-Jones & Kauppi, 2018). The following hypotheses are postulated:

H3-1: Relative advantage positively influences the PU of blockchain technology.
H3-2: Relative advantage positively influences. the PEU of blockchain technology.
H3-3: Relative advantage positively influences the BIU of blockchain technology.

## 3.4 Compatibility

To effectively optimize the supply chain and ensure transparency, it is imperative for all participants to work collaboratively and share data. This involves developing common process standards, defining supply chain goals, and establishing norms for information disclosure (Mendling et al., 2018). The use of blockchain technology to preserve detailed data accessibility and keep internal traceability might necessitate changing internal operational processes (Agi & Jha, 2022).

To determine attitudes toward using a system and BIU, the concept of compatibility has frequently been employed when studying on information systems adoption (Venkatesh et al., 2003). A higher compatibility of blockchain technology is expected to lead to higher PU and PEU of the technology and a stronger BIU to adopt it. The following hypotheses are developed:

H4-1: Compatibility positively influences the PU of blockchain technology.
H4-2: Compatibility positively influences the PEU of blockchain technology.
H4-3: Compatibility positively influences the BIU of blockchain technology.

## 3.5. Complexity

The complexity is the measure of an innovation's perceived level of difficulty for users (Rogers, 1995). Evidently, blockchain is a revolutionary and challenging technology (Agi & Jha, 2022). Before using new inventions and disruptive technologies, it is crucial to understand possible difficulties and complexity in order to reduce risks and prevent failures from bringing negative technical, social, and political effects (Janssen et al., 2020).

The adoption of new technology may be hampered by its complexity. A higher level of complexity of blockchain technology is expected to lead to lower PU and PEU of the technology, and a weaker BIU to adopt it. The following hypothesis is postulated:

H5-1: Complexity negatively influences the PU of blockchain technology.

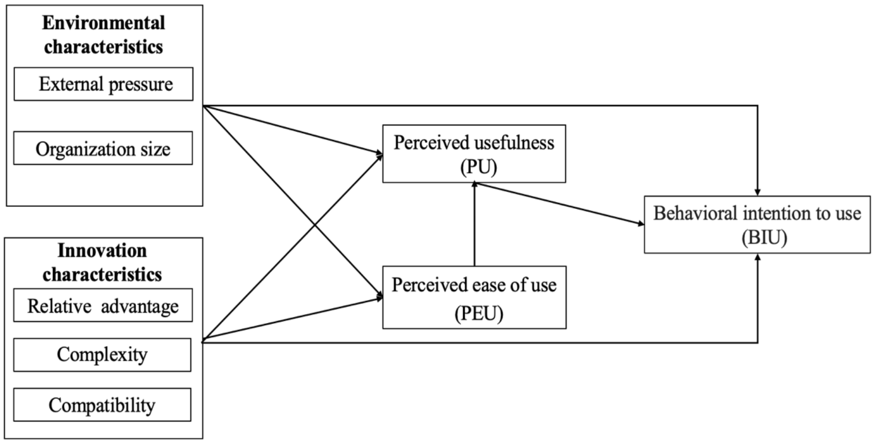


Fig. 1 Research Model

H5-2: Complexity negatively influences the PEU of blockchain technology.

H5-3: Complexity negatively influences the BIU of blockchain technology.

### 3.6 PU

The word PU relates to how much a decision-maker believes an innovation, technology, or system would help them execute their jobs better (Davis, 1989). Policymakers adopt innovations when they believe they work (Kwon et al., 2021; Singh & Michels, 2018). In other words, if the user believes that a system can help him complete the task successfully, he will have a favorable impression of the system.

When more participants in the chain of organic food suppliers recognize the value of blockchain technology for boosting information transparency, there would be a stronger BIU and a more favorable attitude towards using blockchain technology. That is, a higher level of PU of blockchain technology is expected to lead to a stronger BIU to adopt it. The following hypothesis is postulated:

H6-1: PU positively influences the BIU of blockchain technology.

### 3.7 PEU

The technology acceptance model identifies PEU as a another cognitive driver that influences technology adoption. PEU refers to the users' perception of the ease and simplicity of using technology (Davis, 1989). Therefore, the PEU represents the degree to which users believe that they can easily and effectively use the technology without significant effort or difficulty. In the model of this research, PEU refers to the users' perception of the ease of adopting blockchain technology.

According to Davis (1989), the PEU of information technology significantly influences the PU of the technology. Gefen & Straub (2020) conducted a comprehensive study on the relationship between PEU and PU and confirmed that PEU is a key factor that drives PU in most cases. When users have a high perception of ease of use for blockchain technology, they have a higher likelihood of wishing to employ blockchain technology. The following hypothesis is developed:

H7-1: PEU positively influences the PU of blockchain technology.

The research model is shown in <Fig. 1>.

## 4. Materials and Methods

### 4.1 Data Collection

Between February 2023 and April 2023, data from 375 managers of organic food businesses in China were collected. The survey in this study was supported by Sojump (http://www.sojump.com) paid sample service. The survey data were collected via web-based and mail-in questionnaires. The questionnaire items included measures of environmental characteristics, innovation characteristics, as well as issues relating to PU, PEU, and BIU. In addition, participants were requested to provide general information regarding their company's specific context.

The survey had 167 responses in total, which translates to a response rate of 45%. After screening for completeness, 11 questionnaires were deemed unsuitable, resulting in 156 valid questionnaires collected from Chinese organic food enterprises. Of the total number of participants, the distribution of job positions was as follows: 61 owners or CEOs 39.1%, 78 directors or managers 50%, and 17 other positions 10.9%. Participants' level of awareness of blockchain technology was as follows: 23 much aware 14.7%, 90 somewhat aware 57.7 %, and 43 less aware 27.6%. The industry sector breakdown of the participants was as follows: 36 organic farming 23.1%, 59 organic food processing 37.8%, 57 organic food retail/wholesale 36.5 %, and 4 other sectors 2.6 %. In terms of years in operation, 46 operated for 5 years or less 29.5%, 102 operated for 6-10 years 65.4%, while 8 operated for 11 years or more 5.1%.

### 4.2 Measures

Each participant marked a 5-point Likert-type scale to rate his/her level of agreement or disagreement with each measurement item. These scales have been validated in numerous studies conducted in various countries.

External pressure was scored using four items revised from Kwon et al. (2021). Organization size scored using four items modified from Looi (2003) and Mabert et al. (2003). Four items amended from Karahanna et al. (1999) and Moore & Moore & Benbasat (1991) were used to measure relative advantage. The compatibility was scored using four items. Complexity was scored using four items adapted from Venkatesh et al. (2003). Four items adopted from Davis (1989) and Venkatesh et al. (2003) were used to measure PEU as was PU. Lastly, BIU was scored using four items revised from Davis (1989).

## 5. Research Results

This study employed SEM as the analytical tool to validate the study objectives and test research hypotheses. As indicated by Chen and Huang (2013), SEM can effectively test both causal relationships and measurement models, particularly when multiple items are incorporated into each construct. Before evaluating the conceptual model, the validity and reliability of measurements were checked.

### 5.1 Measurement Model Results

To ensure an acceptable model fit, items with low (less than 0.5) factor loading values were excluded from the initial items. The results of the confirmatory factor analysis were shown in <Table 1>. The fit of the final measurement model was evaluated by using several model fit indices. The Cronbach's alpha values (greater than 0.7) of variables confirmed the internal consistency of items (Nunnally, 1978). The composite reliability (CR) ratings were greater than the reference criterion of 0.7. The AVE values were greater than the recommended threshold of 0.5. They demonstrated the validity and dependability of the measurement model.

Table 1. Confirmatory Factor Analysis Results

| Variable / Item | Factor Loading | CR | AVE | Cronbach's Alpha |
|---|---|---|---|---|
| External pressure | | 0.875 | 0.637 | 0.875 |
| Our stakeholders expect us to adopt blockchain technology. | 0.857 | | | |
| Our competitors have embraced blockchain technology. | 0.811 | | | |
| Our organizations that lead in our industry have adopted blockchain technology. | 0.775 | | | |
| Our failure to adopt blockchain technology could result in the loss of customers to competitors who have embraced it. | 0.745 | | | |
| Organization size | | 0.842 | 0.641 | 0.829 |
| Our organization's size has a significant impact on investment in blockchain technology. | 0.885 | | | |

Table 1. Confirmatory Factor Analysis Results(Continued)

| Variable / Item | Factor Loading | CR | AVE | Cronbach's Alpha |
|---|---|---|---|---|
| Our organization's size limits the scope of blockchain technology solutions. | 0.751 | | | |
| Our organization's size influences the level of risk we are willing to accept for blockchain technology adoption. | 0.759 | | | |
| Relative advantage | | 0.814 | 0.593 | 0.808 |
| The blockchain technology has a significant advantage over traditional systems. | 0.763 | | | |
| The blockchain technology will provide a better solution for my work processes than current systems. | 0.819 | | | |
| The blockchain technology can provide my organization with a competitive advantage. | 0.726 | | | |
| Compatibility | | 0.898 | 0.692 | 0.894 |
| The blockchain technology is compatible with my organization's current systems and processes. | 0.804 | | | |
| The blockchain technology can be easily integrated into my current workflow. | 0.654 | | | |
| The blockchain technology aligns with my organization's goals and values. | 0.923 | | | |
| The blockchain technology is a suitable fit for my organization's needs. | 0.918 | | | |
| Complexity | | 0.858 | 0.604 | 0.849 |
| The complexity of blockchain technology leaves me feeling overwhelmed and unsure of where to start. | 0.862 | | | |
| The technical aspect of blockchain makes it tough for me to comprehend. | 0.711 | | | |
| The amount of time required to learn and understand blockchain technology is excessive for me. | 0.752 | | | |
| The use of blockchain technology involves too much time spent on mechanical operations. | 0.775 | | | |
| PEU | | 0.849 | 0.654 | 0.833 |
| I find the blockchain technology easy to use. | 0.913 | | | |
| I find the blockchain technology accessible and convenient to use. | 0.76 | | | |
| I would not experience difficulty in understanding how to use the blockchain technology. | 0.742 | | | |
| PU | | 0.885 | 0.66 | 0.877 |
| I believe that using the blockchain technology would improve the company's operational efficiency. | 0.921 | | | |
| I believe that using the blockchain technology would enhance the transparency and security of the company's supply chain operations. | 0.757 | | | |
| I believe that using blockchain technology would enhance the accuracy of data tracking and management. | 0.78 | | | |
| I believe that using blockchain technology would increase the trust of stakeholders in the company. | 0.782 | | | |
| BIU | | 0.843 | 0.642 | 0.842 |
| My organization intends to adopt the blockchain technology to improve our work processes within the next 1 year. | 0.834 | | | |
| My organization intends to invest in blockchain technology within the next 1 year. | 0.827 | | | |
| My organization believes that should start using the blockchain technology as soon as possible. | 0.739 | | | |
| Fit: $x^2/df$ = 1.477, CFI = 0.941, TLI = 0.931, SRMR = 0.061, and RMSEA = 0.055. | | | | |

Both convergent and discriminant validity were evaluated in order achieve the validity of the research model, The AVE values of each factor are greater than the recommended threshold of 0.5 for the convergent validity (Hair et al., 2006). Information about AVE were presented in <Table 2>. The off-diagonal elements in the table indicate correlations between the constructs. There are strong correlations between all the constructs. The coefficients of correlation between each construct and the other constructs were less than the square root of the AVE of the construct. This shows the discriminant validity.

Table 2. Discriminant Validity and Square Root of the AVE

| Variable | Mean | S.D. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| External pressure | 3.612 | 0.949 | **0.798** | | | | | | | |
| Organization size | 3.697 | 0.941 | .309** | **0.801** | | | | | | |
| Relative advantage | 3.588 | 0.957 | .218** | .294** | **0.770** | | | | | |
| Compatibility | 3.510 | 1.033 | .216** | .245** | .195* | **0.832** | | | | |
| Complexity | 3.516 | 0.914 | -.347** | -.276** | -.283** | -.335** | **0.777** | | | |
| PEU | 3.684 | 0.916 | .451** | .304** | .223** | .387** | -.417** | **0.809** | | |
| PU | 3.569 | 0.959 | .484** | .412** | .459** | .455** | -.528** | .635** | **0.812** | |
| BIU | 3.427 | 1.040 | .488** | .510** | .503** | .471** | -.531** | .541** | .693** | **0.801** |

Note: Bold numbers along the diagonal indicate the square root.

## 5.2 Structural Model Results

In the subsequent phase, the SEM was employed to evaluate the research hypotheses. The measurement model exhibited an acceptable level of goodness-of-fit (refer <Table 3>). The path coefficients of the proposed research model are depicted in <Fig. 2>.

The findings of this study suggest that the PU of the technology was positively influenced by four exogenous factors, including external pressure, relative advantage, compatibility, and complexity. These results show hypotheses H1-1, H3-1, H4-1, and H5-1 were supported. However, the analysis result shows no influence of organization size on PU (hypothesis H2-1 was not supported).

The PEU was positively affected by three exogenous factors, including external pressure, compatibility, and complexity. Therefore, hypotheses H1-2, H4-2, and H5-2 were supported. However, the analysis results show non-significant effect of organization size and relative advantage on PEU (hypotheses H2-2 and H3-2 were not supported).

The BIU was positively affected by five exogenous factors, including external pressure, organization size, relative advantage, compatibility, and complexity. These results show hypotheses H1-3, H2-3, H3-3, H4-3, and H5-3 were supported.

Furthermore, the analysis results showed that PU significantly impacted on BIU. That means hypothesis H6-1 was supported. Also, PEU positively impacted on PU. It was shown that hypothesis H7-1 was supported. Hypotheses test results were presented in <Table 3>.

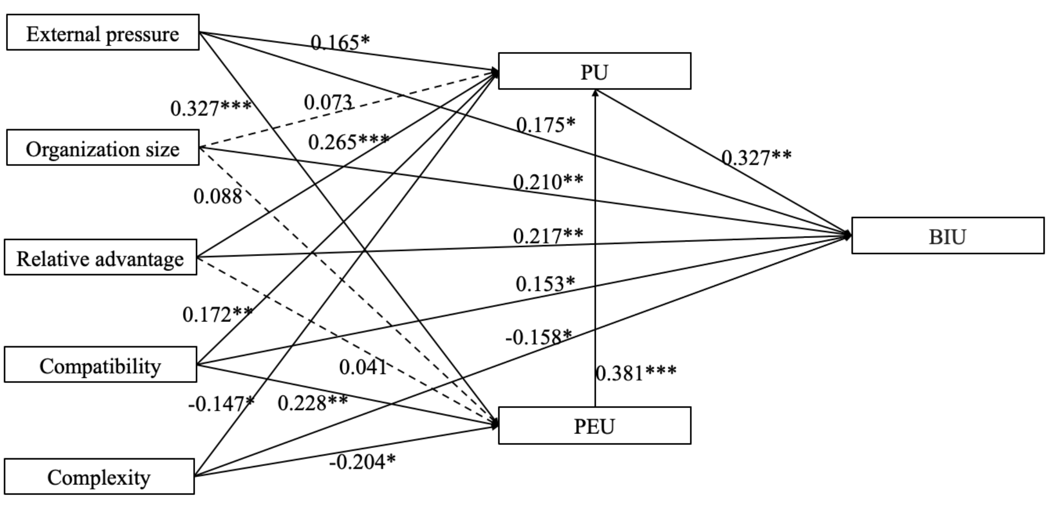


Fig. 2 Research Model Path Test

Table 3. Test Results of Hypotheses

| Hypothesis / Path | Standardized coefficient | T value | Result |
|---|---|---|---|
| H1-1: External pressure → PU | 0.165* | 2.236 | Supported |
| H2-1: Organization size → PU | 0.073 | 1.064 | Not Supported |
| H3-1: Relative advantage → PU | 0.265*** | 3.748 | Supported |
| H4-1: Compatibility → PU | 0.172** | 2.604 | Supported |
| H5-1: Complexity → PU | -0.147* | -2.053 | Supported |
| H1-2: External pressure → PEU | 0.327*** | 3.633 | Supported |
| H2-2: Organization size → PEU | 0.088 | 0.998 | Not Supported |
| H3-2: Relative advantage → PEU | 0.041 | 0.47 | Not Supported |
| H4-2: Compatibility → PEU | 0.228** | 2.768 | Supported |
| H5-2: Complexity → PEU | -0.204* | -2.254 | Supported |
| H1-3: External pressure → BIU | 0.175* | 2.361 | Supported |
| H2-3: Organization size → BIU | 0.210** | 3.052 | Supported |
| H3-3: Relative advantage → BIU | 0.217** | 2.875 | Supported |
| H4-3: Compatibility → BIU | 0.153* | 2.268 | Supported |
| H5-3: Complexity → BIU | -0.158* | -2.188 | Supported |
| H6-1: PU → BIU | 0.327** | 3.268 | Supported |
| H7-1: PEU → PU | 0.381*** | 4.684 | Supported |

Fit: $x^2/df$ = 1.478, CFI = 0.941, TLI = 0.931, SRMR = 0.062, and RMSEA = 0.056.
Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

## 6. Discussion and Conclusions

This study presented a framework that extends the existing models of IDT and TAM. The framework examines how the environmental characteristics and the innovation characteristics indirectly influence the organic food firms' perception of the blockchain technology's PU and PEU. However, they directly affect their BIU in the near future.

First, external pressure, relative advantage, and compatibility positively influence the PU of blockchain technology in organic food enterprises. However, the complexity has a negative impact on the PU. Organization size, however, has no significant effect on PU. In a competitive market, external pressure may pursue the prompt adoption of technologies that offer cost-effectiveness and efficiency. Interestingly, this study found that organization size does not have a significant effect on PU. This is because the challenges faced by organic food enterprises are ensuring food safety and quality, tracking product production process, and keeping stable distribution process, regardless of enterprise size by applying blockchain technology,

Second, the analysis results suggest that external pressures and compatibility positively impact on the PEU of blockchain technology for organic food enterprises, while complexity has a negative impact on the PEU. Organizational size and relative advantages of blockchain have not significant effect on PEU. A seamless integration of blockchain with existing systems and applications would improve its ease of use. However, the complexity of the technology may increase costs and risks but reduce its ease of use. Enterprises need to possess the necessary technical skills and knowledge, but size is not a limiting factor in the use of blockchain technology.

Thirdly, when considering adopting blockchain technology, companies need to consider the impact of multiple factors and weigh the pros and cons. Blockchain technology is known to have a certain technical threshold. Since its implementation is relatively complex, it may hinder the realization of BIU. In order to overcome these challenges, companies can take measures such as improving the technical literacy and application capabilities of their employees.

Finally, as originally proposed by Davis (1989), there is a close relationship between PEU and PU, which are considered the important determinants of BIU. Therefore, it is crucial for companies not only to perceive the usefulness and ease of use of blockchain technology but also to have a positive attitude towards its adoption. Ultimately, a greater comprehension of the variables affecting BIU can help the organic food sector applying blockchain technology more successfully.

## 7. Limitations and Further Research

Considering the analysis results, there are limitations and further research section.

First, future research may include a more representative sample of organic food enterprises in China and expand the sample size to boost external validity as the study's sample size and selection may limit the generalization of the findings.

Second, the study used self-reported data. Future research may complement the self-reported data with objective measures of blockchain adoption to improve validity and reliability.

## REFERENCES


[1] Agi, M. A., & Jha, A. K. (2022). Blockchain technology in the supply chain: An integrated theoretical perspective of organizational adoption. *International Journal of Production Economics*, 247, 108458.

[2] Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179-211.

[3] Bracci, E., Tallaki, M., Ievoli, R., & Diplotti, S. (2022). Knowledge, diffusion and interest in blockchain technology in SMEs. *Journal of Knowledge Management*, 26(5), 1386-1407.

[4] Brandon-Jones, A., & Kauppi, K. (2018). Examining the antecedents of the technology acceptance model within e-procurement. *International Journal of Operations & Production Management*, 38(1), 22-42.

[5] Chaudhuri, A., Bhatia, M. S., Kayikci, Y., Fernandes, K. J., & Fosso-Wamba, S. (2021). Improving social sustainability and reducing supply chain risks through blockchain implementation: role of outcome and behavioural mechanisms. *Annals of Operations Research*, 1-33.

[6] Chen, M. F. & Huang, C. H. (2013). The impacts of the food traceability system and consumer involvement on consumers' purchase intentions toward fast foods. *Food Control*, 33(2), 313-319.

[7] Chong, A. Y. L., Lin, B., Ooi, K. B., & Raman, M. (2009). Factors affecting the adoption level of c-commerce: An empirical study. *Journal of Computer Information Systems*, 50(2), 13-22.

[8] Christopher, M. (2016). *Logistics & Supply Chain Management*. Pearson Uk.

[9] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 319-340.

[10] DeLone, W. H. (1981). Firm size and the characteristics of computer use. *Mis Quarterly*, 5(4), 65-77.

[11] Dolgui, A., Ivanov, D., & Sokolov, B. (2018). Ripple effect in the supply chain: an analysis and recent literature. *International Journal of Production Research*, 56(1-2), 414-430.

[12] Fishbein, M. & Ajzen, I., (1975), *Belief, Attitude, Intention and Behavior: An introduction to theory and research*, Addison-Wesley Publishing Company, Reading, MA.

[13] Gefen, D., & Straub, D. (2000). The relative importance of perceived ease of use in IS adoption: A study of e-commerce adoption. *Journal of the Association for Information Systems*, 1(8), 1-30.

[14] Gillenson, M. L. & Sherrell, D. L. (2002). Enticing online consumers: An extended technology acceptance perspective. *Information & management*, 39(8), 705-719.

[15] Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2009). *Multivariate Data Analysis*, Upper Saddle River, NJ, Pearson Prentice Hall.

[16] Holland, M. (1997). Diffusion of innovation theories and their relevance to understanding the role of librarians when introducing users to networked information. The Electronic Llibrary.

[17] Iacovou, C. L., Benbasat, I., & Dexter, A. S. (1995). Electronic data interchange and small organizations: Adoption and impact of technology. *MIS quarterly*, 19(4), 465-485.

[18] Janssen, M., Weerakkody, V., Ismagilova, E., Sivarajah, U., & Irani, Z. (2020). A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. *International Journal of Information Management*, 50, 302-309.

[19] Joo, J., & Han, Y. (2021). An evidence of distributed trust in blockchain-based sustainable food supply chain. *Sustainability*, 13(19), 10980.

[20] Karahanna, E., Straub, D. W., & Chervany, N. L. (1999). Information technology adoption across time: A cross-sectional comparison of pre-adoption and post-adoption

beliefs. *MIS Quarterly*, 23(2), 183-213.

[21] Klaas, B. S., Klimchak, M., Semadeni, M., & Holmes, J. J. (2010). The adoption of human capital services by small and medium enterprises: A diffusion of innovation perspective. *Journal of Business Venturing*, 25(4), 349-360.

[22] Koh, L., Dolgui, A., & Sarkis, J. (2020). Blockchain in transport and logistics – paradigms and transitions. *International Journal of Production Research*, 58(7), 2054–2062.

[23] Kwon, W. S., Woo, H., Sadachar, A., & Huang, X. (2021). External pressure or internal culture? An innovation diffusion theory account of small retail businesses' social media use. *Journal of Retailing and Consumer Services*, 62, 102616.

[24] Lee, Y. H., Hsieh, Y. C., & Hsu, C. N. (2011). Adding innovation diffusion theory to the technology acceptance model: Supporting employees' intentions to use e-learning systems. *Journal of Educational Technology & Society*, 14(4), 124-137.

[25] Lekha, D., Chakaravarthi, S., & Visu, P. (2021). Food Supply Chain Management Using Blockchain in Food Traceability. *EAI Endorsed Transactions on Smart Cities*, 5(16), e6-e6.

[26] Looi, H. (2003). A model of factors influencing electronic commerce adoption among small and medium enterprises in Brunei Darussalam. *International Journal of Information Technology*, 10(1), 72-87.

[27] Mabert, V. A., Soni, A., & Venkataramanan, M. A. (2003). The impact of organization size on enterprise resource planning (ERP) implementations in the US manufacturing sector. *Omega*, 31(3), 235-246.

[28] Manning, L. & Kowalska, A. (2021). Considering fraud vulnerability associated with credence-based products such as organic food. *Foods*, 10(8), 1879.

[29] Mendling, J., Weber, I., Aalst, W. V. D., Brocke, J. V., Cabanillas, C., Daniel, F., ... & Zhu, L. (2018). Blockchains for business process management-challenges and opportunities. *ACM Transactions on Management Information Systems (TMIS)*, 9(1), 1-16.

[30] Moore, G. C. & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research*, 2(3), 192-222.

[31] Niknejad, N., Ismail, W., Bahari, M., Hendradi, R., & Salleh, A. Z. (2021). Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis. *Environmental Technology & Innovation*, 21, 101272.

[32] Nunnally, J. (1978). *Psychometric Methods*, McGraw-Hill, New York.

[33] Oliveira, T., & Martins, M. F. (2011). Literature review of information technology adoption models at firm level. *Electronic Journal of Information Systems Evaluation*, 14(1), 110-121.

[34] Pavlou, P. A. (2003). Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model. *International Journal of Electronic Commerce*, 7(3), 101-134.

[35] Queiroz, M. M. & Wamba, S. F. (2019). Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. *International Journal of Information Management*, 46, 70-82.

[36] Rajnak, V., & Puschmann, T. (2021). The impact of blockchain on business models in banking. *Information Systems and e-Business Management*, 19(3), 809-861.

[37] Rogers, E. (1995). *Diffusion of Innovations* (4th Eds.) ACM The Free Press (Sept. 2001). New York, 15-23.

[38] Singh, J. & Michels, J. D. (2018, April). Blockchain as a service (BaaS): Providers and trust. In *2018 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW)* (pp. 67-74). IEEE.

[39] Song, J., Zhang, P., Alkubati, M., Bao, Y., & Yu, G. (2022). Research advances on blockchain-as-a-service: Architectures, applications and challenges. *Digital Communications and Networks*, 8(4), 466-475.

[40] Tapscott, A. & Tapscott, D. (2017). How blockchain is changing finance. *Harvard Business Review*, 1(9), 2-5.

[41] Thanujan, T., Rajapaksha, C., & Wickramarachchi, D. N. (2022). Scalable and Socially Inspired Blockchain Architecture for the Organic Food Supply Chain. *Journal of Innovation Information Technology and Application (JINITA)*, 4(2), 163-177.

[42] Treiblmaier, H. & Garaus, M. (2023). Using blockchain

to signal quality in the food supply chain: The impact on consumer purchase intentions and the moderating effect of brand familiarity. *International Journal of Information Management*, 68, 102514.

[43] Trienekens, J. H., Wognum, P. M., Beulens, A. J., & van der Vorst, J. G. (2012). Transparency in complex dynamic food supply chains. *Advanced Engineering Informatics*, 26(1), 55-65.

[44] Tsolakis, N., Niedenzu, D., Simonetto, M., Dora, M., & Kumar, M. (2021). Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry. *Journal of Business Research*, 131, 495-519.

[45] Van Hilten, M., Ongena, G., & Ravesteijn, P. (2020). Blockchain for organic food traceability: case studies on drivers and challenges. *Frontiers in Blockchain*, 3, 43.

[46] Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), 425-478.

[47] Wu, J. H., & Wang, S. C. (2005). What drives mobile commerce?: An empirical evaluation of the revised technology acceptance model. *Information & Management*, 42(5), 719-729.

[48] Zhu, K., Kraemer, K., & Xu, S. (2003). Electronic business adoption by European firms: a cross-country assessment of the facilitators and inhibitors. *European Journal of Information Systems*, 12, 251-268.

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# 텍스트 마이닝을 이용한 공급사슬과 블록체인 관련 키워드 문헌 분석: 2020년 이전 연구를 중심으로*

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# Literature Analysis on Supply Chain and Blockchain Keywords Using Text Mining: Focusing on Studies Prior to 2020

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This study examines the initial research trends related to the supply chain for about ten years from right after 2008 when the concept of blockchain emerged. To this end, using text mining, English literature, including blockchain and supply chain as keywords corresponding to the 2010-2020 period, was collected from major academic databases. Finally, 2,185 papers and conference proceedings were collected, and the main topics of the literature were examined by analyzing words vectorized with information such as authors, titles, and abstracts. As a result, the ‘mainstream’ appeared as blockchain technology, such as RFID, security, and digital ledgers, and the ‘emerging stream’ appeared as blockchain applications to various fields like education, government, trading, and management. Furthermore, six research trends were derived from five clusters derived through topic modeling.

***Keyword*** : Blockchain, Supply Chain, Text-Mining, Clustering

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# 1. 서론

블록체인 기술은 이해관계자(노드) 간의 정보를 암호화하고, 정보를 최신 상태를 유지하는 기술이다. 블록체인은 공급사슬관리의 효율성과 비용 최적화에 긍정적인 영향을 줄 수 있을 것이라는 실무진의 의견이 많다. 그렇기에 학계에서도 많은 관심을 갖고 있다(김준석, 2022). 블록체인 관련 연구 주제가 기초연구 위주로 이루어진다면, 산업에 적용 가능한 구체적 기술이 개발되기까지 시간이 필요하다. 그와 달리 응용 연구가 활발히 이루어진다면 블록체인의 실무 활용 시기가 가까워 짐을 추정할 수 있을 것이다(Chen & Yang, 2022). 따라서, 기존 연구의 방향을 분석할 수 있다면, 블록체인 기술의 산업 내 적용 가능성 예측할 수 있을 것으로 판단했다.

블록체인(blockchain)은 2008년 처음 등장한 개념으로 이후 그 영향력을 꾸준히 키워가고 있다. 처음에는 암호화폐 형태로 시장에 소개되었으나 10년이 지난 지금은 대체화폐, 보안, 교육, 문화 등 수많은 영역에서 활용가능 대상으로 여겨진다. 학술 데이터 베이스에서 '블록체인(blockchain)'과 '공급사슬(supply chain)'을 키워드로 한 연구의 개수를 살펴보면 2019년까지는 연간 500개 미만이었던 연구가, 2020년 이후 연간 1000개 이상으로 2배이상 급격히 증가하고, 현재까지 매년 2000개에 가까운 연구가 수행되고 있다. 본 연구는 블록체인이 등장한 2008년 직후부터 약 10년 여간의 공급사슬과 연관된 블록체인 연구의 방향의 뿌리를 살펴보는 연구이다.

문헌 분석에는 메타분석(meta-analysis)이 주로 사용된다(Glass, 1976). 하지만, 메타분석의 경우 분석 대상의 수집에 있어 시간적인 물리적인 한계라는 약점이 존재한다. 텍스트 마이닝(text-mining) 기법을 사용하면 메타분석에 비해 많은 수의 문헌을 비교 분석할 수 있다. 본 연구는 텍스트 마이닝 사용해 데이터 수집을 진행했으며, 주요 연구주제 및 연구 흐름을 도출하기 위해 문장과 글을 토큰화 시켜 쪼갠 단어들의 집합으로 문헌의 주제를 역으로 추정해내는 토픽모델링(topic modeling)을 사용했다. 또한 군집화 분석을 통해 등장 빈도수가 높거나, 중요도가 높게 나타나는 키워드와 토픽을 선정하고, 토픽의 변화를 해석했다.

학술 데이터베이스인 'Science Direct'와 'Springers link'에서 'Blockchain'과 'Supply chain'을 키워드를 포함한 문헌을 수집했다. Blockchain이 2008년 등장했으나, 학술논문으로 반영될 기간지연을 고려하여 2010년부터 10년 후인 2020년까지를 수집 기간으로 설정했다. 파일럿 테스트로 10년 일부 기간에 해당하는 2015년~2018년 동안 'blockchain'과 'SCM'을 키워드로 하여 실시했을 때 수집된 문헌은 394개였다. 따라서 10년의 전체 기간의 분석대상이 1000여개 내외가 될 것으로 추정했으나 최종적으로 2000개가 넘는 문헌을 분석했다. 클러스터링과 토픽모델링을 이용한 분석으로 공급사슬(supply chain)과 블록체인(blockchain) 관련된 연구 시작점의 중심이 어디에 있는지 파악하여 2020년 이후 급격하게 증가한 최신 문헌과의 비교를 위해 사전연구로서 본 연구를 진행한다.

# 2. 문헌연구

## 2.1 메타분석 과 텍스트 마이닝

메타분석은 가장 활발히 사용되는 연구동향 분석법으로 정량적 문헌연구 방법에 속한다. 1970년 교육학 분야에서 처음 시작되어 현재까지도 다양한 분야에서 기존 문헌을 분석하는 방법으로 활발히 적용되고 있다(Glass, 1976). 메타분석을 통해 일정 기간 동안 수행된 수많은 연구를 질적으로 평가하여, 향후 연구에 질적으로 신뢰성 있는 연구 결과를 보증하기 위해 근거 중심을 확보할 목적으로 활발히 사용되어 왔다.

다시 말하면, 메타분석은 수많은 동질적인 또는 이질적인 연구결과를 종합해 학계에서 동의할 수 있는 연구의 합의점을 도출하는데 기여한다. 가장 대표적인 메타분석의 모형(model)은 고정효과 모형(Fixed-effect model)과 임의효과 모형(Random-effect model)으로 구분된다(Glass, 1976). <Table 1>은 전통적인 메타분석을 사용하여 연구의 주요 토픽(Topic)을 분석한 문헌들이다. 대부분의 연구에서 검토 문헌이 200여개 내에 그치는 것을 확인할 수 있다. 특히, Supply chain과 관련 연구는 215개의 연구를 다룬 Golicic & Smith(2013) 분석대상이 많은 편에 속한다.

기존의 메타분석은 시간과 비용의 소요가 크기 때문에 주로 100건 내의 문헌이 분석대상으로 채택되어 왔다. 하지만, 텍스트 마이닝을 접목하여 메타분석을 실시하면 이론적으로 1만 개 이상의 문헌에 대해 분석을 수행할 수 있다.

수집된 문장과 텍스트에 내재된 의미를 계량화하는 기법에 관심이 높아지며, 텍스트 간 유사도를 기반으로 문서 군집 및 분류 알고리즘이 개발되었다(blei, 2012). Hung & Zhang(2012)는 텍스트 분석을 사용하여 2003~

2008년 문헌을 대상으로 모바일러닝 연구 트렌드를 분석했으며, 비정형 자료(Unstructured data)인 학술 논문에 쓰여진 연구를 메타 분석적인 접근으로 분석한 초기 연구에 해당한다. 이들은 주요 키워드 아래로 4개의 하위 토픽을 정하고, 각 토픽의 영역에 해당되는 연구 트렌드를 정의하여 총 13가지 연구 트렌드를 제시했다. 그리고 Martí-Parreño et al.(2016)은 교육방법 게임화(gamification in education) 연구의 주요 토픽을 분석하며, 주요 키워드인 집중, 만족, 효율성, 향상, 평가, 인지, 유용성 등 간의 네트워크 관계와 연관성을 수치로 분석한 바 있다.

Table 1. Qualitative Analysis of Existing Research through Meta-analysis

| Authors | Topic | # of Article |
|---|---|---|
| Damanpour (1996) | Organizational innovation | 46 |
| Orlitzky et al.(2003) | Corporate social and financial performance | 52 |
| Meyer et al.(2002) | Affective, Continuance, and Normative Commitment to the Organization | 155 |
| Lux et al.(2011) | Outcomes of corporate political activity | 78 |
| Golicic & Smith (2013) | Sustainable Supply Chain Management Practices and Firm Performance | 215 |
| Leuschner et zl. (2013) | Supply chain integration and firm performance | 86 |
| Eagly & Johnson (1990) | Gender and leadership style | 162 |
| Brewin et al.(2000) | Posttraumatic stress disorder in trauma-exposed adults | 77 |
| Görg & Strobl (2000) | Multinational companies and productivity spillovers | 37 |

Table 2. Meta-analysis Literature Using Text Mining

| Author | Subject & Keywords | Source |
|---|---|---|
| Lis et al.(2020) | Research trend of SSCM | Web of Science, Scopus |
| Yang et al. (2018) | Research trend of Smart Factory | Web of Science, Scopus/ NDSL, RISS) |
| Shin et al.(2020) | Research trend of Maritime | Web of Science, Scopus |
| Choi and Song(2018) | Tech trend | US patent data |
| Chae(2015) | Supply chain trend and CSR | Twitter |

텍스트 마이닝 기법은 꾸준히 개발되고 진화되고 있으며, 텍스트 간의 유사도를 분석하는 토픽모델링이 사용된 학술연구는 2019년도를 전후로 더욱 활발해졌다. 텍스트 마이닝을 사용하여 메타분석을 진행한 연구는 <Table 2>에 정리했다. 학술 문헌의 경우 Web of Science, Scopus 등의 데이터베이스를 대상(Lis et al., 2020; Yang et al., 2018; Shin et al., 2020)으로 표본을 수집하였고, 특허 데이터를 사용하거나, 트위터(Choi & Song, 2018)와 같은 소셜 네트워크 포스팅을 분석한 연구도 있다. 특히 학술연구에 대한 메타분석은 특히 학술지 및 도서 출판사의 데이터 베이스에서 주로 연구 대상이 선정되는 것을 확인할 수 있다.

공급사슬관련 메타 분석 연구 역시 텍스트 마이닝을 사용해 이루어지고 있다. 공급사슬관리(Seo, 2020)의 18년 간의 연구 트렌드 및 최신 문헌연구방향 연구, 코로나19 전후의 글로벌공급망의 변화(Rha, 2020; Lee & Song, 2022)를 기사자료 분석을 통해 최신 이슈를 분석한 연구가 있다. 블록체인을 포함한 공급사슬 관련 연구로는 Science mapping 분석(Chen & Kim, 2022)을 수행한 연구가 있다. 본 연구는 기존 연구와 달리 블록체인 이슈가 폭발적으로 증가하기 이전에 초기 연구 중심이 어디 있는지 파악하는 연구로, 후속연구와의 비교를 위해 2020년 이전까지 문헌을 대상으로 연구를 수행하였다.

## 3. 연구방법

### 3.1 토픽모델링

클러스터링(clustering)은 사전정보 없이 주어진 데이터 분포(data distribution)로 부터 유사한 대상 간 군집화(grouping) 하는 비지도 학습기법 (unsupervised learning)으로, 데이터의 유사도에 따라 모아주는 과정이다. 일반적으로 군집화 분석 방법은 크게 유클리디안 거리(Euclidean distance)와 코사인 유사도(cosine similarity)를 이용한 측정방법이 있다(Lim & Maglio, 2018). 유클리디안 거리를 이용한 유사도 측정의 경우, 간단한 거리측정 개념으로 문서 군집화 시 문서길이에 영향을 받을 수 있다.

$$sim(A,B) = \cos(\theta) = \frac{A \cdot B}{\|A\| \cdot \|B\|} \quad (1)$$

$$= \frac{\sum_{i=1}^{n} A_i \times B_i}{\sqrt{(\sum_{i=1}^{n}(A_i)^2} \times \sqrt{\sum_{i=1}^{n}(B_i)^2}}$$

그에 비해 코사인 유사도는 두 벡터 간 크기 차이가 아닌 방향의 차이만 판단하므로

$$P(\beta_{1:K}, \theta_{1:D}, z_{1:D}, w_{1:D}) = \quad (2)$$
$$= \prod_{i=1}^{K} P(\beta_i|\eta) \prod_{d=1}^{D} P(\theta_d|\alpha)$$
$$\left[ \prod_{n=1}^{N} P(z_{d,n)} \mid \theta_d) P(w_{d,n} \mid \beta_{1:K}, z_{d,n}) \right]$$

$\beta_k$: 해당 단어가 k번째 토픽에서 등장할 확률,
$\theta_d$: d 문서가 가진 토픽 비중,
$z_{d,n}$: 문서별 특정 토픽의 할당 여부,
$w_{d,n}$: 단어의 특정 토픽 할당 여부

문서크기의 영향을 받지 않아 본 연구에서 채택하였다. 코사인 유사도 측정은 공식 (1)에 설명되어 있다. 단어 간의 유사도에 따라 군집화를 하는 과정에서 2000여개 이상의 문헌에 속한 대규모 단어를 군집화 하기 위해서 토픽모델의 사용이 필요하다. 토픽 모델링(Topic Modeling)은 비정형 데이터인 각각의 문서 집합으로부터 해당 문서가 어떤 주제를 지니고 있는지 분류가 되어있지 않는 상황에서 비지도 학습(Unsupervised learning)으로 문서 내 드러나지 않은 추상적인 주제(Topic)를 추출하는 방법이다.

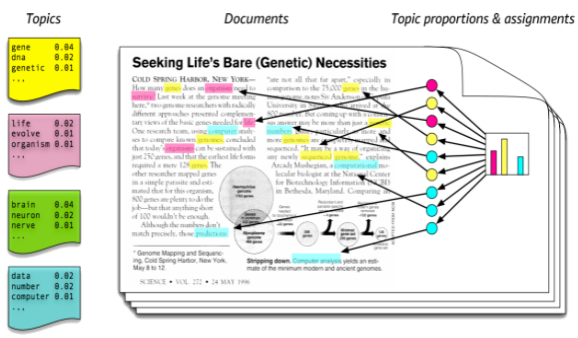


Fig. 1 Latent Dirichlet Allocation(Blei, 2012)

본 연구의 분석 대상은 텍스트로 구성된 2000여개의 연구논문이며, 대규모 연구 집합으로부터 추상적인 연구 주제를 도출하기 위해 토픽모델링을 적용할 수 있다. 토픽모델링을 구현하기 위한 기법인 LDA(Latent Dirichlet Allocation)은 <Fig. 1>으로 설명될 수 있다. 주어진 문서 집합들 로부터 확률적으로 잠재 토픽(Latent Topic)을 생성하고, 해당 토픽에 각각의 문서가 속할 확률을 구하는 방법이다. 다시 말하면, 해당 문서 내에 잠재 토픽이 분포하고 있는 정도와 문서 내 활용된 단어가 어떤 주제에 할당되는지를 확률적으로 추정한다(Blei, 2012).

토픽 모델링은 임의의 토픽 내에 등장 확률이 높은 단어들의 조합으로 특정 주제를 내포한 문서를 생성하는 과정을 표현한다. Blei(2012)는 LDA를 통한 문서 생성 과정을 공식(1)과 같이 표현하였다. K는 토픽의 수, D는 전체 문서집합의 수, N은 단어의 수이며, $\alpha$와 $\eta$는 디리클레(Dirichlet) 분포를 만들기 위한 하이퍼-파라미터(Hyper parameter)이다. 문서 생성과정은 먼저, 각 주제가 D개의 문서에 얼마나 분포하고 있는지를 파악하고, 각 문서마다 문서를 구성하는 단어가 어떤 주제를 나타내는지 추정한다. 다음으로 각 토픽을 구성하는 단어가 생성되는 확률 분포를 추정하여 최종적으로 문서의 생성 확률을 구한다. 위 과정을 거쳐 LDA는 각 문서 내에 각 토픽이 얼마나 분포하고 있는지, 단어가 어떤 주제를 표현하고, 토픽 당 해당 단어가 얼마나 해당 토픽을 표현하고 있는지를 확률 분포를 통해 파악할 수 있다.

LDA를 통해 각 문서에 활용된 단어와 해당 문서에서 등장한 단어들이 어떤 주제를 표현하고 있는지를 확률적으로 추정할 수 있다. LDA를 통해 도출된 확률을 각각의 연구집합에 나타난 단어의 빈도(Frequency)에 가중하여 특정 연구가 t개의 주제(Topic)에 대해 각각 어느 정도의 주제를 나타내고 있는지를 점수화 할 수 있다.

### 3.2 연구순서

연구 순서는 다섯 단계로 이루어지며 <Fig. 2>에 표현되었다. 데이터수집과 분석을 위해 파이썬(Python)을 사용했으며, 본 연구는 3.7 버전을 사용하였다.

첫째, "Blockchain"과 "Supply chain" 분야의 연구 중심 변화를 분석하기 위해서 주요 논문 출판 플랫폼인 Elsevier의 Science Direct와 Springer의 Springer Link에서 해당 키워드를 포함한 문헌의 목록페이지를 추출했다. 데이터 수집을 위해서 웹페이지를 구성하는 HTML의 구조를 파악하여 원하는 데이터가 포함된 텍스트 데이터를 수집하는 웹크롤링(Web Crawling)을 활용하였다. 본 연구는 Python ver. 3.7의 라이브러리 뷰티풀 숩(Beautiful Soup)을 활용하였다. 뷰티풀 숩을 활용하여 제목, 저자, 저널, 초록을 수집하였다. 초기 계획은 2010~2020년의 10년간의 연구를 분석하는 것이었으나, 데이터베이스 검색결과 2012년 이전에는 두 키워드를 모두 포함하는 연구가 없는 것으로 확인되어 2012~2020년의 8년으로 기간을 변경하여 데이터 수집했다.

수집된 데이터 개요는 <Table 3>와 같다. 두 개 데이터베이스에서 총 2,185개의 문헌을 수집했으며, 수집된 데

이터에서 눈 여겨 볼 부분은 2012년 자료는 conference proceeding이 706건으로 주를 이뤘으며, 게재된 학술논문은 2015년 이후부터 발견되었다. 데이터베이스에서 추출된 문헌의 데이터는 저널명, 저자, 출판년도, 제목, 초록의 내용이 <Figure 3>와 같이 텍스트 파일로 저장되었다.

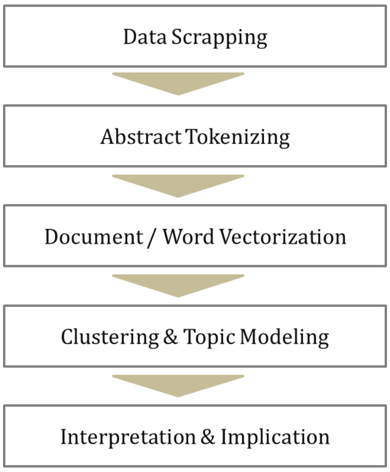


Fig. 2 Research Process

Table 3. Data Collection Overview

| Discipline | Contents |
|---|---|
| Source | Springer Link, Science Direct |
| Keywords | “Blockchain”, “Supply Chain” |
| Published year | 2012 - 2020 |
| Language | English only |
| Contents Type | Journal article, Conference proceedings |
| Extracted Contents | Journal name, Authors, published year, Article title and Abstract |

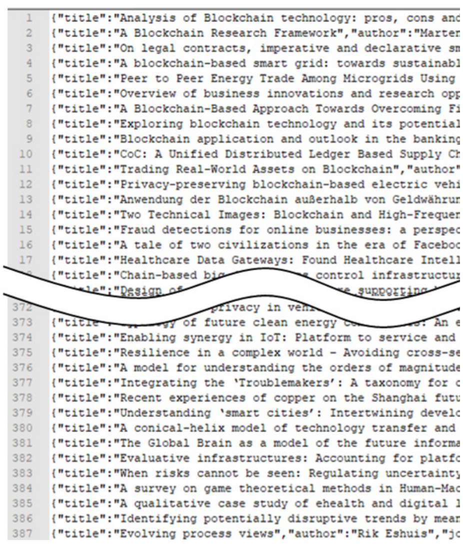


Fig. 3 Example of Data Collection

둘째, 웹크롤링으로 수집된 데이터는 텍스트 마이닝을 실시했다. 텍스트 마이닝은 단어를 기반으로 다양한 패턴을 규명하며 새로운 정보를 추출할 수 있는 기법이다(Kim & Kwak, 2021). 이를 위해서 수집된 데이터 중 초록(abstract)을 단어 단위로 쪼개는 토큰화(word tokenization)하는 과정이 필요하다. 본 연구는 파이썬 패키지의 자연어처리를 위한 NLTK(Natural Language Toolkit)를 사용했으며, 텍스트 내의 형태소 분석에서 명사, 부사, 조사, 동사 중 명사를 중심으로 분석을 수행했다.

셋째, 토큰화 된 데이터를 단어의 빈도(frequency) 및 임베딩(embedding)을 이용해 각각의 연구문헌을 벡터공간에 표현한다. 즉, 벡터공간에 단어를 흩뿌리고 유사한 단어로 군집화 하기 전의 과정에 해당한다. 자주 등장하는 단어를 도출하여 주요 토픽 후보를 유추하기 전의 처리 단계이다. 텍스트 분석을 위해 비정형으로 표현된 텍스트를 숫자로 변환시키는 임베딩(embedding)이 필요하며, 본 연구는 빈도기반(frequency-based) 방법 중 TF-IDF(Frequency Inverse Document Frequency)를 채택하였다.

넷째, 앞서 소개된 군집화(clustering) 기법을 통해 전처리 했던 단어를 유사도에 따라 모아주기 위해 파이썬 패키지의 계층적 군집분석을 활용했다. 다섯째로 대규모 단어 집합에서 연구주제를 추출하기 위해, 겐심(genism) 라이브러리를 사용했다. 최종적으로 유사단어의 조합으로 추출된 토픽을 해석하고 정리하는 과정을 거쳤다.

## 4. 분석 결과

### 4.1 키워드 빈도 분석 결과

블록체인(blockchain)과 공급사슬 (supply chain)을 키워드로 하는 문헌들의 초록에서 등장한 단어 가운데 가장 빈번히 등장하는 단어 가운데 20개를 빈도순으로 나열했으며, <Table 4>에 정리했다.

‘paper’, ‘research’ 및 ‘model’ 등 연구주제와 무관하게 일반적으로 쓰이는 단어의 빈도가 높으며 ‘technology’, ‘system’ 및 ‘digital’등 직접적인 기술과 관련된 단어 역시 빈도가 높은 것으로 나타났다. 또한 블록체인 기술이 주로 쓰이는 암호화폐 ‘Bitcoin’ 역시 상위에 등장하는 것을 확인할 수 있다. 단, ‘business’, ‘development’, ‘financial’ 및 ‘energy’ 등의 단어는 블록체인 기술이 적용될 것으로 기대되는 분야들로 예측할 수이 있다. 또한 해당 단어들을 <Fig. 4>의 워드 클라우드로 표현하였다.

Table 4. Frequent Keywords

| # | Keyword | Freq | # | Keyword | Freq |
|---|---|---|---|---|---|
| 1 | technology | 192 | 11 | technologies | 115 |
| 2 | data* | 184 | 12 | systems | 112 |
| 3 | new | 173 | 13 | chapter | 109 |
| 4 | blockchain* | 157 | 14 | such | 107 |
| 5 | based | 140 | 15 | information | 93 |
| 6 | system | 137 | 16 | development* | 89 |
| 7 | Bitcoin | 129 | 17 | financial* | 84 |
| 8 | digital | 124 | 18 | research | 83 |
| 9 | business* | 123 | 19 | energy* | 81 |
| 10 | paper | 119 | 20 | model | 81 |

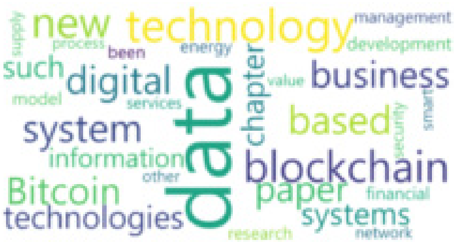


Fig. 4 Word-Cloud

하지만, 빈도(frequency)에 기반한 키워드 추출은 일반적인 단어들이 함께 포함되어 연구주제 선정을 위한 정보를 추출하는데 제한이 있어, 클러스터링과 토픽모델링을 통해 유사도 분석결과를 살펴본다.

## 4.2 클러스터링 분석 결과

군집화 후 먼저 넓은 연구 방향을 살펴보고, 다음으로 토픽모델링을 통해 도출된 토픽을 논문과 매칭하여 구체적 연구 트렌드를 추출했다. 클러스터링을 통해 크게 5개의 방향으로 구분하고, 주제의 유사성에 따라 6개의 토픽으로 정리했다. 먼저 큰 방향성 검토를 위해 가장 많은 수의 문헌이 포함된 그룹을 주 연구 분야(mainstream)로, 두번째로 많은 수의 연구가 포함된 연구들의 그룹을 신흥 연구 분야(emerging stream)로 구분했다(<Fig. 5>).

<Table 5>는 main stream에 해당하는 문헌 중 일부를 발췌한 것이다. 해당 문헌의 제목을 보면, ‘Mining Ether’, ‘RFID reader protocol’, ‘Smart contracts’, ‘Blockchain based Storage System’, ‘Threat Landscape for the Internet-of-Things’, ‘Trust issues in Code’ 등의 제목을 포함하고 있으며, RFID 리더와 클라우드 컴퓨팅을 SCM 환경에 적용하기 위한 기술, Internet-of-Things와 관련해서 하드웨어 보안, 블록체인 기술을 사용한 전자계약의 주제를 다루고 있는 것을 확인할 수 있었다. 즉, 구체적인 기술, 보안문제 등의 실질적인 기술 이슈에 초점을 맞추고 있다.

그에 비해 <Table 6>는 신흥연구 분야(emerging)에 해당하는 연구제목과 저널명을 정리한 것으로 ‘M-payment and economic issues’, ‘Blockchain in government’, ‘education’, ‘Trading’, ‘Business Process monitoring’ 등이 등장한다. 비트 코인과 모바일결제 방식의 경제적 이슈, 블록체인 정보 공유와 정부의 대응, 블록체인 기술의 교육분야에 잠재적 적용가능성 등의 내용을 다룬다. 경제적, 교육, 재무, 경영 분야에 응용 방안을 모색하는 연구로 블록체인을 타 분야로 확장하는 경향을 보이고 있었다.

Table 5. Literature in Mainstream Cluster

| Article Title | Journal |
|---|---|
| An automatic RFID reader-to-reader delegation protocol for SCM in cloud computing environment | The Journal of Supercomputing |
| Surveying the Hardware Trojan Threat Landscape for the Internet-of-Things | Journal of Hardware and Systems Security |
| Mining Ether | Introducing Ethereum and Solidity |
| Smart Contracts – Blockchains in the Wings | Digital Marketplaces Unleashed |
| A Blockchain-Based Storage System for Data Analytics in the Internet of Things | New Advances in the Internet of Things |

Table 6. Literature in Emerging Stream Cluster

| Article Title | Journal |
|---|---|
| Economic Issues on M-Payments and Bitcoin | Bitcoin and Mobile Payments |
| Blockchain in government: Benefits and implications of distributed ledger technology for information sharing | Government Information Quarterly |
| Quantitative Analysis of the Full Bitcoin Transaction Graph | Financial Cryptography and Data Security |
| Exploring blockchain technology and its potential applications for education | Smart Learning Environments |
| Trading Real-World Assets on Blockchain | Business & Information Systems Engineering |

다음으로 Python으로 계층적 군집화(sklearn.feature_extraction.text) 패키지에서 Tf-IdfVectorizer을 사용하여 KMeans를 통해 군집을 추출하였다. 그 결과 5개의 군집을 주출할 수 있었다. 또한 군집별 중심단어와 군집에 등장하는 키워드를 바탕으로 추상적인 연구주제를 조합하여 주요 주제를 유추했다(<Table 7>).

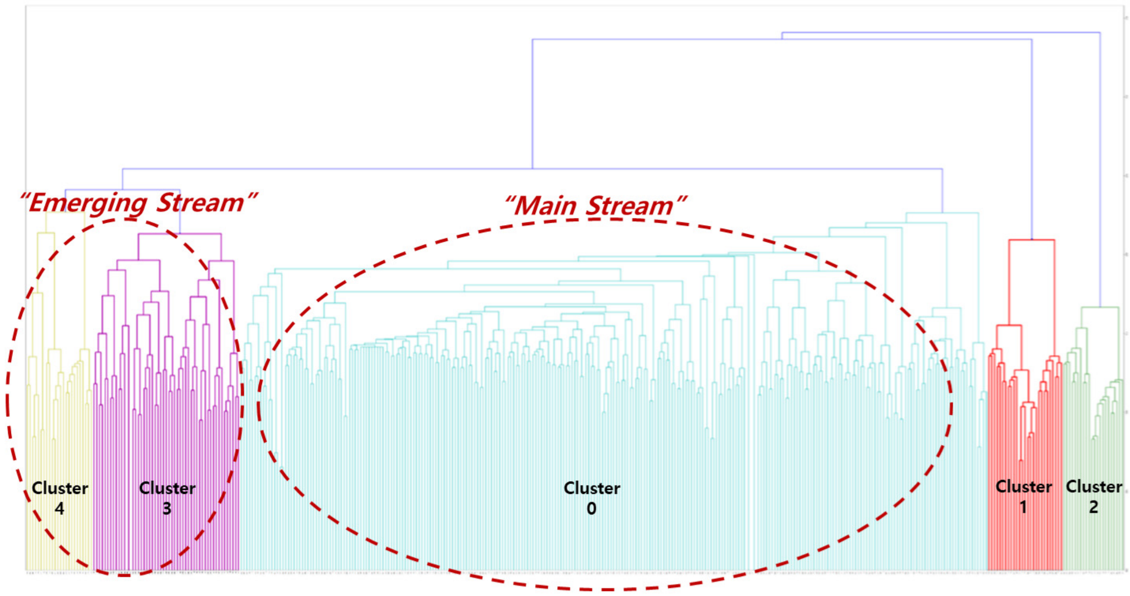


Fig. 5 Main Stream & Emerging Stream in Clusters

Table 7. Derivation of Topics Through Clustering

| Discipline | Keyword | Description |
|---|---|---|
| Cluster 0 | ethereum, scf, data, bitcoin, big, **smart**, further, finally, von, **blockchain**, first, **process**, **fintech**, due, **ict**, **china**, describe, new, technology, **security** | • Smart FinTech Transaction Process and Security Technology Using ICT and Blockchain (China related) |
| Cluster 1 | iot, **internet**, **things**, web, **smart**, **blockchain**, besides, daos, mrc, **multimedia**, **world**, **global**, ethereum, first, case, scholars, jarvsis, hmn, hmns, **automated** | • Global Internet web multimedia transactions using blockchain technology (NFT, etc.)<br>• Use of blockchain to accept IoT technology |
| Cluster 2 | industry, revolution, ets, **procurement**, security, industrial, cctv, added, **prototype**, connected, production, solutions, therefore, **crowdsourcing**, olli, chap, internet, digitalization, **artificial**, **intelligence** | • Procurement and crowdfunding systems using artificial intelligence |
| Cluster 3 | **blockchain**, bitcoin, **pos**, specifically, special, **practical**, **internet**, how, china, **fintech**, therefore, fadada, walmart, microsoft, ibm, european, **chain**, **supply**, **ict**, types | • Global supply chain management changes due to the application of retail trading POS data and fintech technology |
| Cluster 4 | **bitcoin**, **ethereum**, digital, recent, emv, november, covenants, brands, namecoin, psp, small, psps, dna, gox, **blockchain**, tor, **litecoin**, **channels**, contract, **regulatory** | • Cryptocurrency (Bitcoin, Ethereum, Litecoin) Transaction Channels and Regulations Using Blockchain Technology |

첫 번째 토픽은 군집 0의 'blockchain', 'Smart', 'Process', 'ICT', 'Technology', 'security' 및 'China'의 키워드를 바탕으로 'ICT와 블록체인을 활용한 핀테크 시장 활성화 및 그에 따른 프로세스상의 보안 기술'을 유추했다. 그리고, 군집 1에서 'multimedia', 'global' 그리고 'blockchain' 키워드를 조합하여, 블록체인 기술을 활용한 NFT 등의 하이테크 멀티미디어 글로벌 유행의 토픽을 유추했으며, 'IOT'와 'things'의 키워드 등을 바탕으로 IoT 시장의 활성화에 관한 연구방향을 유추할 수 있었다. 군집 2의 경우 'procurement', 'production', 'prototype' 그리고 'crowdfunding', 'artificial', 'intelligence'의 단어를 통해서 '인공지능을 활용한 크라우드 펀딩'과 '생산조달 시스템의 발달'의 연구 주제를 도출했다. 군집 3에서는 'Walmart', 'IBM', 'Microsoft' 등의 특정 기업명칭과 'POS(point of sales)', 'fintech', 'practical' 등의 단어를 바탕으로 '소매 거래 시 POS 데이터와 핀테크 기술로 인한 공급사슬 변화 추이'의 연구 트랜드를 엿볼 수 있었다. 마지막으로 군집 4에 등장하는 'bitcoin', 'Ethereum', 'Litecoin'의 주요 암호화폐 명칭과 'channels', 'regulatory' 등 단어를 통해 '암호화폐 거래 시스템과 규제에 변화'와 관련된 연구 트렌드를 유추할 수 있었다.

## 5. 결론 및 제언

본 연구는 블록체인(blockchain)의 개념이 등장한 2008년 직후부터 약 10년여 기간의 공급사슬과 관련된 초기 연구 트렌드를 살펴본다. 이를 위해 2010~2020년 기간에 해당하는 블록체인(blockchain)과 공급사슬(supply chain)을 키워드로 포함한 문헌을 주요 학술 데이터 베이스인 'Science Direct'와 'Springer Link'에서 수집하였다. 최종적으로 2185개의 논문과 학술대회 발표자료를 수집하여, 저자, 제목, 초록 등의 정보를 토픽모델링과 군집화 기법으로 분석하여 2020년 이전 연구의 주제를 살펴보았다.

키워드 빈도 분석 결과 'paper', 'research' 및 'model' 등 연구주제와 무관하게 일반적으로 쓰이는 단어를 제외하면, 'technology', 'system' 및 'digital' 등 직접적인 기술과 관련된 단어의 빈도가 높게 나타났다. 본 연구의 대상이 블록체인의 등장 이후 초기 연구를 대상으로 분석하기에 'Bitcoin', 'Ethereum' 등 암호화폐 키워드의 빈도도 높게 나타났다. 주목할 부분은 블록체인 관련 연구의 초창기 임에도, 'business', 'development', 'financial' 및 'energy' 등 응용 가능성이 높은 분야를 엿볼 수 있는 키워드도 상대적으로 높은 빈도를 나타냈다.

2020년까지의 연구를 주요 연구 흐름(main stream)과 신흥 연구 흐름(emerging stream)으로 분석한 결과, 블록체인 기술연구가 대부분을 차지했으나 여러 분야로의 응용 연구가 시작되고 있음을 확인할 수 있었다. 마지막으로 토픽모델링으로 도출된 5개 군집(cluster)을 분석하여 최종적으로 6개의 연구 트렌드 도출했다. 중국과 연관하여, ICT와 Blockchain을 활용한 스마트 핀테크 거래 프로세스 및 보안 기술 개발, 블록체인 기술을 활용한 글로벌 인터넷 전파가능 멀티미디어 거래의 활성화, IoT(Internet of Things)와 블록체인 관련 연구, 인공지능(Artificial intelligence)을 활용한 조달(procurement) 및 크라우드펀딩(crowd funding) 시스템, 소매거래(POS연관)와 핀테크 기술 변화로 인한 세계적인 공급사슬관리 변화, 암호화폐(bitcoin, Ethereum, Litecoin) 거래 채널 및 규제 관련 연구가 최종적으로 선정되었다.

본 연구의 시사점은 다음과 같다. 첫 번째 학술적 시사점은 공급사슬과 관련된 블록체인 연구의 초기 연구의 방향에 대해 주요 구성개념, 키워드, 이슈 등을 정리하여 연구의 방향과 트렌드를 제시했다는 점이다. 기존 블록체인과 관련 텍스트 마이닝 문헌 연구는 최신 트렌드 파악에 주목했다. 블록체인 기술의 확장성과 공급사슬의 복잡한 구조를 고려할 때 최신 연구가 수많은 영역으로 확장될 수 있기에 큰 그림을 살펴볼 필요가 있었다. 공급사슬에 대한 블록체인 연구 방향의 시작점과 큰 줄기를 본 연구를 통해 살펴볼 수 있었다. 두 번째 학술적 시사점은 토픽모델링 분석으로 주요 토픽을 정의하기에 앞서 문헌을 크게 주요 흐름과 신흥흐름으로 구분하여 연구의 큰 줄기를 살펴보았다는 점이다. 여러 토픽모델링 연구는 키워드 간의 유사성을 통해 확률적 값을 통해 네트워크 효과를 분석한다. 본 연구는 연구 초창기의 큰 흐름을 살펴보기 위해서 키워드와 논문들을 제목과 저널을 통해 직접 대조하는 분석을 연구 트렌드 확인에 대한 신뢰를 높이고자 했다. 셋째 확률적으로 도출된 토픽 뿐 아니라 실제 논문과 키워드를 대조하는 확인을 통해, 블록체인이 등장한 초창기부터 꾸준히 블록체인 기술, 보안 관련 연구가 주로 이루어져 왔음을 확인할 수 있었다. 이를 통해 기업들이 블록체인 기술 활용에 대해 긍정적인 검토가 필요함을 본 연구를 통해 확인할 수 있었다.

이러한 시사점에도 불구하고 본 연구는 다음의 한계점을 가지고 있다. 첫째, 데이터 수집대상이 영문논문만을 포함하고 있다는 점이다. 본 연구가 블록체인에 대한 초창기 연구를 중심으로 파악하였기 때문에 블록체인이 처음 등장한 미국, 유럽 등을 중심으로 한 해외 논문을 중심으로 분석을 진행했다. 따라서 국내 시장의 공급사슬과 블록체인 기술 추이를 설명하는데 한계가 있다. 둘째, 분석 대상이 최근 몇 년간의 연구를 반영하지 못하고 있다는 점이다. 하지만, 본 연구는 최근 3년간 문헌과 국내 시장을 반영한 관련 문헌을 포함하여 후속연구를 진행하고, 본 연구결과와 비교를 통해 의미 있는 결과를 도출할 계획이다. Science Direct 단일 데이터베이스 기준으로 블록체인과 공급사슬 키워드로 한 연구가 2021년 1,437개, 2022년 1,996개 검색되어 2020년 이후 관련 연구가 폭발적으로 증가하는 추이를 보이고 있다. 이들을 대상으로 후속 연구를 진행하여, 본 연구의 결과를 비교할 수 있다면 더욱 의미 있는 연구가 될 것이다.

## REFERENCES

[1] 김유진, 곽규훈 (2021). 빅데이터를 활용한 시대별 홈트레이닝 키워드 분석. 한국체육과학회지, 30(1), 103-115.

[2] 김재우, 김동진 (2019). 텍스트 마이닝을 활용한 사회과 연구 동향 분석: 2000 년대 이후의 학술 논문을 중심으로. 시민교육연구, 51(2), 35-70.

[3] 김준석 (2021). 구매 업무에서의 블록체인 기술 도입을

위한 개념적 프레임워크. 한국 SCM 학회지, 21(1), 79-88.

[4] 나진성 (2020). 코로나19 시대의 공급사슬관리 관련 이슈 분석: 기사자료 네트워크 텍스트 분석을 중심으로. 한국산업정보학회논문지, 25(6), 109-123.

[5] 서창교 (2020). 토픽모델링과 소셜 네트워크 분석을 이용한 공급사슬관리 연구 탐색. 한국 SCM 학회지, 20(1), 36-51.

[6] 이소연, 송민채 (2022). 자연어처리기법을 활용한 코로나19 전후 지속가능한 글로벌 공급망 연구 동향 변화와 시사점. 한국산학기술학회논문지, 23(10), 246-255.

[7] 이재윤, 문주영, 김희정 (2007). 텍스트 마이닝을 이용한 국내 기록관리학 분야 지적구조 분석. 한국문헌정보학회지, 41(1), 345-372.

[8] 진영, 김용진 (2022). Challenges and Tendencies in Blockchain for SCM: Science Mapping Analysis. 물류학회지, 32, 55-67.

[9] Blei, D. M. (2012). Probabilistic topic models. *Communications of the ACM*, 55(4), 77-84.

[10] Brewin, C. R., Andrews, B., & Valentine, J. D. (2000). Meta-analysis of risk factors for posttraumatic stress disorder in trauma-exposed adults. *Journal of Consulting and Clinical Psychology*, 68(5), 748.

[11] Chae, B. K. (2015). Insights from hashtag# supplychain and Twitter Analytics: Considering Twitter and Twitter data for supply chain practice and research. *International Journal of Production Economics*, 165, 247-259.

[12] Choi, D. & Song, B. (2018). Exploring technological trends in logistics: Topic modeling-based patent analysis. *Sustainability*, 10(8), 2810.

[13] Damanpour, F. (1996). Organizational complexity and innovation: developing and testing multiple contingency models. Management Science, 42(5), 693-716.

[14] Eagly, A. H., & Johnson, B. T. (1990). Gender and leadership style: A meta-analysis. Psychological bulletin, 108(2), 233.

[15] Golicic, S. L. & Smith, C. D. (2013). A meta-analysis of environmentally sustainable supply chain management practices and firm performance. *Journal of supply chain management*, 49(2), 78-95.

[16] Görg, H., Strobl, E., & Ruane, F. (2000). Determinants of firm start-up size: An application of quantile regression for Ireland. *Small Business Economics*, 14(3), 211-222.

[17] Hung, J. L., & Zhang, K. (2012). Examining mobile learning trends 2003–2008: A categorical meta-trend analysis using text mining techniques. *Journal of Computing in Higher Education*, 24, 1-17.

[18] Leuschner, R., Rogers, D. S., & Charvet, F. F. (2013). A meta-analysis of supply chain integration and firm performance. *Journal of Supply Chain Management*, 49(2), 34-57.

[19] Lim, C., & Maglio, P. P. (2018). Data-driven understanding of smart service systems through text mining. *Service Science*, 10(2), 154-180.

[20] Lis, A., Sudolska, A., & Tomanek, M. (2020). Mapping research on sustainable supply-chain management. *Sustainability*, 12(10), 3987.

[21] Lux, S., Crook, T. R., & Woehr, D. J. (2011). Mixing business with politics: A meta-analysis of the antecedents and outcomes of corporate political activity. *Journal of management*, 37(1), 223-247.

[22] Martí-Parreño, J., Méndez-Ibáñez, E., & Alonso-Arroyo, A. (2016). The use of gamification in education: a bibliometric and text mining analysis. *Journal of Computer Assisted Learning*, 32(6), 663-676.

[23] Meyer-Baron, M., Schaeper, M., & Seeber, A. (2002). A meta-analysis for neurobehavioural results due to occupational mercury exposure. *Archives of toxicology*, 76(3), 127-136.

[24] Orlitzky, M., Schmidt, F. L., & Rynes, S. L. (2003). Corporate social and financial performance: A meta-analysis. *Organization Studies*, 24(3), 403-441.

[25] Shin, S. H., & Shin, Y. J. (2020). The impact of organizational culture and strategy on shipping liner's awareness and utilization of the 4th IR technologies. *Maritime Policy & Management*, 1-19.

[26] Yang, H. L., Chang, T. W., & Choi, Y. (2018). Exploring the research trend of smart factory with topic modeling. *Sustainability*, 10(8), 2779.

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# 한국SCM학회 연구 윤리 규정

**제1조 (목적)**

본 규정은 “한국SCM학회 연구 윤리 규정”이라 부르며 한국SCM학회(이하 “학회”라 한다)와 관련된 연구행위가 연구 목적을 달성하기 위해 수행되는 과정에서 인간의 기본적, 사회 공동 윤리를 손상하지 않도록 윤리 규정과 기준을 정함을 목적으로 한다. 여기서 연구 행위라는 것은 학회가 주관 공동 주관하는 학술대회와 학회 학술지와 관련된 연구 수행, 결과, 발표 및 게재 등을 포함한다.

**제2조 (적용대상)**

학회가 주관 또는 공동 주관하는 학술대회 발표와 학회 학술지 투고에 참여하는 학회의 회원들 외에 비회원들(이하 “저자”라 한다)에게도 준용된다.

**제3조 (저자의 연구 윤리)**

1. 저자는 아이디어의 도출, 실험 방법의 설계, 결과의 분석, 연구 결과의 발표, 연구 심사 등의 연구 행위에 있어 정직하여야 한다.
2. 저자는 타인의 연구나 주장의 전체 또는 일부분을 인용할 수 있다. 그러나 자신의 연구처럼 기술해서는 안 되며 반드시 정확하게 출처 표시와 참고문헌 목록을 작성하여야 한다.
3. 저자는 연구 수행과 결과에서 획득한 정보를 이용하여 부당한 이익을 추구하지 않는다.

**제4조 (연구 내용의 기록 보존 및 공개)**

1. 저자의 연구 내용은 타 연구자가 해석 및 확인이 용이하도록 정확하게 기록하여야 하며, 연구 수행 시 활용된 주요 사실 및 증거는 보존해야 한다.
2. 연구 결과가 출판된 후 타 연구자의 요청이 있을 경우 보안이 보장되는 범위 내에서 연구 결과물이 타 연구자의 연구 수행에 도움이 되도록 최대한 노력한다.

**제5조 (저저의 책임과 보상)**

1. 연구 결과에 기재된 모든 저자들은 발표된 사실에 책임을 다하도록 한다.
2. 저자는 공식적인 공동 연구자 또는 연구에 직간접적으로 기여한 사람들로만 구성되며 상대적 지위와 무관하게 학술적 기여도에 따라 저자 표기 순서가 결정된다.
3. 학회지 및 학술대회 발표논문집에 게재된 논문은 저자가 저작권을 가지나 공동의 목적으로 사용될 때는 학회가 사용권을 가진다.

**제6조 (연구 부정행위)**

연구 수행 중에 발생하는 부정행위는 다음과 같다.

1. 위조: 존재하지 않는 데이터나 연구결과를 허위로 만들어 내는 행위를 말한다.
2. 변조: 데이터의 변형이나 연구과정을 조작하여 연구결과를 왜곡하는 행위를 말한다.
3. 표절: 정당한 인용 없이 타 연구자의 연구 결과를 저자의 연구 결과에 사용하는 행위를 말한다.
4. 중복게재: 타 학술지에 게재 또는 투고 중인 원고를 본 학회지에 투고하는 행위를 말한다.
5. 부당한 논문 저자 표시: 연구 수행 중에 학술적 기여도가 없는 자에게 연구 결과의 저자 자격을 부여하는 행위를 말한다.

**제7조 (윤리위원회 구성)**

1. 학회는 연구 윤리와 관련된 사항을 검토·심의·의결하기 위해 학회 내에 윤리위원회를 운영한다.
2. 윤리위원회 구성은 위원장 1인과 부위원장 1인을 포함하여 5인으로 구성한다.
3. 윤리위원장은 학회 공동회장 중 한 분이 담당하며, 윤리위원회 부위원장은 학회지 공동 편집위원장 중 한 분을 윤리위원장이 임명하며, 나머지 3인의 위원회 회원은 윤리위원장과 부위원장의 합의로 임명한다.

**제8조 (연구 부정행위 제재)**

연구 부정행위가 적발된 연구 및 저자에 대해서는 윤리위원회의 검토를 거쳐 정도에 따라 다음과 같이 제재를 가할 수 있다.

1. 학회 징계 서한 발송
2. 학회의 해당 학회지에서 해당 연구 결과 삭제 또는 수정 요구
3. 연구 관련자의 적정 기간 동안 논문 투고 금지
4. 연구 관련자의 적정 기간 동안 회원자격 상실 및 연구 관련자 소속기관 세부사항 통보
5. 학회에서 제명

**제9조 (윤리위원회 운영)**

1. 필요한 연구 윤리 제정 및 개정을 담당한다.
2. 제소된 회원 및 연구에 대해 윤리 규정 위반 여부 심의 및 위반에 대한 제재를 의결한다.
3. 제소된 사안에 대해 접수된 날로부터 60일 이내에 심의·의결한다.
4. 위원회는 위원회의 조사 기간 동안 조사 내용 및 과정에 대해 일체의 보안을 유지하고, 관련자들의 신상정보를 보호한다.
5. 윤리위원회는 조사 결과 제소된 내용이 무혐의이거나 충분한 소명으로 혐의 사실이 해소될 경우 피고발자 혹은 혐의자의 명예를 회복하기 위해 적절한 후속 조치를 취할 수 있다.

**제10조 (윤리위원회 제소 및 혐의자 의무)**

1. 윤리위원회 제소는 회원 5인 이상의 서명을 받아야 한다.
2. 윤리위원회에 제소된 회원은 윤리위원회의 조사에 협조해야 한다.

**제11조 (윤리위원회 의무)**

1. 윤리위원회는 제소된 자에 대해 심의 결과가 확정되기 전까지는 회원으로 권리를 보장한다.
2. 윤리위원회에 제소된 자는 위원회에 충분히 소명할 권리를 갖으며, 위원회는 소명 및 반론 기회를 부여해야 한다.

**제12조** 기타 본 규정에 포함되지 않은 사항은 관계 법령과 사회적 규범에 의거 판단한다.

## 부 칙

**제1조 (시행일)**

본 규정은 이사회에서 의결된 날부터 시행한다.

2013. 1. 16. 이사회 제정

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