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Evaluation of Management Efficiency in the Cold Chain Industry using DEA Techniques

Hyunwoo Goh[1]

Abstract

This study grouped cold chain into industries and evaluated and analyzed management efficiency that can strengthen competitiveness despite changes in internal and external environments. For this purpose, DEA methodology was used. DEA's relative efficiency analysis was detailed through technical efficiency and pure technical efficiency analysis methods. By analyzing the efficiency level of inefficient cold chain companies according to the ranking, we benchmarked and set improvement targets for input elements, thereby deriving target values to overcome the gap. In conclusion, the cold chain industry was separated from the existing industrial group, and management efficiency was comparatively evaluated and benchmarked to provide an empirical and specific analysis system to improve the efficiency of the cold chain industry.

Keywords: *Cold Chain Industry, Relative Efficiency, Data Envelopment Analysis (DEA), Decision Making Unit (DMU), COVID-19.*

INTRODUCTION

We have entered an era in which the supply chain has become an important factor among the many factors that determine a company's competitiveness. In the supply chain, cold chain is attracting attention from climate and environmental aspects. The existing perception of the cold chain was simply limited to food and focused on appropriate temperature management of refrigeration and freezing throughout the process from production to consumers.

However, due to the Global COVID-19 pandemic, there has been a change in awareness that the cold chain is connected to human life. In a pandemic situation, technical problems arose during the production and distribution process after the development of the vaccine, including temperature management and delivery and storage at a specified time. As a result, the supply of vaccines was not smooth in the early stages, which frequently led to an increase in patient deaths around the world.

In addition, the cold chain of bio/pharmaceutical products such as blood products, cell therapies, and gene therapies, which are sensitive to changes in the external environment, must handle the production, transportation, storage, shock prevention, humidity management, and light exposure prevention of products in a temperature-controlled environment. It has played an important role in the safety of the pharmaceutical supply chain.

Cold chain is not limited to industries such as bio/pharmaceuticals and fresh food. Cold chains also exist in certain fields that are not generally known. In other words, along with the technology industry that monitors pressure, temperature, system status, etc. in the cold chain through displays or mobile devices and connects IoT technology and big data in maintenance areas such as breakdown and system diagnosis, the device industry is also growing together with the cold chain.

Korea's cold chain industry is developing rapidly by applying cutting-edge technologies such as digital, artificial intelligence, network, cloud, and database. In order to provide optimal freezing and refrigeration services, we are developing an appropriate temperature control system that takes into account the expansion of the global cold chain supply chain, management of counterfeit food and medicines, and packaging material resource circulation. In addition, we are researching and developing core cold chain components to optimize cryogenic temperature food cooling technology and temperature management in frozen and refrigerated warehouses,

[1] Seokyeong University, Seoul, Korea, Email: skuie@naver.com

trucks, and logistics centers using the heat of vaporization of LNG.

Due to the rapid paradigm shift in the cold chain following the Global COVID-19 pandemic, analysis and evaluation of the efficiency of cold chain companies must be prioritized in order to improve competitiveness and achieve sustainable growth by combining cold chains scattered across industries into one industry. By analyzing the efficiency and productivity of the cold chain industry with digital new technology that combines traditional cold chain basic industries, key component industries, and IoT technology, we analyze the efficiency of the cold chain industry's management activities and the causes of differences in efficiency in the cold chain industry. It is time to identify the determining factors and apply them to decision-making and strategy establishment, and to analyze the determining factors of productivity changes. However, the industrial classification of the cold chain industry is not yet clear, and therefore there has been no research on it at all.

Therefore, in this study, we redefine the classification of the cold chain industry and use DEA to evaluate and analyze the relative efficiency of related companies. As a result of the research, a process for evaluating the efficiency of the cold chain industry is naturally presented. Ultimately, by deriving the difference in inefficiency of inefficient companies compared to efficient companies, we aim to provide a basis for ultimately improving corporate competitiveness by setting goals to reduce the difference and making improvements.

Theoretical Considerations

We review the background knowledge necessary to evaluate and diagnose the efficiency of cold chain companies distributed in various industries and DEA, an efficiency evaluation methodology.

Current Status of Cold Chain Industry

We look at industries where cold chains exist in Korea and their characteristics.

Food Distribution/Storage Service Cold Chain

The fresh food cold chain can be viewed as a series of logistics supply chains to maintain the value and characteristics of food through a certain level of temperature control technology through the distribution stages from the farm and fishing ground.

Product temperature management is an important element of the cold chain. In fresh food logistics, temperature management standards are divided into room temperature and low temperature refrigerated and frozen foods. Fresh foods are deep frozen when the temperature control is below -45°C, tuna and frozen fish are frozen, and when the temperature control is -45°C to -10°C, they are frozen and frozen meat, frozen fish, frozen foods, ice cream, temperature control standard -10°C ~ +10°C is chilled, and dairy products, eggs, fruits, vegetables, grains, temperature control standard +10°C and above require constant temperature control even at room temperature. Fixed temperature includes grains, confectionery, chocolate, wine, edible oil, etc.

System Semiconductor Cold Chain

The main technology of cold chain is system semiconductor technology, which is essential in packaging materials, environmental control, and monitoring and traceability for work management.

The fields of monitoring through IoT, semiconductors, cloud communication technology, and big data require a lot of investment in building professional manpower and infrastructure through technology. In the packaging sector, the cost of use varies greatly depending on the technical elements involved in the active cold chain, which can control temperature by power, and the passive cold chain, which has the function of maintaining temperature during transportation and distribution.

Among cold chain systems, the cloud-based system is divided into sensor IoT, business process, and cloud-based domains.

Frozen/Refrigerated Storage Transportation Cold Chain

In the case of cold transport, we are actively utilizing the digital technology of the 4th industrial revolution to build a smart logistics system to transport frozen and refrigerated foods such as agricultural, livestock, marine products, processed foods, and flowers, as well as fresh foods. By maintaining a constant temperature at an appropriate temperature, biological reactions are suppressed, and the product is distributed using a cold chain system to maintain freshness and the intrinsic value of the product.

In particular, the transportation of medical devices and medicines, which require special management as they are sensitive to temperature and have a high risk of deterioration, which can greatly affect public health, are currently showing great growth in the medical logistics industry, and in particular, cold storage regulations for frozen and refrigerated vehicles are changing. It follows the national standard (KS R 4051), and the loading box must secure warming/freezing performance, airtightness performance, and strength in accordance with the national standard (KS T 1374).

During transportation, the temperature of the vehicle cargo compartment must be measured and recorded at least every 5 to 10 minutes and preserved for the period requested by the shipper. Therefore, electronic equipment and equipment that can maintain the temperature of the vehicle cargo compartment in real time through continuous monitoring and technical supplementation System advancement, stability, and reliability must be prioritized.

Pharmaceutical/ Bio Medicine / Chemical Cold Chain

In particular, pharmaceutical, bio medicine, and chemical cold chains are rapidly establishing themselves in Korea due to vaccine supply. With the rapid growth of biopharmaceuticals, the demand for cold chain systems is changing from treatment-oriented to policy-based diagnosis and prevention, and precision medicine, biotechnology, and ICT technologies are converged and managed based on advance information on the genome. It is expanding into the smart healthcare market.

After COVID-19, the social impact of the bio industry is showing up as market expansion, and national strategies to foster the bio healthcare convergence industry are being established and implemented around the world. The problem of not ensuring the quality and safety of pharmaceuticals, including vaccines, is occurring in many countries around the world, including Korea.

Problems of the Cold Chain Industry

Due to the rapid growth of the cold chain industry, the forms and terminology used by each supplier are different, and the reality is that there is no unified management plan to ensure the increasing complexity of information in the cold chain and lack of consumer trust.

Currently, cold chains are connected to various and numerous step-by-step platforms, and numerous steps are managed by suppliers in various roles, resulting in a lack of a blockchain platform that uses unified documentation and systematic terminology.

There are issues such as product quality, cost reduction, and speed in cold chain, and logistics manages history based on blockchain technology that tracks and manages various situations that occur in this process and prevents forgery and falsification of data. A platform is needed.

After identity authentication and authorization, wallet management for private key storage and use, and detection and tracking of asset movements or transaction events occur, and development of a logistics platform through transparent policy implementation and implementation of insufficient temperature management and reliability caused by the existing cold chain. If so, it will be possible to solve the problem.

Concept of DEA (Data Envelopment Analysis)

We look at DEA, the methodology of this study on the efficiency of the cold chain industry.

The DEA model is a non-parametric methodology that measures the relative efficiency between input and output variables of DMUs based on the concept of Farrell (1957). Among DEA models, the CCR model and BCC model are the most widely used.

The CCR model is a model developed by Charnes et al. (1978) and assumes CRS (Constant Return to Scale), in which the relationship between input and output factors increases at the same rate. The BCC model is a model developed by Banker et al. (1984) and assumes VRS (Variable Return to Scale), in which the relationship between input and output factors changes depending on scale.

Additionally, the DEA model is divided into input-oriented and output-oriented. An oriented model must be selected by clearly identifying the purpose of the research and the direction in which it is intended to improve efficiency. Input orientation means minimizing input by fixing output, while output orientation means improving efficiency by fixing input and maximizing output. In this study, the input-oriented CCR model and BCC model were ultimately used.

The input-oriented CCR model is the same as equation (1), and if constraint $\sum_{j=1}^{J} \lambda_j = 1$ is included in the CCR model, it becomes a BCC model.

$$\min \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \quad (1)$$

subject to

$$\sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- = \theta x_{io} \quad (i = 1,2, \dots, m);$$

$$\sum_{j=1}^{n} y_{rj} \lambda_j - s_r^+ = y_{ro} \quad (r = 1,2, \dots, s);$$

$$\lambda^j \geq 0 \quad (j = 1, 2, \dots, n)$$

where

θ : DMUs Efficiency of DMUs

n : Number of DMUs

m : Number of inputs

s : Number of output factors

x_{ij}: Value of the jth input of DMUs

y_{rj}: Value of the jth input of DMUs

ε : non-Archimedean constants

λ : weight of reference set

Dea Analysis

We empirically conduct efficiency evaluation and analysis of cold chain companies using the DEA model.

Efficiency Evaluation Procedure

A six-step process is performed to evaluate the operational efficiency of cold chain companies based on the DEA model.

The first step was to define the problem, adopt DEA as an appropriate evaluation methodology for the purpose of evaluating the relative efficiency of cold chain companies, and consider it in the previous section.

The second step was the selection of DMUs, which selected companies with cold chain business models in each industry.

In the third step, data was collected to evaluate and analyze the efficiency of cold chain companies.

In the fourth step, candidates for input and output elements were selected and selected, and the final elements were selected.

Step 5 was DEA model analysis, where the input-oriented CCR model and BCC model were applied.

Step 6 was an efficiency evaluation, evaluating the efficiency of cold chain companies based on the DEA model.

Selection of DMUs and Input/Output Factors

The cold chain companies subject to efficiency research are DMU, and 17 companies in the electronics, communications, machinery, semiconductor, life, health, pharmaceutical, transportation, automobile parts, software, and chemical industries are conducting cold chain business.

To select input/output factors, assets, liabilities, capital, sales, operating profit, and net profit of 17 companies were selected as candidates, and data were collected from the 2023 financial statements. By conducting a correlation analysis between these data, an element with a high correlation between input and output elements and a relatively low correlation between input elements was selected as the final element. Finally, liabilities and capital were selected as input factors, and sales and operating profit were selected as output factors (<Table 1>).

Table 1. Descriptive statistics of input/output factors

(unit: hundred million won)

Factor / Statiscs	Input factor		output factor	
	Liabilities	Capital	Sales	Operational Profit
Max	9,752	10,695	12,571	862
Min	36	-1,269	126	-328
Average	1,325	1,566	1,896	54
SD	2,251	2,649	3,077	260

The correlation between input and output factors is analyzed for candidate factors, multicollinearity between input factors is analyzed, and input/output factors are finally determined.

DEA Model Application and Analysis

Efficiency Evaluation Results for CCR and BCC Models

In this study, the efficiency was evaluated using the input-oriented CCR model and BCC model targeting 17 cold chain companies in 2023 (<Tab. 2>)

Efficiency is calculated as a relative value based on the most efficient frontier observed in the group (Bhagavath, 2006). If the efficiency value is '1', it is evaluated as an efficient company, and if the value is lower than '1', it is evaluated as an inefficient company. The lower the efficiency score, the greater the potential improvement over efficient DMUs (Agarwal et al., 2010).

As a result of the efficiency evaluation, among the 17 companies, 6 companies (D02, D05, D07, D09, D10, D11) were evaluated as efficient in the CCR model, and the remaining 11 companies were found to be inefficient. The efficiency score ranged from 0.237 to 1, with the average value being 0.677. The input improvement goal of the CCR model is 76.3% for the company with the lowest efficiency (D14) and 32.3% for the average efficiency.

The evaluation results of the BCC model showed that 9 out of 17 companies (D01, D02, D05, D07, D08, D09, D10, D11, D17) were evaluated efficiently, while the remaining 8 companies were inefficient. The efficiency score ranged from 0.273 to 1, and the average value was 0.792. The BCC model's input improvement target is 72.7% for the company with the lowest efficiency (D06) and 20.8% for the average efficiency. As a result, the efficiency value of the BCC model was found to be higher than that of the CCR model, and this is because the CCR model assumes CRS, but the BCC model assumes VRS.

Table 2. Efficiency evaluation results for CCR and BCC models

DMU	CCR		BCC	
	Score	Rank	Score	Rank
D01	0.248	16	1	1
D02	1	1	1	1
D03	0.889	8	0.892	10
D04	0.310	14	0.321	16
D05	1	1	1	1
D06	0.271	15	0.273	17
D07	1	1	1	1
D08	0.482	11	1	1
D09	1	1	1	1
D10	1	1	1	1
D11	1	1	1	1
D12	0.312	13	0.404	14
D13	0.655	10	0.657	13
D14	0.237	17	0.401	15
D15	0.377	12	0.703	12
D16	0.741	9	0.807	11
D17	0.991	7	1	1

Reference Analysis

One of the main reasons for efficiency evaluation is to improve the performance of inefficiently evaluated DMUs compared to efficiently evaluated DMUs (Odeck and Alkadi, 2001). DMUs evaluated as inefficient refer to efficient DMUs that form similar input combinations, so they can be used as a measure to improve efficiency in the future.

<Table 3> summarizes the reference count and reference set of efficiently evaluated companies. In the CCR model, 6 efficient companies were observed, and 6 companies had a high number of references. These companies are D07 and D09, and are referenced 9 times each. In the BCC model, 9 efficient companies were observed, and 3 companies had a high number of references. These companies are D02, D07 and D09 and are referenced 5, 6 and 5 times respectively. It is necessary to pay attention to D07 and D09, which have a large number of references in common in the CCR model and the BCC model.

Table 3. Reference Sets and Reference Count for CCR and BCC Models

Efficient DMUs	CCR		BCC	
	reference count	Reference set	reference count	Reference set
D01			1	D15
D02	1	D03	5	D03, D04, D12, D14, D15
D05	1	D16	1	D16
D07	9	D01, D04, D06, D08, D12, D13, D14, D15, D17	6	D04, D06, D12, D13, D14, D15

D08			0	
D09	9	D01, D03, D04, D08, D12, D13, D14, D15, D17	5	D03, D04, D12, D13, D14
D10	0		1	D03
D11	4	D03, D06, D08, D16	3	D03, D06, D16
D17			2	D06, D13

In the case of companies with a large reference count, inefficient companies can be interpreted as good reference companies for benchmarking. On the other hand, it can be concluded that companies that are efficiently evaluated but have a low reference count are not desirable reference companies for benchmarking because they are likely to form heterogeneous input combinations. If there are no efficient companies with a high reference count among inefficient companies, it is judged desirable to mainly refer to companies with the most similar environments or companies with the most similar operating scale.

Efficiency Improvement Goal Analysis

In order to become an efficient company, DEA allows inefficient companies to benchmark efficient companies and derive target values for improvement. In other words, it makes it easier to improve the efficiency of an inefficient company by providing a quantitative goal for how much an inefficient company must improve its inputs to become an efficient company. Improvement goals can be calculated using efficiency rankings, reference sets, and weights, which are called projection values (<Table 4>, <Table 5>).

For example, in the CCR model in <Table 4>, inefficient company D03 must reduce input factors by 11.1% to become an efficient company. In other words, the improvement goal should be to reduce liabilities from the current KRW 93.1 billion to KRW 82.8 billion and reduce capital from the current KRW 358.1 billion to KRW 31.8 billion.

Likewise, in the BCC model in <Table 5>, inefficient company D03 must reduce input factors by 10.8% to become an efficient company. In other words, the improvement goal should be to reduce liabilities from the current KRW 93.1 billion won to KRW 83.1 billion won and capital from the current KRW 38.3 billion won to KRW 32 billion won.

Table 4. Efficiency improvement goal of CCR models

(unit: hundred million won)

DMU	Score	Liabilities			Capital		
		Data	Projection	Diff.(%)	Data	Projection	Diff.(%)
D01	0.248	171	42	-75.2	271	67	-75.2
D02	1	511	511	0.0	-208	-	0.0
D03	0.889	931	828	-11.1	358	318	-11.1
D04	0.310	732	227	-69.0	1,475	457	-69.0
D05	1	36	36	0.0	571	571	0.0
D06	0.271	1,237	336	-72.9	5,415	1,470	-72.9
D07	1	153	153	0.0	487	487	0.0
D08	0.482	9,752	4,704	-51.8	10,695	5,159	-51.8
D09	1	3,429	3,429	0.0	846	846	0.0
D10	1	1,835	1,835	0.0	-1,269	-	0.0
D11	1	467	467	0.0	2,331	2,331	0.0
D12	0.312	768	240	-68.8	898	281	-68.8

D13	0.655	289	189	-34.5	852	558	-34.5
D14	0.237	1,065	252	-76.3	596	141	-76.3
D15	0.377	469	177	-62.3	348	131	-62.3
D16	0.741	230	171	-25.9	1,740	1,290	-25.9
D17	0.991	451	447	-0.9	1,216	1,205	-0.9

Table 5. Efficiency improvement goal of BCC models

(unit: hundred million won)

DMU	Score	Liabilities			Capital		
		Data	Projection	Diff.(%)	Data	Projection	Diff.(%)
D01	1	171	171	0	271	271	0
D02	1	511	511	0	-208	-	0
D03	0.892	931	831	-10.8	358	320	-10.8
D04	0.321	732	235	-67.9	1,475	474	-67.9
D05	1	36	36	0	571	571	0
D06	0.273	1,237	337	-72.7	5,415	1,476	-72.7
D07	1	153	153	0	487	487	0
D08	1	9,752	9,752	0	10,695	10,695	0
D09	1	3,429	3,429	0	846	846	0
D10	1	1,835	1,835	0	-1,269	-	0
D11	1	467	467	0	2,331	2,331	0
D12	0.404	768	310	-59.6	898	363	-59.6
D13	0.657	289	190	-34.3	852	560	-34.3
D14	0.401	1,065	427	-59.9	596	239	-59.9
D15	0.703	469	330	-29.7	348	245	-29.7
D16	0.807	230	186	-19.3	1,740	1,182	-32.1
D17	1	451	451	0	1,216	1,216	0

CONCLUSION

This study selected cold chain business processes that exist in various industries, grouped them into industries, and named them cold chain industries. Additionally, a framework was established to evaluate and diagnose the management efficiency of companies in this industry.

17 companies belong to the cold chain industry, and these companies were defined as DMUs and their efficiency was evaluated using DEA techniques. The input factors were liability and capital, and the output factors were sales and operating profit.

As a result of the analysis, 6 companies were found to be efficient based on the CCR model and 9 companies were found to be efficient based on the BCC model. Targets or improvement values for inputs that inefficient companies can improve by benchmarking efficient companies are presented in each of the two models. In addition, the method of selecting companies that inefficient companies should benchmark was shown using a reference set.

This study was evaluated and analyzed using data from one year after the end of the COVID-19 pandemic. In the future, it is believed that research that evaluates efficiency annually or periodically and research that evaluates long-term changes in efficiency will be necessary.

It is expected that the results and processes of this study will be useful in evaluating and analyzing the management efficiency of companies.

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