ICIC Express Letters
Part B: Applications
Volume **13**, Number **7**, July **2022**
ICIC International ©2022 ISSN 2185-2766
pp. 735–740

ESTIMATION OF CONSTRUCTION COST OF SMART JOINT REFRIGERATED LOGISTICS CENTER APPLYING COLLABORATIVE GAME THEORY –A CASE STUDY OF REPUBLIC OF KOREA–

Jae-Min Kim[1], Gyusung Cho[2,*] and Young-Tae Park[3]

[1]Korea Keyence Co., Ltd.
326, Hwangsaeul-ro, Bundang-gu, Seongnam-si, Gyeonggi-do 13591, Korea
jmkim@keyence.co.kr

[2]Department of Port Logistics System
Tongmyong University
428, Sinseon-ro, Nam-gu, Busan 48520, Korea
[*]Corresponding author: gscho@tu.ac.kr

[3]Division of International Trade and Distribution
Dong-Eui University
176, Eomgwangno, Busan jin-gu, Busan 47340, Korea
gregory@deu.ac.kr

Received November 2021; accepted January 2022

Abstract. *In Korea, the smart logistics center is jointly developed to meet the exact material delivery schedule for the smart manufacturing process. The reason is that the utilization rate of the smart manufacturing process can be increased by decreasing the material delivery schedule through the smartization of the common logistics center. However, because the cost of constructing a smart joint logistics center is very high, efforts to reduce the construction cost are required. In this study, we developed a construction cost estimation model for logistics companies involved in constructing a smart joint logistics center, to which a collaborative game theory is applied. In addition, Korea's smart joint logistics center was divided into four scales based on the construction cost calculation model, and the construction cost of the smart joint logistics center was determined for each scale capable of supporting smart manufacturing processes. Therefore, the application of the proposed methodology will help expand the construction of the smart joint logistics center and continuously operate the smart manufacturing process.*
Keywords: Smart factory, Joint logistics center, Collaborative game theory, Construction cost

1. **Introduction.** In Korea, 99.7 percent of goods (import, export) come from the sea. Among them, Busan Port handles more than half. Therefore, logistics companies can reduce logistics costs by reducing the lead time as they are closer to the Busan Port hinterland [1,2]. However, it is challenging for small logistics companies in Busan to move in, mainly due to the high entry barriers even if they want to move into the port hinterland. In the case of a port hinterland, the operation cost and sales of the companies are strictly reviewed, and the competition is focused on large companies. Therefore, the Busan Port Authority is planning to build a public logistics center in the Busan Port hinterland to make it easier for small logistics companies to move into the Busan Port hinterland [3-5]. The research on port hinterlands can be classified into three categories. The first category of research, particularly in South Korea, focuses on the occupancy policy for the smart logistics facilities in the port hinterland [2]. The second category focuses on the design and operation of smart logistics facilities [3,4]. Finally, the third category studies the collaboration between private and public services using smart logistics facilities located

DOI: 10.24507/icicelb.13.07.735

in S. Korea [5]. Port development and logistics facilities have been deployed around the hinterland of the port, thereby increasing the port competitiveness between companies. Thus, these companies use only the neighboring private smart logistics centers. The purpose of this study is to determine the construction costs of a public logistics center built by a combined enterprise consisting of companies of different sizes. The companies joining the enterprise are classified into four categories depending on their size: small, medium, large, and hub. Moreover, as the amount of money required to be paid is not policy-wise, the Shapley value is used to allocate the costs for each member of the enterprise efficiently. In the last five years, the alliance between the public and private sectors weakened owing to the emphasis on increasing the number of tenant companies. Furthermore, two main challenges hindered the Busan Port hinterland development [6,7]: 1) small and medium logistics companies were unable to use the port owing to port laws, and 2) guidelines for managing the port hinterland caused problems, thereby increasing the competitiveness among large companies. In the last five years, the alliance between the public and private sectors weakened owing to the emphasis on increasing the number of tenant companies. Furthermore, two main challenges hindered the Busan Port hinterland development: 1) small and medium logistics companies were unable to use the port owing to port laws, and 2) guidelines for managing the port hinterland caused problems, thereby increasing the competitiveness among large companies. This study investigates the public nature of the port hinterland, identifies problems, suggests measures for improvements, and employs the construction costs of the public logistics center to strengthen the public sector perspective of the port hinterland. Furthermore, we suggest a collaborative game theory approach to appropriately distributing the construction costs among logistics companies in the public logistics center. In our study, as a strategy for high value-added port hinterland development, the differences between the domestic and the foreign port logistics are elucidated based on the operation method. The logistics status and related problems concerning the logistics system in Korea and Busan were described in the introduction. Section 2 discusses the costs incurred by each private enterprise when operating the public logistics center by scale and develops a mathematical equation for the construction of public logistics center using the Shapley value. Section 3 provides the results derived arbitrarily by directly applying a mathematical formulation. Finally, Section 4 concludes this study.

2. **Repair Model for the Construction Cost of a Smart Joint Refrigerated Logistics Center.** In this study, the problem of allocating the construction costs of a public logistics center is analyzed by allocating costs while considering the size of the logistics company [8-10]. The size of the logistics center is used to classify the appropriate logistics companies that can use the center. Thereafter, the costs are allocated to these companies. Each logistics company, of the four different types, has its own logistics center with the following sizes: 1,000-2,000 m^2, 2,000-5,000 m^2, 5,000-10,000 m^2, and 10,000 m^2. Moreover, when more than one public logistics center exists, the company using the 1,000-2,000 m^2 logistics center is considered the smallest logistics company. Table 1 summarizes the volume of goods with respect to the size of the logistics center defined by the government. In this study, the construction cost was investigated on-site for five enterprises, and the size and construction costs of these enterprises were calculated. The public logistics centers considered here are limited by the area of public logistics centers available to each logistics company. For example, companies that process 15,000 tons of goods can use logistics centers of all sizes. However, companies that handle more than 60,000 tons of goods cannot use logistics centers smaller than the hub-sized centers. This limits the use of public logistics centers if their storage capacity is smaller than the volume of goods handled by the enterprise.

Table 1. Construction costs of logistics center by size

Index	Area (m^2)	Volume of goods (kg)	Construction cost* ($10)
1	1,000-2,000	< 15,000,000	64,206
2	2,000-5,000	< 30,000,000	179,626
3	5,000-10,000	< 60,000,000	552,818
4	More than 10,000	> 60,000,000	949,233
Total	–	–	1,745,883

*Source: National Logistics Information Center (http://www.nlic.go.kr).

A public logistics center should feature a size that can handle the volume of all logistics companies, ranging from small- to hub-sized centers. The objective function in this study is a repair model. For this model, the construction cost was derived by substituting the number of logistics centers in the status. This limits the marginal contributions of logistics companies included in the overall joint S to the partial union S and the overall coalition N. S represents the partial union included in N, and N represents a full union. The repair model is expressed as [11,12].

$$\min c(S) = \sum_{i=1, s_i \in S} H_{s_i} \left(c_{s_i} - c_{s_{i-1}} \right) \tag{1}$$

such that

$$c(S \cap N) \geq c(S) + c(N) \tag{2}$$

$$i < j, \quad c_i < c_j \tag{3}$$

$$S = \{s_1, \ldots, s_n\}, \quad s_i < s_j,\, c_{s_i} < c_{s_j} \tag{4}$$

$$\sum_{i \in S} c_i \leq c(S), \quad \sum_{i \in N} c_i \leq c(N) \tag{5}$$

$$c_i = \{c_1, c_2, \ldots, c_m\}, \quad i \geq 0,\, c(\emptyset) = 0 \tag{6}$$

Equation (1) is the sum of the costs of available logistics centers of each entity belonging to the federation. Here, H_{s_i} is the size of the available distribution center of the entity s_i participating in the sub-union S. Equation (2) defines the value of the characteristic function $c(S)$ as the cost of constructing the logistics center of union S. $c(i)$ represents the cost of constructing the logistics center and H_{s_i} is the cost of the union for each logistics company to establish a public logistics center. Here, the cost of a union can be considered as the total value for applying the Shapley value. In Equation (3), the construction costs increase as the size of the logistics center used in proportion to the volume of the enterprise increases. Equation (4) is a conditional formula where the construction costs increase based on Equation (3) when a coalition forms. Constraints (5) are conditional formulas stating that the sum of the construction costs for entities constituting partial union S and alliance N should be similar to the joint construction costs of partial union S and united N. For Equation (6), the entity i also indicates that the number of such entities would vary depending on the union. Moreover, a value of zero implies that the entity would not participate in the union.

3. **Cooperative Game Theory for the Construction Cost Allocation of a Smart Joint Refrigerated Logistics Center.** In this study, securing sufficient financial revenue for the operating costs of the public logistics center is the highest priority. Therefore, the full-cost allocation method is adopted by allocating the cost of providing public services to all users, using the cooperative game theory. The number of players ($n \geq 2$) participating in the federation ranges from 1 to n, where N represents a group of players; thus, the group of players can be represented as $N = \{1, 2, \ldots, n\}$. Any subset S of N

is referred to as the union, and N is referred to as the great alliance. If two players are participating in a game, four federations (i.e., $\{\emptyset\}$, $\{1\}$, $\{2\}$, and N) will be formed. If three competitors are formed, eight federations $\{\emptyset\}$, $\{1\}$, $\{2\}$, $\{3\}$, $\{1,2\}$, $\{1,3\}$, $\{2,3\}$, and N will be formed. The cooperative game comprises a pair of $c(N, c)$, a characteristic function of the set of competitors N, and its subset, the federated S. The characteristic function with the value c: $2^N \to R$ is the cost defined for all federations 2^N. Moreover, the cost of $c(S)$ that does not provide services to competitors belonging to the federation S in the most efficient approach is assumed to be zero (i.e., $c(\emptyset) = 0$). If q public logistics centers exist in the port hinterland, the collection of public logistics centers can be represented by $Q = \{1, 2, \ldots, q\}$. Furthermore, when the cost of $q = \{q_1, q_2, \ldots, q_n\}$ for each logistics company is $c(q)$, the cost of the public logistics center to achieve the demand of all logistics companies is $c\left(\sum_{i=1}^{n} q_i\right)$. In this study, c assumes that each logistics company accepts the construction costs. Assuming that c is the set of the cost functions when the logistics companies jointly bear the cost of constructing the public logistics center, the problem of allocating costs is pairs. The year is a group of R^N costs to be shared by each logistics company. Table 2 summarizes the cost of constructing a public logistics center derived through a coalition of logistics companies. The value of each logistics company is derived from the limited contribution of the Shapley value. In this study, the weight of small logistics companies that can use public logistics centers, ranging from small centers to hubs, was determined because the companies using these centers were different for each size of the centers. In Table 2, the numbers 1, 2, 3, and 4 in parentheses of the federated phrase indicate the federation of the logistics companies.

Table 2. Construction cost of the public logistics center with respect to the union of logistics companies

Union	Equation based on marginal cost	Method	Construction cost ($10)
$c(1)$	$4 \times c_1$	–	256,824
$c(2)$	$3 \times c_2$		538,878
$c(3)$	$2 \times c_3$		1,105,636
$c(4)$	c_4		949,233
$c(1,2)$	$3(c_2 - c_1) + 4 \times c_1$	$c_1 + 3 \times c_2$	603,084
$c(1,3)$	$2(c_3 - c_1) + 4 \times c_1$	$2(c_1 + c_3)$	1,234,048
$c(1,4)$	$(c_4 - c_1) + 4 \times c_1$	$3 \times c_1 + c_4$	1,141,851
$c(2,3)$	$2(c_3 - c_2) + 3 \times c_2$	$c_2 + 2 \times c_3$	1,285,262
$c(2,4)$	$(c_4 - c_2) + 3 \times c_2$	$2 \times c_2 + c_4$	1,308,485
$c(3,4)$	$(c_4 - c_2) + 2 \times c_3$	$c_3 + c_4$	1,502,051
$c(1,2,3)$	$2(c_3 - c_2) + 3(c_2 - c_1) + 4 \times c_1$	$c_2 + c_1 + 2 \times c_3$	1,349,468
$c(1,2,4)$	$(c_4 - c_2) + 3(c_2 - c_1) + 4 \times c_1$	$c_1 + 2 \times c_3 + c_4$	2,119,075
$c(1,3,4)$	$(c_4 - c_3) + 2(c_3 - c_1) + 4 \times c_1$	$2 \times c_1 + c_3 + c_4$	1,630,463
$c(2,3,4)$	$(c_4 - c_3) + 2(c_3 - c_2) + 3 \times c_2$	$c_2 + c_3 + c_4$	1,681,677
$c(1,2,3,4)$	$(c_4 - c_3) + 2(c_3 - c_2) + 3(c_2 - c_1) + 4 \times c_1$	$c_1 + c_2 + c_3 + c_4$	1,745,883

Table 3 lists the distribution process derived by applying a cooperative game to the construction cost of the public logistics center. The table indicates that the value is divided according to the association of each logistics company. The logistics company located in front of the union is estimated to have the highest marginal contribution; the prices vary depending on limited contribution. The results are calculated according to the contribution of each logistics center. The Shapley value is the average value of the contribution of each distribution center. To build a public logistics center, the construction costs calculated for the four category sizes considered in this study were as follows: small 195,961,

Table 3. Comparison of actual construction costs and those obtained using the Shapley value

Index	Actual construction costs	Construction costs obtained using Shapley value	Difference
1	54,308	186,062	+131,754
2	179,626	343,359	+163,733
3	552,818	506,829	−45,989
4	949,233	699,735	−249,498
Total	1,735,985	1,735,985	0

medium 343,359, large 506,829, and hub 699,735, respectively. These costs were established according to the Korean government. The Shapley value can be used to determine the burden of construction costs. This cost burden can vary if the construction cost of the public logistics center for each area is distributed among small-, medium-, large-, and hub-sized logistics companies. The cost burden of small logistics companies in terms of the Shapley value is higher than the actual construction costs because these companies are available when constructing small-, medium-, large-, and hub-sized public logistics centers. Conversely, the cost burden on hub-sized companies reduced because only hub-sized public logistics centers of hub logistics companies could use them.

To build a public logistics center, the first and second companies had higher construction costs for private logistics centers. However, it is important to note here that the vote is not a single company but a coalition. In the case of the fourth company, the construction costs would decrease because of its narrowest location in the public logistics center. Therefore, the company with the highest position appeared to be in the order $2 > 1 > 3 > 4$. Currently, there is only one public logistics center built in South Korea. However, it is suspended due to operating cost problems. The logistics center is very innovative in terms of public nature, but the problems related to cost cannot be ignored. Therefore, the Busan Port Authority is considering a prudent approach to the public logistics center plan. However, because there are no specific bills on how much the state supports public logistics centers, construction costs were calculated only by a group of private companies.

4. **Conclusion.** This study examined the problems related to the development of a port hinterland in South Korea. The study presented a construction method for improving the logistics facilities in public logistics centers. The characteristics of the logistics company were summarized as follows. First, owing to the constraints on size and the volume of goods, small logistics companies can use larger logistics centers; however, hub logistics companies cannot use smaller centers. Second, a trend of logistics centers to increase their size, owing to the rise in the logistics business volume, was observed, which is because the Busan hinterland is under the Busan Port Authority Law. Because it is difficult for small businesses to follow the law, this study focused on building a public logistics center where small businesses can enter. Currently, the Busan Port Authority is planning to attract small businesses by building a public logistics center. Thus, this study presented an operational model and improvement plan. The existing literature only mentions the use of port hinterland and logistics-related facilities, but this study presented a model for the construction of an efficient port hinterland using the Shapley value. The presented model can serve as a method for efficiently improving logistics facilities. According to the company size, this study selected four types of participants to build one public logistics center. If the companies do not collaborate, the cost of construction does not change. In the case of collaboration, construction costs for small- and medium-sized units increase, but construction costs for large and hub areas decrease. Large- and hub-sized companies

are at a disadvantage in comparison with small- and medium-sized companies. The proposed model does not reflect the most used (by size) logistics centers of the smart logistics companies that moved into the distribution centers. Even if the tenant companies use the entire available storage space during installation to minimize storage time, a smart logistics center would still exist that is used steadily. However, the proposed model does not reflect this aspect and in the future we will consider the most used (by size) logistics centers of the smart logistics companies that moved into the distribution centers.

Acknowledgment. This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2019S1A5A2A030522 17).

REFERENCES

[1] H.-S. Kim and G. Cho, Case study on the operation of smart refrigerated warehouse in Busan, *ICIC Express Letters, Part B: Applications*, vol.9, no.4, pp.369-374, 2018.
[2] J. E. Yoon, G. S. Cho and J. Y. Jeong, Trend analysis on Korea's national R&D in logistics, *Journal of Ocean Engineering and Technology*, vol.34, no.6, pp.461-468, 2020.
[3] N. S. Hong, Morphological change in seabed surrounding Jinwoo-Island due to construction of New Busan Port –Qualitative evaluation through numerical simulation–, *Journal of Ocean Engineering and Technology*, vol.32, no.3, pp.192-201, 2018.
[4] D. J. Jang and G. U. Ham, An analysis of wave height distribution in the vicinity of Samcheon New-Harbor, *Journal of Ocean Engineering and Technology*, vol.24, no.1, pp.39-46, 2010.
[5] T. S. Kang, S. R. Moon, S. Y. Nam and J. S. Shim, The vulnerability of the reclaimed seashore land attendant upon storm surge/coastal inundation, *Journal of Ocean Engineering and Technology*, vol.24, no.1, pp.68-75, 2010.
[6] K. H. Chung, S. Y. Ko and J. J. Roh, A strategic alliance model with a regional monopoly of service centers in express courier services, *International Journal of Services and Operations Management*, vol.5, no.6, 2009.
[7] K. H. Chung, S. Y. Ko, C. U. Lee and C. S. Ko, Sustainable collaboration model with monopoly of service centers in express delivery services based on Shapley value allocation, *International Journal of Industrial Engineering*, vol.23, no.3, pp.166-173, 2016.
[8] K. H. Chung, Slot exchange model for strategic collaboration of liner shipping industry, *Journal of the Korean Society of Supply Chain Management*, vol.18, no.2, pp.163-171, 2018.
[9] H. Wang and J. Chen, Research on the transformation strategy of international port logistics service under the cross-border e-commerce environment, *International Journal of Innovative Computing, Information and Control*, vol.15, no.2, pp.803-810, 2019.
[10] B. Zhu and B. Lin, Efficiency evaluation of ports in Bohai Rim region based on three-stage DEA, *International Journal of Innovative Computing, Information and Control*, vol.17, no.3, pp.1067-1074, 2021.
[11] J. M. Kim, *Allocation of Shared Logistics Cost in Collaborative-Based Cold Chain*, Master Thesis, Tongmyoung University, Pusan, 2021.
[12] S. K. Sung, A game theoretic approach to the container quay construction in Busan, *Journal of Korea Port Economic Association*, vol.24, no.3, pp.23-35, 2008.