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Automated Construction Cost Estimation System Using DB Modeling of a TBM Construction Classification System

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Abstract

In this study, a work information classification system for the TBM tunnel construction was proposed along with a conceptual model of an automated cost estimation system, with the goal of relieving the cumbersome operation of existing systems. The conceptual modeling of the automated cost estimation system involves systematizing the construction cost estimation process, by organizing a work information classification system in the form of a relational data base which reflects the processes that comprise the construction work. This proposed automation system is expected to be effectively applied to TBM tunnel construction sites as a scientific cost estimation system.

Keywords*: TBM tunnel construction, work information classification system, relational data base, automated cost estimation system*

1. Introduction

A cost estimation system using a scientific approach to provide construction cost estimation has to be consistent. For the system to have maximum effect, a systematic work information classification system and computer system have to be set up as priorities. However, in existing cost estimation systems, the operators have to classify and input work information one by one, followed by the analysis process, so cost estimation system operators need to be sufficiently knowledgeable for the system to be useful.

Various tunneling methods are utilized in Korea today including NATM, SHIELD, and TBM depending on geological conditions, such as terrain and rock quality. But after 1990, the use of the TBM method, which is a large-diameter tunnel excavation method, increased due to various complaints, labor cost increases, reduction in construction time, and government establishment of construction standards. According to statistical data provided by the International Tunneling Association (ITA), around 30% of the tunnels constructed in the U.S., Austria, and Germany have used the TBM method [1]. The TBM method has also been actively utilized in consideration of the global push for industrial disaster prevention and environmental protection, because the method repeats the processes of excavation, mucking, and support.

Prior to undertaking this research, domestic and international previous studies were surveyed with regard to a preliminary cost estimation method. Park *et al.* [1] presented the basic data for golf course construction cost prediction in the initial planning stage based on a formula that estimates construction cost by considering the construction scale and time of actual construction data for other golf courses constructed in similar locations. Kim [2] developed a cost estimation model for power plant construction using construction models of similar construction types, and Kim [3] derived a preliminary construction cost estimation model for the basic design stage of the RC Rahmen Bridge.

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Also, Han [5] derived a construction cost estimation model formula based on detailed statements from city subway construction data. International literature on the subject includes the study of Williams, C. Miller, P.E. Leonard Gallina [6] which proposed a method for managing estimates and costs for gas construction design, and Dodge, W. J [7] who presented a model method for estimating possible financial support when predicting facility capital cost. In this manner, previous studies were also carried out that mainly concerned golf courses, plants, apartments, and roads [8]

As an alternative, in this study, a work information classification system for the TBM tunnel construction was proposed along with a conceptual model of an automated cost estimation system, with the goal of relieving the cumbersome operation of existing systems. The conceptual modeling of the automated cost estimation system involves systematizing the construction cost estimation process, by organizing a work information classification system in the form of a relational data base which reflects the processes that comprise the construction work. This cost estimation automation system conceptual model resolved the issue of inconvenience which exists in the operation of existing cost estimation systems, where the basic data for the cost estimation had to be inputted one by one. This proposed automation system is expected to be effectively applied to TBM tunnel construction sites as a scientific cost estimation system.

2. TBM Construction Work Information Classification System

In this study, a work information classification system standard for TBM tunnel construction is presented, and based on this standard, a work information classification system is constructed. Also, the construction types within each information classification system are connected to the entire range of construction codes as the Key Field. Using this approach, the cost estimation automation relational D/B structure and cost estimation automation data modeling were carried out

2.1. Work Information Classification System Composition

Construction projects can be classified into functional components which represent the basic configuration for each facility or structure, and these functional component classifications are individually related to specific work components. In addition, the work components classification corresponds to resource components, including their specific functionality and equipment, depending on the material used. When put together in a hierarchy, these 4 classifications systematize the work information classification system, and produces a form that is similar to faceted classification. As shown in Figure 1, the TBM tunnel construction information classification system is composed in a hierarchical order of facility component-functional component-work component-resource component. Figure 2 shows the TBM tunnel construction information classification system based on Figure 1. The function division is categorized into two classifications. The first is a facility classification, based on the facility or structure type, which in this case is the TBM tunnel construction diameter (for example, ø2.6 TBM tunnel construction, ø3.0 TBM tunnel construction, ø3.5 TBM tunnel construction, ø5.0 TBM tunnel construction, ø8.0 TBM tunnel construction). The second is a functional component classification based on the structure type for each facility or structure (for example, TBM excavation, mucking process, support construction, lining and waterproof work, machinery and electrical work, subsidiary work). This completes the sub-commodity classification that composes all tunnel construction.

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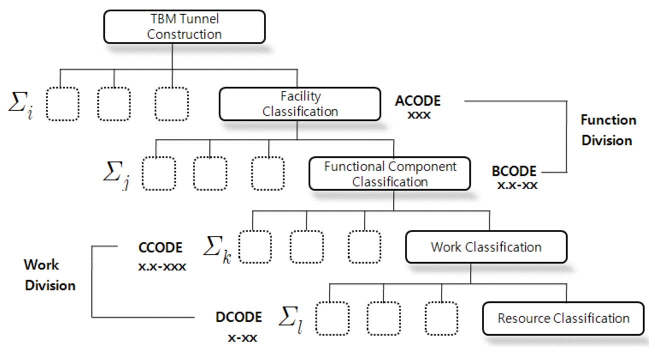

Figure 1. TBM Tunnel Construction Information Classification System

2.2. Detailed Classification of the TBM Tunnel Construction Information Classification System

The TBM tunnel construction information classification system is divided into a facility component, functional component, work component, and resource component according to the standard presented in Figs. 1 and 2. The constituents of each component are independent of each other, and systematic code numbers were assigned in order to keep the constituents independent. Using the codes for the constituents of each LEVEL, the degradation and aggregation of each commodity comprising the construction can be performed.

2.2.1. Facility Component Classification

This is the highest level classification for the TBM tunnel construction and this classification refers to the facility or structure. The TBM tunnel construction uses excavation equipment of ø2.6M , ø3.0M, ø3.5M, ø5.0M, and ø8.0M, and the TBM tunnel construction of each diameter comprises the facility component classification.

ACODE DES
2.6-1 ø2.6 TBM Tunnel Construction
2.6-2 ø3.0 TBM Tunnel Construction
2.6-3 ø3.5 TBM Tunnel Construction
2.6-4 ø5.0 TBM Tunnel Construction
2.6-5 ø8.0 TBM Tunnel Construction

2.2.2. Functional Component Classification

The functional component classification is composed of the subcategories of the categories within the facility component and it is composed of independent structures with independent functionality. Hence, the TBM tunnel construction is carried out per structure, corresponding to the TBM excavation work per diameter, the mucking process work, support construction work, lining and waterproofing work, machinery and electrical work, and subsidiary work. These work types become the functional component classification.

BCODE DES
2.6-10 ø2.6 TBM Excavation Work
2.6-20 ø2.6 Mucking Process Work
2.6-30 ø2.6 Support Construction Work
2.6-40 ø2.6 Lining and Waterproofing Work
2.6-50 ø2.6 Machinery and Electrical Work
2.6-60 ø2.6 Subsidiary Work
3.0-10 ø3.0 TBM Excavation Work

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3.0-20 ø3.0 Mucking Process Work
3.0-30 ø3.0 Support Construction Work
3.0-40 ø3.0 Lining and Waterproofing Work
3.0-50 ø3.0 Machinery and Electrical Work
3.0-60 ø3.0 Subsidiary Work

2.2.3. Work Component Classification

The work component classification is composed of sub-sub-commodity works conducted directly on-site, among the commodities that comprise the TBM tunnel construction. In other words, the work component classifications correspond to works with direct resource input, essentially the lowest steps in the work type classification. These works are connected to the corresponding cost estimate, construction quantity, and resource.

CCODE DES
2.6-100 ø2.6 TBM Excavation
2.6-110 TBM Excavation Work
2.6-120 PILOT Excavation(NATM)
2.6-200 ø2.6 Mucking Process Work
2.6-210 Underground Mucking Process Work
2.6-220 PILOT Underground Mucking Process
2.6-230 Surface Mucking Process Work
2.6-240 PILOT Surface Mucking Process
2.6-300 ø2.6 Support Construction Work
2.6-310 ROCK BOLT Installation
2.6-320 PILOT ROCK BOLT
2.6-330 SHOTCRETE Installation
2.6-340 PILOT SHOTCRETE
2.6-350 STEEL RIB Installation
2.6-360 PILOT STEEL RIB
2.6-370 Reinforcement Method
2.6-400 ø2.6 Lining and Waterproofing Work
2.6-410 STEEL FORM Installation and Dismantling
2.6-420 Concrete Underground Transportation
2.6-430 Lining Concrete Deposition
2.6-440 Waterproofing SHEET
2.6-450 BACK FILL GROUTING
2.6-500 ø2.6 Machinery and Electrical Work
2.6-600 ø2.6 Subsidiary Work

3.0-100 ø3.0 TBM Excavation
3.0-110 TBM Excavation Work
3.0-120 PILOT Excavation(NATM)
3.0-2008 ø3.0 Mucking Process Work
3.0-210 Underground Mucking Process Work
3.0-220 PILOT Underground Mucking Process
3.0-230 Surface Mucking Process Work
3.0-240 PILOT Surface Mucking Process
3.0-300 ø2.6 Support Construction Work
3.0-310 ROCK BOLT Installation
3.0-320 PILOT ROCK BOLT
3.0-330 SHOTCRETE Installation .

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2.2.4. Resource Component Classification

The work classification system is a collection of construction work component classifications (facility component, functional component, work component), completing the work breakdown related to the TBM tunnel construction. Among these, the lowermost commodity work component involves the direct input of resources. Thus, this resource component classification includes the excavation unit cost, mucking process unit cost, support construction unit cost, and lining concrete deposition unit cost for the excavation of sound rock, regular rock, soft rock, and weathered rock

DCODE	DES
Exc-01	ø2.6 TBM Main Line Excavation (sound rock)
Exc-01	ø2.6 TBM Main Line Excavation (regular rock)
Exc-01	ø2.6 TBM Main Line Excavation (soft rock)
Exc-01	ø2.6 TBM Main Line Excavation (weathered rock)
Exc-02	ø2.6 PILOT Excavation(NATM)
Und-01	ø2.6 Underground Mucking Process (sound rock)
Und-01	ø2.6 Underground Mucking Process (regular rock)
Und-01	ø2.6 Underground Mucking Process (soft rock)
Und-01	ø2.6 Underground Mucking Process (weathered rock)
Und-02	ø2.6 PILOT Underground Mucking Process
Und-03	ø2.6 Surface Mucking Transportation (sound rock)
Und-03	ø2.6 Surface Mucking Transportation (regular rock)
Und-03	ø2.6 Surface Mucking Transportation (soft rock)
Und-03	ø2.6 Surface Mucking Transportation (weathered rock)
Und-04	ø2.6 PILOT Surface Mucking Transportation
Roc-01	ø2.6 TBM ROCK BOLT (sound rock)
Roc-01	ø2.6 TBM ROCK BOLT (regular rock)
Roc-01	ø2.6 TBM ROCK BOLT (soft rock)
Roc-01	ø2.6 TBM ROCK BOLT (weathered rock)
Roc-02	ø2.6 PILOT ROCK BOLT
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (sound rock)
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (regular rock)
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (soft rock)
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (weathered rock)
Sho-03	ø2.6 PILOT SHOTCRETE-Light Fiber
Ste-01	ø2.6 TBM STEEL RIB
Ste-02	ø2.6 PILOT STEEL RIB
Rei-01	ø2.6 Reinforcement Method
Lin-01	ø2.6 STEEL FORM Installation and Dismantling
Lin-02	ø2.6 Concrete Underground Transportation
Lin-03	ø2.6 Lining Concrete Deposition
Lin-04	ø2.6 Waterproofing SHEET
Lin-05	ø2.6 BACK FILL GROUTING
Mac-01	ø2.6 Machinery and Electrical Work
Sub-01	ø2.6 Subsidiary Work .

3. Cost Estimation Automation Model

In this study, the information management system comprising the cost estimation automation relational D/B structure shown in Figure 2, which is based on the TBM tunnel construction work information classification system of Section 2, is largely composed of the function division classification and work division classification. Also, each classification automatically connects related information by connecting the major codes to the Key Field. First, the function division classification and work division classification are connected to the relational database of [facility component classification-functional component classification-work component classification-resource component classification] based on the TBM tunnel construction work information classification system described in Section 2. Also, the lowermost classification [resource component classification] of the work information classification system is connected to the [cost estimate code-resource quantity-resource code] through the [cost estimate code] as the medium and to the [resource unit cost] through the [resource code] as the medium. Moreover, when the user inputs the [construction quantity] in the [QUANTITY] resource component classification, the construction cost is calculated automatically by multiplying the R(QUANTITY) with the Unit Cost(COST), and the D/B structure is constructed so that the total construction cost is calculated by aggregating the construction cost for each classification system. First, the function division classification and work division classification are connected to the relational database of [facility component classification-functional component classification-work component classification-resource component classification] based on the TBM tunnel construction work information classification system described in Section 2. Also, the lowermost classification [resource component classification] of the work information classification system is connected to the [cost estimate code-resource quantity-resource code] through the [cost estimate code] as the medium and to the [resource unit cost] through the [resource code] as the medium. Moreover, when the user inputs the [construction quantity] in the [QUANTITY] resource component classification, the construction cost is calculated automatically by multiplying the R(QUANTITY) with the Unit Cost(COST), and the D/B structure is constructed so that the total construction cost is calculated by aggregating the construction cost for each classification system.

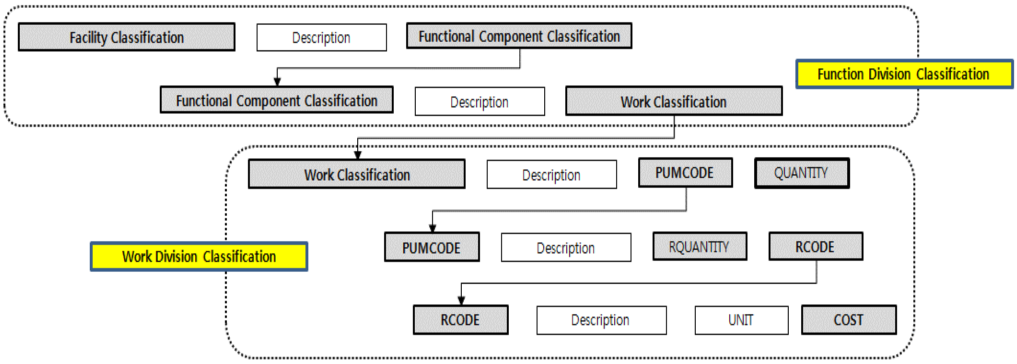

Figure 8. Relational Data Base Structure for Automated Cost Estimating

3.1. Cost Estimation Automation Data Modeling Work Information Classification System Composition

This section presents data modeling based on the cost estimation automation relational D/B structure discussed in the previous section. The cost estimation automation conceptual modeling, which uses the TBM tunnel construction information classification system presented in Figure 1, is composed of the Table 1 Facility Classification (ACODE) D/B, the Table 2 Functional Component Classification (BCODE) D/B, the Table 3 Work Classification (CCODE), the Table 4 Resource Classification (DCODE) D/B, and the Table 5 Unit Price D/B. The commodities within each classification are interconnected from the upper commodity codes to the lower commodity codes through the Key Field. The [ACODE] work commodity of Table 1 is connected to the [BCODE] work commodity of Table 2, and the [BCODE] work commodity is connected to the [CCODE] work commodity of Table 3. The [CCODE] work commodity of Table 3 is connected to the production [PCODE] and construction quantity [QUANTITY] as well as

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being connected to the production quantity [RQUANTITY] through the Table 4 [PCODE] as the medium and to the resource unit cost [COST] of Table 5 through the [RCODE] as the medium, so when the user directly inputs the construction quantity to [QUANTITY] of Table 3, automated cost estimation is carried out for the TBM tunnel construction. Table 1~Table 5 presents the TBM tunnel construction cost estimation automation data modeling using this work information classification system, and Tables 6 and 7 show the results of the automated cost estimation performed by the described process

Table 1. Facility Classification (ACODE) Information Data Base

ACODE	DES	BCODE
2.6-1	**ø2.6 TBM Tunnel Construction**	2.6
2.6-2	ø3.0 TBM Tunnel Construction	
2.6-3	ø3.5 TBM Tunnel Construction	
2.6-4	ø5.0 TBM Tunnel Construction	
2.6-5	ø8.0 TBM Tunnel Construction	

Table 2. Functional Component Classification (BCODE) Information Data Base

BCODE	DES	CCODE1
2.6-10	ø2.6 TBM Excavation Work	**2.6-100**
2.6-20	ø2.6 Mucking Process Work	**2.6-200**
2.6-30	ø2.6 Support Construction Work	**2.6-300**
2.6-40	ø2.6 Lining and Waterproofing Work	**2.6-400**
2.6-50	ø2.6 Machinery and Electrical Work	**2.6-500**
2.6-60	ø2.6 Subsidiary Work	**2.6-600**
3.0-10	ø3.0 TBM Excavation Work	
3.0-20	ø3.0 Mucking Process Work	
3.0-30	ø3.0 Support Construction Work	
3.0-40	ø3.0 Lining and Waterproofing Work	
3.0-50	ø3.0 Machinery and Electrical Work	
3.0-60	ø3.0 Subsidiary Work	

Table 3. Work Classification (CCODE) Information Data Base

CCODE	DES	DCODE	QUANTITY
2.6-100	ø2.6 **TBM Excavation**		
2.6-110	TBM Excavation Work	Exc-01	2,800
2.6-120	PILOT Excavation(NATM)	Exc-02	20
2.6-200	ø2.6 **Underground Mucking Process Work**		
2.6-210	Underground Mucking Process Work	Und-01	2,800
2.6-220	PILOT Underground Mucking Process	Und-02	20
2.6-230	Surface Mucking Process Work	Und-03	2,800
2.6-240	PILOT Surface Mucking Process	Und-04	20
2.6-300	**ø2.6 Support Construction Work**		
2.6-310	ROCK BOLT Installation	Roc-01	2,800
2.6-320	PILOT ROCK BOLT	Roc-02	20
2.6-330	SHOTCRETE Installation	Sho-01	2,800
2.6-340	PILOT SHOTCRETE	Sho-02	20
2.6-350	STEEL RIB Installation	Ste-01	2,800

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2.6-360	PILOT STEEL RIB	Ste-02	20
2.6-370	Reinforcement Method	Rei-01	1
2.6-400	**ø2.6 Lining and Waterproofing Work**		
2.6-410	STEEL FORM Installation and Dismantling	Lin-01	3,000
2.6-420	Concrete Underground Transportation	Lin-02	3,000
2.6-430	Lining Concrete Deposition	Lin-03	3,000
2.6-440	Waterproofing SHEET	Lin-04	3,000
2.6-450	BACK FILL GROUTING	Lin-05	3,000
2.6-500	ø2.6 Machinery and Electrical Work	Mac-01	3,000
2.6-600	ø2.6 Subsidiary Work	Sub-01	3,000

Table 4. Resource Classification (DCODE) Information Data Base

DCODE	DES	RQUANTY	RCODE
Exc-01	ø2.6 TBM Main Line Excavation (sound rock)	2.2600	T001
Exc-01	ø2.6 TBM Main Line Excavation (regular rock)	1.6950	T001
Exc-01	ø2.6 TBM Main Line Excavation (soft rock)	1.1300	T001
Exc-01	ø2.6 TBM Main Line Excavation (weathered rock)	0.5650	T001
Exc-02	ø2.6 PILOT Excavation(NATM)	8.0000	T005
Und-01	ø2.6 Underground Mucking Process (sound rock)	2.2600	T010
Und-01	ø2.6 Underground Mucking Process (regular rock)	1.6950	T010
Und-01	ø2.6 Underground Mucking Process (soft rock)	1.1593	T010
Und-01	ø2.6 Underground Mucking Process (weathered rock)	0.5796	T010
Und-02	ø2.6 PILOT Underground Mucking Process	8.1500	T015
Und-03	ø2.6 Surface Mucking Transportation (sound rock)	2.2600	T020
Und-03	ø2.6 Surface Mucking Transportation (regular rock)	1.6950	T020
Und-03	ø2.6 Surface Mucking Transportation (soft rock)	1.1593	T020
Und-03	ø2.6 Surface Mucking Transportation (weathered rock)	0.5796	T020
Und-04	ø2.6 PILOT Surface Mucking Transportation	8.1500	T025
Roc-01	ø2.6 TBM ROCK BOLT (sound rock)	0.3543	T030
Roc-01	ø2.6 TBM ROCK BOLT (regular rock)	0.3989	T030
Roc-01	ø2.6 TBM ROCK BOLT (soft rock)	0.5321	T030
Roc-01	ø2.6 TBM ROCK BOLT (weathered rock)	0.4654	T030
Roc-02	ø2.6 PILOT ROCK BOLT	3.5000	T035
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (sound rock)	0.0000	T040
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (regular rock)	0.0000	T041
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (soft rock)	0.1668	T042
Sho-01	ø2.6 TBM SHOTCRETE-Light Fiber (weathered rock)	0.0832	T043
Sho-03	ø2.6 PILOT SHOTCRETE-Light Fiber	1.0500	T044
Ste-01	ø2.6 TBM STEEL RIB	0.1329	T065
Ste-02	ø2.6 PILOT STEEL RIB	1.0000	T070
Rei-01	ø2.6 Reinforcement Method	1.0000	T075
Lin-01	ø2.6 STEEL FORM Installation and Dismantling	1.0000	T080
Lin-02	ø2.6 Concrete Underground Transportation	2.1803	T085
Lin-03	ø2.6 Lining Concrete Deposition	2.1803	T090
Lin-04	ø2.6 Waterproofing SHEET	8.1623	T095
Lin-05	ø2.6 BACK FILL GROUTING	2.1803	T100
Mac-01	ø2.6 Machinery and Electrical Work	1.0000	T105
Sub-01	ø2.6 Subsidiary Work	1.0000	T110

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Table 5. Unit Price Item Information Data Base

RCODE	DES	UNIT	COST
T001	ø2.6 Main Line Excavation	M3	120,000
T005	ø2.6 PILOT Excavation	M3	45,000
T010	ø2.6 Underground Mucking Process	M3	45,000
T015	ø2.6 PILOT Underground Mucking Process	M3	40,000
T020	ø2.6 Surface Mucking Transportation	M3	10,000
T025	ø2.6 PILOT Surface Mucking Transportation	M3	10,000
T030	ø2.6 TBM ROCK BOLT	EA	52,000
T035	ø2.6 PILOT ROCK BOLT	EA	48,000
T040	ø2.6 TBM SHOTCRETE (Light Fiber)sound rock	M3	-
T041	ø2.6 TBM SHOTCRETE (Light Fiber) regular rock	M3	-
T042	ø2.6 TBM SHOTCRETE (Light Fiber) soft rock	M3	335,000
T043	ø2.6 TBM SHOTCRETE (Light Fiber) weathered rock	M3	335,000
T044	ø2.6 PILOT SHOTCRETE (Light Fiber)	M3	320,000
T065	ø2.6 TBM STEEL RIB	SET	550,000
T075	ø2.6 Reinforcement Method	Method	200,000,000
T080	ø2.6 STEEL FORM Installation and Dismantling	M	380,000
T085	ø2.6 Concrete Underground Transportation	M	25,000
T090	ø2.6 Lining Concrete Deposition	M3	80,000
T095	ø2.6 Waterproofing SHEET	M2	25,000
T100	ø2.6 BACK FILL GROUTING	Work	150,000
T105	ø2.6 Machinery and Electrical Work	M	480,000
T110	ø2.6 Subsidiary Work	M	480,000

Table 6. Cost Aggregate of Functional Component Classification

WBS	Commodity	Φ2.6m			
		Production	Unit Cost	Quantity	Cost
2.6-10	TBM Excavation	13.65	525,000	11,220	1,905,600,000
2.6-20	Underground Mucking Process	13.8439	220,000	11,220	723,955,000
2.6-20	Surface Mucking Process (L=10KM)	13.8439	50	11,220	161,060,000
2.6-30	Reinforcement Work	8.6836	202,316,000	19,661	914,484,000
2.6-40	Lining and Waterproofing Work	13.7222	666,000	15,000	2,528,680,000
2.6-50	Machinery and Electrical Work	1.0000	730,000	3,000	2,190,000,000
2.6-60	Subsidiary Work	1.0000	480,000	3000	1,440,000,000
Total					9,863,779,000

Table 7. Cost Aggregate of Work Classification

WBS	Commodity	Unit	Φ2.6m			
			Production	Unit Cost	Quantity	Cost
2.6-10	TBM Excavation					
	TBM Excavation(t-1)	㎥	2.2600	120,000	2,800	759,360,000
	TBM Excavation(t-2)	㎥	1.6950	120,000	2,800	569,520,000
	TBM Excavation(t-3)	㎥	1.1300	120,000	2,800	379,680,000
	TBM Excavation(t-4)	㎥	0.5650	120,000	2,800	189,840,000
	PILOT Excavation (NATM)	㎥	8.0000	45,000	20	7,200,000

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Total						**1,905,600,000**
2.6-20	Underground Mucking Process					
21	Underground Mucking Process	㎥	2.2600	45,000	2,800	284,760,000
22	Underground Mucking Process	㎥	1.6950	45,000	2,800	213,570,000
23	Underground Mucking Process	㎥	1.1593	45,000	2,800	146,070,000
24	Underground Mucking Process	㎥	0.5796	45,000	2,800	73,035,000
25	PILOT Underground Mucking Process	㎥	8.1500	40,000	20	6,520,000
Total						**723,955,000**
2.6-20	Surface Mucking Process(L=10KM)					
21	Surface Mucking Process	㎥	2.2600	10,000	2,800	63,280,000
22	Surface Mucking Process	㎥	1.6950	10,000	2,800	47,460,000
23	Surface Mucking Process	㎥	1.1593	10,000	2,800	32,460,000
24	Surface Mucking Process	㎥	0.5796	10,000	2,800	16,230,000
25	PILOT Surface Mucking Process	㎥	8.1500	10,000	20	1,630,000
Total						**161,060,000**
2.6-30	Reinforcement Work					
31	ROCKBOLT Installation					
32	TBM ROCKBOLT	EA	0.3543	52,000	2,800	51,584,000
33	TBM ROCKBOLT	EA	0.3989	52,000	2,800	58,084,000
34	TBM ROCKBOLT	EA	0.5321	52,000	2,800	77,480,000
	TBM ROCKBOLT	EA	0.4654	52,000	2,800	67,756,000
	PILOT ROCKBOLT	EA	3.5000	48,000	20	3,360,000
	SHOTCRETE					
	TBM SHOTCRETE (Steel Fiber)	㎥				
	TBM SHOTCRETE (Steel Fiber)	㎥				
	TBM SHOTCRETE (Steel Fiber)	㎥	0.1668	335,000	2,800	156,445,000
	TBM SHOTCRETE (Steel Fiber)	㎥	0.0832	335,000	2,800	78,055,000
	PILOT SHOTCRETE (Steel Fiber)	㎥	1.0500	320,000	20	6,720,000
	STEEL RIB					
	TBM STEEL RIB	SET	0.1329	550,000	2,800	204,600,000
	PILOT STEEL RIB	SET	1.0000	520,000	20	10,400,000
	Reinforcement Method					
	Reinforcement Method	Method	1.0000	200,000,000	1	200,000,000
Total						**914,484,000**
2.6-40	Lining and Waterproofing Work					
41	STEEL FORM Installation and Dismantling	M	1.0000	380,000	3,000	1,140,000,000
42	CON'C Underground Transportation	㎥	2.1803	25,000	3,000	163,525,000
43	LINING CON'C	㎥	2.1803	80,000	3,000	523,280,000

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	Deposition					
44	Waterproofing SHEET	㎡	8.1623	25,000	3,000	612,175,000
45	BACKFILL GROUTING	Work	0.1993	150,000	3,000	89,700,000
Total						**2,528,680,000**
2.6-50	Machinery and Electrical Work		1.0000	730,000	3,000	2,190,000,000
Total						2,190,000,000
2.6-60	Subsidiary Work		1.0000	480,000	3000	1,440,000,000
Total						1,440,000,000
Net Total						**9,863,779,000**

3.2. Preliminary Construction Cost Prediction Formula Model According to the TBM Diameter

The direct construction cost prediction formula model was obtained using spreadsheets based on the construction cost data per TBM diameter of Table.7, analyzed in the previous section, and the result is shown in Table. 9. In order to verify the validity of the regression analysis equations, the construction cost per m obtained from the regression analysis result of the subsidiary work construction cost in Table 8, and the construction cost per m of Table. 7 are compared and the result is shown in Table. 9. Analysis of Table. 9 showed that a deviation existed in the construction cost of 10,000 Korean Won, and taking into consideration the construction cost of a TBM tunnel construction, this deviation of 10,000 Won was determined to be negligible. So the regression analysis equations presented in this study were determined to be very reliable. The regression analysis equations for the remaining commodities showed correlation coefficients above $R^2 = 0.9210$, demonstrating their high reliability.

Table 8. Regression Analysis and Correlation Coefficient for Each TBM Tunnel Construction Commodity

Commodity	Regression Analysis Equation	Correlation Coefficient
TBM Excavation Work	$y = 411998x - 558579$	$R^2 = 0.9867$
Underground Mucking Process Work	$y = 136323x - 100412$	$R^2 = 0.9799$
Surface Mucking Process(L=10KM)	$y = 84750x - 189509$	$R^2 = 0.9835$
Reinforcement Work	$y = 134036x - 793420$	$R^2 = 0.9710$
Lining and Waterproofing Work	$y = 264185x + 178680$	$R^2 = 0.9993$
Machinery and Electrical Work	$y = 71099x + 563743$	$R^2 = 0.9210$
Subsidiary Work	$y = 38359x + 376454$	$R^2 = 0.9902$
Indirect Construction Cost	$y = 376375x + 620580$	$R^2 = 0.9986$
Total Construction Cost	$y = 2E+06x + 274471$	$R^2 = 0.9986$

Table 9. Comparison of the Subsidiary Work and Regression Analysis Derived Construction Costs

Category	Construction Cost				
	ø2.6m	ø3.0m	ø3.5m	ø5.0m	ø8.0m
Subsidiary Work	476,187	491,531	510,711	568,249	683,326
Regression Analysis Result	480,000	490,000	500,000	580,000	680,000
Deviation	-3,813	+1,531	+10,711	-11,751	+3,326

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4. Conclusion

In this study, an operating system utilizing a new cost estimation system was presented to replace the inefficiencies of computer applications in existing cost estimation systems, which lack a standard work information classification system. The main contents of the study are as follows.(1) A work information classification system for TBM tunnel construction was presented, which applied classifications of facility-structural component-work-resource, along with a structure that connects the work information classification system, production information, and resource information into a relational database.(2) An automation model was systematically presented based on the cost estimation automation database structure, and the cost estimation automation model concept was established. In this study, the presented TBM tunnel construction cost estimation automation model maximized computer operation tasks by implementing a knowledge-based process expressed by a relational database between the work information classification system, production information, and resource information. The new approach was demonstrated to be superior to existing systems which require the operator to directly input all information relating to the cost estimation.

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