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USING FACTOR ANALYSIS TO ASSESS ROUTE CONSTRUCTION PRIORITY FOR COMMON DUCT NETWORK IN TAIWAN

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Key words: common duct, route construction priority, pipelines.

ABSTRACT

This study identifies the critical variables for determining route construction priorities (RCP) in a common duct network (CDN) using expert interviews and questionnaire surveys. Statistical analysis is also conducted to check the validation and verification of the survey results. Furthermore, factor analysis is employed to derive 24 priority determinant variables and classify them into five groups, including utility agency, traffic condition, local government, infrastructure project, and site condition. The paired comparison method is then employed to determine the weightings of the five groups. It is found that the utility agency is the most important factor while the site condition is the least important one in determining RCP for a CDN. An assessment model for ranking the RCP in a CDN is developed. A six-route CDN in northern Taiwan is analyzed using the proposed model, with multiple viewpoints being considered to ensure the objectivity of the analytical results.

I. INTRODUCTION

The human population is supported by various types of life-lines, including power, electricity, water supply, gas, and sewerage, all closely link to civilians. Lifelines generally have three forms, including underground, ground, and overpass. Traditionally, most city lifelines were built either underground or on the ground. To handle the growing demands of these lifelines, construction work was regularly required to fix, expand, or maintain these existing lines. Many types of construction, such as pipeline maintenance, expansion and tearing down, require frequent excavation of roadways and pavements (Beach *et al.* [3], Huang [13]). Consequently, the living environments are impacted by the traffic jams, dusts, noises, and air pollutions, and the social cost is significantly increased. Building common ducts (CDs) to contain various lifelines has been adopted as a new approach to reduce construction work and the associated public impact.

CD, which can be built either above the ground surface or underground, illustrated in Figs. 1 and 2, contains piping and wires for multiple sorts of public utilities, including electricity, water, gas, sewage, communication (also for military and police use), oil, gas, CATV (cable television or community antenna television), street lighting, traffic signs, and relevant surveillance and detection systems (common duct [6]).

Common duct can improve the living quality of cities and villages, integrate public utilities, avoid the need to excavate roadways and thus prolong their lives, and maintain traffic safety and urban appearance (as shown in Fig. 3).

Building a common duct network is extremely costly because the construction size of a CDN is much bigger than that of an ordinary project. Additionally various complex and interacting factors also need to be considered. In reality, a CDN is constructed in distinct phases rather than in a single phase because of budgetary limitations and other factors such as the environmental and traffic impacts. The decision to implement a route in a CDN cannot be made by individuals or any single agency. Efficiently determining CDN route construction priority has become a key issue for the authorities.

II. LITERATURE REVIEW

Currently, only a few studies focus on the route priority setting in a CDN. However, there are some related studies on route map in highway, high-speed rail line, pipelines, etc. Various papers (in Chinese) related to CD disaster mitigation, utility pipelines, and GIS application can be located at the website (w3.cpami.gov.tw).

Wang [28] integrated DAHP, TOPSIS and Satisfaction Analysis to develop an MCDM-based construction priority evaluation model for a CD selected-network. The model included four weighted indexes: construction and maintenance costs (0.167), needs of ducts (0.223), frequency of duct-construction (0.339) and standard roadway services (0.271). Wang concluded that routes with frequent pipeline excavation should receive the highest construction priority. Hue (2005) applied several tools, such as Delphi AHP and TOPSIS, to set construction priority for CDNs in Taiwan's urban areas. The model consists of four layers including: construction and

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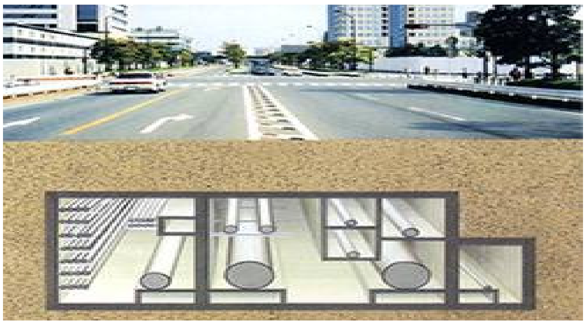


Fig. 1. Pipeline arrangement in a CD.

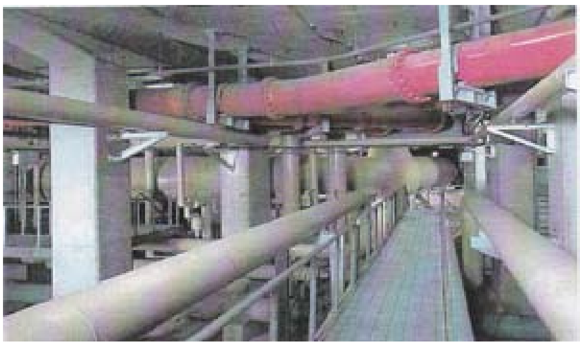


Fig. 2. Pipeline layout in a CD.

Fig. 3. Roadway conditions before/after CD construction (common duct [6]).

maintenance costs (0.167), demands of ducts (0.223), frequency of duct construction (0.339), and standard of road services (0.271). Yao *et al.* [31] introduced the major issues in planning and design of CD system in a city. In their opinions, the network, reserved space, and structure of CD system should be carefully assessed in planning stage with the forecast of city development. Hsu and Chen [12] applied cost-benefit method to analyze the expenditure-shearing of CD. In addition, relative principles of constructing the expenditure-shearing were developed as well. T.Y. Lin International Taiwan [15] also used cost-benefit method to analyze the feasibility of converting routes into CD construction. Yang, *et al.* [30] proposed a model for analyzing the cost-benefit ratio of sewer sub-systems. Brainstorm meetings were carried out to collect related data. An expert survey was conducted by questionnaire to weight each sub-criterion in the five-level AHP model. The proposed model established sewer system rehabilitation priorities by considering budget limitations. The model was applied to the 9th re-planning district in Taichung City, Taiwan. The model was found effective for assisting decision-makers in sewer system rehabilitation.

Amrou *et al.* [1] analyzed the available routes for a 16-inch ductile iron pipe water transmission main route to nearly completed 600 homes. This analysis provided an optimal water transmission main route that had the least impact on cost and schedule and was most favorable when factoring all conditions. Marwa and Kimaro [20] report the use of geomorphologic mapping to obtain a better understanding of the terrain for a dam access road in Tanzania. The research concluded that geomorphologic mapping is a useful tool in selecting the optimum route and appropriate construction method. Anto and Grau [2] used the multi-criteria decision-making methods ELECTRE-I and AHP to a layout alternatives decision for a new high-speed train line in Spain. It is concluded the research results with both multi-criteria decision-making methods in agreement with the official selection.

Catbagan and Regidor [4] developed a system that provides a means for efficient drawing conversion and data manipulation for highway location and route selection. The system was found to be effective in evaluating and comparing results given different alignment schemes, based on the two test cases presented. Ryan [1] developed a versatile route selection procedure that provides an analysis tool to help organize and evaluate many influencing factors and resources available to the planning team. The route selection process has been used successfully on a variety of both sanitary sewer and water system pipelines through the western United States. Wang *et al.* [28] conducted an engineering investigation of long-distance oil and gas pipelines. They found that the flat landform is the first choice in route alignment, and the order of route selection should be pre-choosing, investigation, optimization and adjustment.

Hromadka and Yen [11] developed a computer program for prioritizing future flood control projects in a city master plan. The Cost-to-Benefit Index (CBI) method was used to analyze information regarding master plan prioritization of flood control system elements targeted for improvement. The CBI approach was used to decide which system elements should have the highest priority in construction scheduling. Maps were also employed to graphically illustrate the relative importance of any particular element with respect to the overall master plan. Costa and Oliveira [7] developed a priority assignment model to analyze and evaluate decisions on which a sub-set of potential actions would be taken for a large Lisbon housing tract requiring maintenance, repair and refurbishment. The MACBETH approach was extensively used to derive the value functions associated with each criterion and their respective weights, thus reflecting both municipal policies and the preferences and attitudes of officials. The developed model included aspects such as cost reduction, action coherence and urban environment impact synergies.

Based on the above literature, it is concluded that there is hardly any integrated assessment of the determination of RCP in a CDN currently and thus the appropriate routes may not be selected. Particularly, assessing the weights of route priority determinant variables depends upon various natural and human conditions. Various wide-ranging factors are complicated and difficult to quantify (Ling [17]). All the above factors contribute to the difficulty of setting the RCP for a CDN. To solve the above problems, this study attempts to improve the RCP of a CDN in terms of its decision making value by establishing a practical prioritization model that considers factors and issues which government officials must consider before making decisions.

III. MODEL BUILDING

A model has been developed for the priority setting process to connect the factors identified via a questionnaire survey. Based on agreed criteria among CD professionals, the proposed model will reduce the subjectivity that has been a prominent feature of RCP decisions in Taiwan. The development of the proposed model comprises four main steps: 1) develop a list of nominated priority determinant variables (NPDVs); 2) identify the primary priority determinant variables (PDVs) and classify them into priority determinant groups (PDGs); 3) assign weights to PDGs and PDVs; and 4) use the proposed model to determine the RCP of an actual CDN located in northern Taiwan. For the model development, this study conducted a two-stage questionnaire survey to gather research data. The sample population includes two groups of professionals with sufficient knowledge of CD: 1) authority/design engineers, and 2) contractors/pipeline-firm engineers.

1. Determining PDGs and PDVs

A list of 32 draft NPDVs (DNPDVs) of PRC were developed based on an extensive literature review mainly including domestic researches such as T.Y. Lin International Taiwan [16], Guo *et al.* [9], Song and Huang [25], Su and Wang [26], Zhuang *et al.* [32], and Liou [18], etc. The list of DNPDVs was then reviewed by three experienced CD experts (a manager of a CD design department, a CD construction project manager, and a professor specialized in CD) in Taiwan. Twenty seven NPDVs were concluded and suggested by these experts. In order to extract PDVs from the 27 NPDVs, the stage-one questionnaire was developed and distributed to CD related practitioners in Taiwan. The questionnaire respondents were asked to rate the importance of each NPDV in relation to the RCP setting of a CDN using a 5-point Likert scale where 5 indicates extremely important and 1 indicats extremely unimportant. To ensure consistency in responses, each item was also briefly described. The questionnaire respondents were asked to rate the importance of each NPDV in relation to the RCP setting of a CDN using a 5-point Likert scale where 5 indicates extremely important and 1 indicats extremely unimportant. To ensure consistency in responses, each item was also briefly described.

The sample population used for the stage-one questionnaire survey was limited to 80 CD related practitioners in Taiwan. Each member of the sample population was mailed a copy of the stage-one self-administered questionnaire. The questionnaire was distributed via mail owing to the relatively low cost and the fact that this method enabled the respondents to complete the questionnaire at their leisure (Fowler [8]). Sixty-five respondents completed and returned the questionnaires, representing a response rate of 81.25%. Compared with other similar surveys on the Taiwanese construction industry, this response rate was reasonable. Among the 65 returned questionnaires, seven were ruled invalid and discarded. Of the 58 valid returned questionnaires, 31 were from authority/design engineers and 27 from contractors/pipeline-firm engineers.

The Student t-test was performed to clarify whether the opinions of authority/design engineers and contractors/pipeline-firm engineers were the same for each NPDV. A probability value (p) ranging between 0.05 and 0.95 indicats a large difference of the opinions between the two groups (Norusis [21], Chen and Chen [5]). In and between 0.05 and 0.95, the p values of the t-test being ranged from 0.067 to 0.65 indicate a consensus of the opinions among authority/design engineers and contractors/pipeline-firm engineers. Consequently, the collected sample was considered valid.

Factor analysis can be used to test a hypothesis or to identify constructs within a group of variables (Hair *et al.* [10]). Factor analysis comprises a series of methods used to identify groups of related variables, and thus it is ideal for reducing numerous variables to yield a more easily understood framework (Norusis [21]; Shen and Liu [24]). Factor analysis focuses on a data matrix produced by collecting a number of individual cases or respondents. According to Trost and Oberlender [27], the fit for factor analysis is optimized when the number of variables is between 20 and 50. Factor analysis thus was applied to extract the primary PDVs from the 27 NPDVs listed in the stage-one questionnaire.

The first stage of the factor analysis determines the strength of the relationships among the variables, namely, the 27 NPDVs, measured using the correction coefficients for each pair of variables. The Bartlett's test of sphericity is 1227, and the associated level of significance is 0.000, indicating that the population correlation matrix is not an identity matrix. The value of the Kaiser-Meyer-Olkin (KMO) measure of sampling accuracy is 0.6484, which is much higher than 0.5 and thus is considered acceptable. The test results indicated that the sample data was suitable for factor analysis.

According to Hair *et al.* [10], the Direct Oblique Method should be employed to rotate analyzing factors in the absence of evidence that the factors are independent. Table 1 shows that

Table 1. Group matrix after Direct Oblique Method rotation.

Priority determinant variables	Group 1	Group 2	Group 3	Group 4	Group 5
PDV5	0.9169				
PDV2	0.9128				
PDV6	0.7850				
PDV4	0.7531				
PDV3	0.7369				
PDV7	0.6557				
PDV1	0.5779				
PDV13		0.9153			
PDV14		0.8760			
PDV10		0.8149			
PDV11		0.7141			
PDV12		0.7083			
PDV15			0.9220		
PDV18			0.9174		
PDV16			0.8863		
PDV17			0.7962		
PDV22				0.9381	
PDV23				0.9203	
PDV20				0.8025	
PDV21				0.5532	
PDV26					0.9475
PDV24					0.9393
PDV27					0.9278
PDV25					0.8782
Cumulative percentage of variance	22.0430	46.7200	58.0530	63.6120	34.1630
Cronbach's α	88.07	90.80	83.63	87.16	94.46

Table 2. List of PDGs and PDVs for the RCP of a CDN.

PDGs	PDVs
Utility agency (Group 1)	DV1 Collaboration of the high-voltage electricity agency
	DV2 Collaboration of the low-voltage electricity agency
	DV3 Collaboration of the communication agency
	DV4 Collaboration of the water supply agency
	DV5 Collaboration of the gas agency
	DV6 Collaboration of the sewage agency
	DV7 Collaboration of the oil supply agency
Traffic condition (Group 2)	DV10 Traffic congestion during particular holidays
	DV11 Route geology
	DV12 Extensive roadway needs in the near future
	DV13 Long term traffic congestion
	DV14 Traffic congestion during rush hours
Local government (Group 3)	DV15 Desire to build the CD of local government authority
	DV16 Corporation of the head of a subdivision of a city district
	DV17 Corporation from engineers in charge of the CD project
	DV18 Corporation of the comptrollers
Infrastructure project (Group 4)	DV20 Correlation with the construction of rapid transit system
	DV21 Correlation with the construction of High Speed Railway
	DV22 Correlation with the construction within a re-developed zone
	DV23 Correlation with the construction of highway projects
Site condition (Group 5)	DV24 Complexity of existing underground pipelines
	DV25 Difficulty in performing construction work
	DV26 Aged pavement with poor condition on existing roadways
	DV27 Local residents supporting the CD project

five groups (containing 24 PDVs) with eigenvalues exceeding 1 are extracted using the Principal Component Analysis Method. Each of the PDVs weighs heavily for only one of the groups, given a loading exceeding 0.5. Every α in the five groups significantly exceeds the minimum acceptable standard (70%) proposed by Hair *et al*. [10].

This study thus concluded that the analysis is highly reliable. The five PDGs could explain up to 63.61% of the total variance and are considered acceptable. The five groups labeled in accordance with the attributes of PDVs under them become the aspects of the evaluation model. From Table 2, the five groups are labeled utility agency, traffic condition, local government, infrastructure project, and site condition, respectively.

2. Analyzing PDGs

As discussed previously, the PDV list is extracted from twenty-seven NPDVs in accordance with opinions collected via the stage-one questionnaire survey. The 24 PDVs are extracted by Factor Analysis. The PDVs are discussed in Table 2.

1) Utility agency

An understanding of the benefits of building a CD is crucial, particularly to the authorities. The sharing of construction cost by the related authorities is another key factor that affects the incorporation desire of building a CD for authority officials. It is necessary to know the desires of the authorities in terms of setting the RCP in a CDN.

2) Traffic condition

Roadways with heavy traffic flows significantly impact the urgency of building a CD and thus influence construction priority, especially for roadways with significant congestion problems. Since roadway widening or pipeline maintenance requires excavation of existing pavement and thus worsens traffic conditions, it can sometimes have a significant regional economic impact. Therefore, variables related to traffic condition require to be considered when prioritizing route construction in a CDN.

CD is confined to route geometry of the roadway, and is apt to cause serious traffic jams in the initial stage of the construction. The geology of Taiwan is characterized by complicated landforms. Construction disasters resulting from poor ecological conditions occasionally occur, thereby influencing the schedule and safety of construction projects. Geological conditions requiring additional maintenance work may further disrupt traffic along the CD route. Therefore, geological conditions should be carefully considered when setting RCP.

The significant expansion in the roadway system needed in the near future is designated PDV12. Since utility pipelines often coexist with roadways in Taiwan, the extensive expansion of the roadway system in the near future will also require extension of utility pipelines. If these pipelines are not contained in a CD, the same problems will arise, such as the poor traffic conditions caused by excavation needed for underground pipeline maintenance. Therefore, "extensive roadway needs in the near future" (PDV 12) should be carefully considered when setting RCP.

3) Local government

Via legislation and releasing resources, both local government and regional councils significantly influence CD construction priority. Local government can use its administrative resources to implement CD construction. Through legislation, local councils are able to require the administrative organizations to propose a budget for CD construction. The attitude of the authorities regarding CD construction, and of related departments such as the audit and comptroller departments, all impact the prioritizing of CD construction.

For setting RCP of CD projects, PDV16, PDV17, and PDV18 are primary considerations. Generally, a CDN may cover a large area of a city and may affect local residents living in the CDN. Opinions of local residents regarding CDN construction should be addressed by the city district subdivision head. Thus, the cooperation of the subdivision head is essential for assessing RCP. A CDN construction project involves many utility agencies. Engineers representing those agencies must coordinate effectively. Cooperation with CD project managing engineers is an important factor for assessing RCP. The construction budget for a CDN may be high, and its account titles may be complicated. Thus, the accounting department of government agency should ensure CDN construction efficiency. Effective comptroller cooperation has become one of the most important factors in a successful CD project.

4) Infrastructure project

There are benefits for a CD to cooperate with various other infrastructure projects, including reducing excavation frequency, reducing maintenance expenditure, simplifying maintenance conditions, improving traffic condition, and maintaining city landscape through projects. Thus it is better to incorporate the planning and construction of infrastructure projects into the CDN. That is why many CDNs in Taiwan cooperate with other infrastructure projects, such as the Keelung river CDN project, the Taipei east-west expressway CDN project, the CDN project in Chiayi city, and the station zones of high-speed railway in Hsinchu, Taichung, Chiayi and Tainan cities.

5) Site condition

There are numerous and complicated public pipeline systems below the roadway. These pipeline systems may be damaged by landslides or soft ground. As a result, maintenance department will need to excavate the pavement to fix the broken pipelines. Variable PDV24, complexity of existing underground pipelines, concerns various existing underground utility pipes such as oil pipes, gas pipes and CTAV. This variable excludes macro transportation systems such as underground railways, mass transportation systems and high speed rail. Variable PDV25 (difficult performing construction work), however, includes various existing structures in area surrounding the site (e.g., overpass bridges, underground railways, mass transportation systems, high speed rail) and access to the construction site.

When the construction of pipelines is confined because of the area excavation, the operation and development of the pipeline system may be limited, and thus influence residents' livelihood and the local economic activities as well. The locations of the relaying facilities, such as transformer substation and telecommunications exchange station, should be carefully planned at the same time for each CDN. Moreover, the damage to existing roadways, and the incorporation of local residents strongly impact the implementation of CD construction. These factors should be considered seriously when assessing route construction priority in a CDN.

3. Weighing PDVs and PDGs

A stage-two questionnaire was designed to determine the relative weightings of the five PDGs. The paired comparison method, using a nine point scale, is used to measure the relative importance of PDGs (shown in Appendix B). Each of the five PDGs was compared with each of the other PDGs based on the preferences identified by the questionnaire respondents. The relative weight of one PDG compared to another can range from being extremely significant (5:1) to extremely insignificant (1:5). For example, if the utility agency is three times more important than the traffic condition, a "√" was placed in column "3:1" in the row for "utility agency - traffic condition". Similarly if the utility agency has equal importance to the local government, a "√" was placed in the column "1:1" in the row for "utility agency - local government".

The stage-two questionnaire was sent to the 110 individuals. All of these individuals had also received the stage-one questionnaire. Seventy-five completed questionnaires returned, representing a 68.18% return rate. A consistency test (homogeneity of fit) was applied to validate the 75 stage-two questionnaires. According to Saaty and Vargas [23], the consistency ratio (CR) of each returned questionnaire was calculated with questionnaires with CR values ≤ 0.1 being considered valid.

A total of 59 returned questionnaires (78.76%) passed the consistency test, and thus were considered valid. PDG weights were obtained by averaging the item scores of the 59 valid questionnaires. The relative weights of the five groups (utility

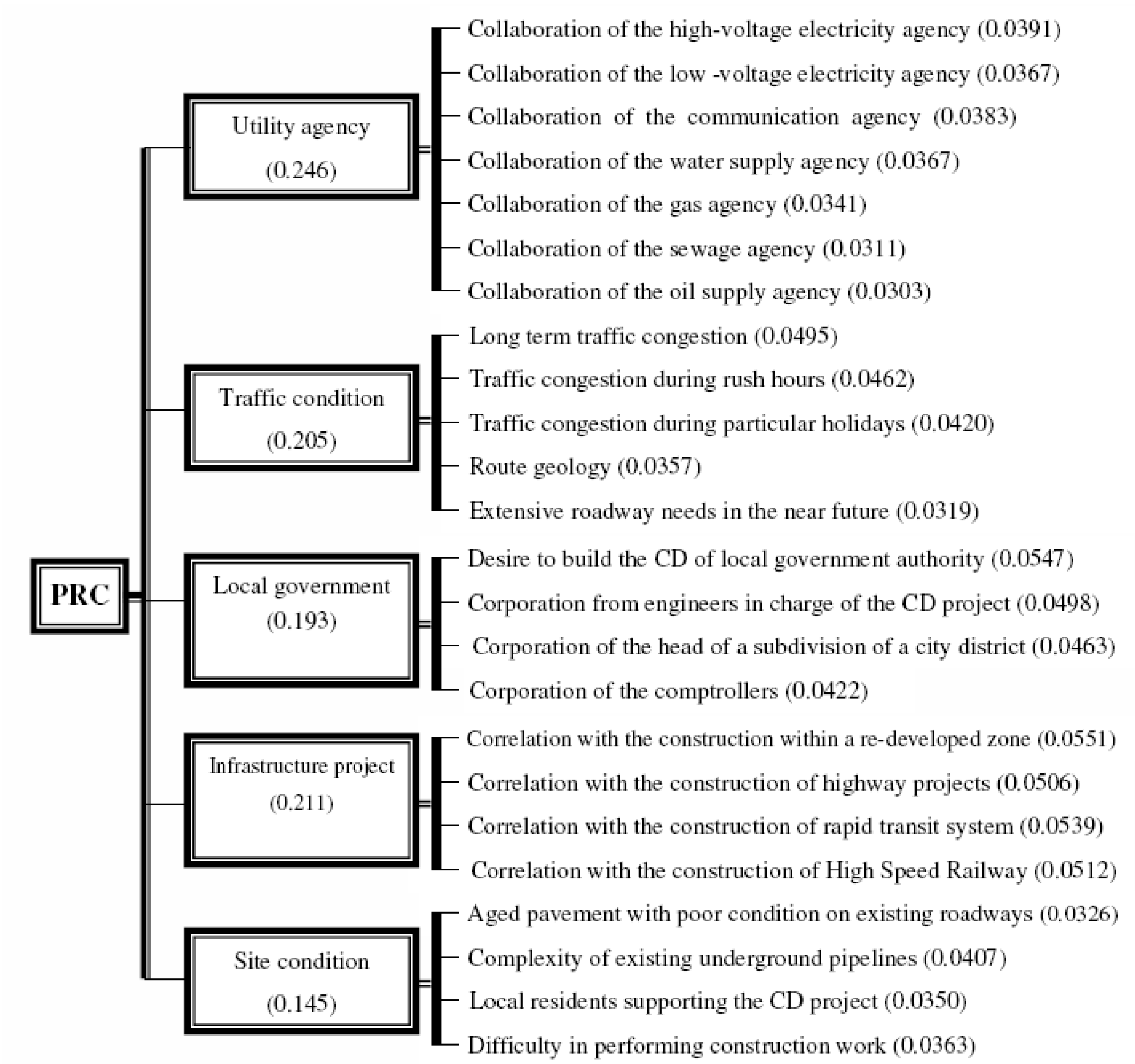


Fig. 4 Scheme of the proposed model.

agency, traffic condition, local government, infrastructure project, site condition) are 0.246:0.205:0.193:0.211:0.145. The relative weightings of PDVs were calculated using Simple Weight Average Method (SWAM) based on the stage-one 58 valid returned questionnaires.

This study concludes that decision makers mainly consider the collaboration among the pipeline agency, traffic condition, and corresponding infrastructure projects along each route when assessing RCP in a CDN. For further discussion, "PDGs" and "PDVs" are changed to "Aspects" and "Evaluation Items" respectively. Fig. 4 shows the complete scheme of the proposed model.

4. Procedure of Using the Assessment Model to Set RCP

This research proposed an assessment model for setting the RCP in a CDN. The procedure of carrying out the RCP is shown in Fig. 5. When using the proposed assessment model, steps 2-5 should be repeated until all routes have been assessed, and the results should be listed in the RCP summary table as shown in Table 3.

1) Collect background information of the routes

Background information of the routes will assist the assessment team to understand the condition of the routes, and thus improve the accuracy of the assessment results. The collected information should include width of existing roadway, up-to-date pavement restoration, budget costs, distribution of budget costs, frequency of pavement excavation, number and types of pipelines accommodated, and etc.

2) Rate IOF

Each evaluation item in the RCP assessment table is rated in terms of its intensity of favorite (IOF) of RCP on a five-point scale (Score of Favorite; SOF) ranging from "5" to "1". A SOF of "5" means "favorable" while "1" means "unfavorable".

3) Calculate SOI

The concept of SWAM is applied to calculate Score of Item (SOI), where SOI is calculated from (1).

$$SOI = SOF * WOI \tag{1}$$

where: SOF = Score of Favorable, WOI = Weight of Item.

Table 3. Steps and corresponding results for setting the RCP of the six routes.

Steps	Corresponding results shown in Tables
Gather routes background information	Table 4
Rate IOF	Appendix C and D
Calculate SOI	Appendix E
Calculate SOA	Appendix E
Calculate ROS	Appendix E
Prioritize routes construction	Table 5

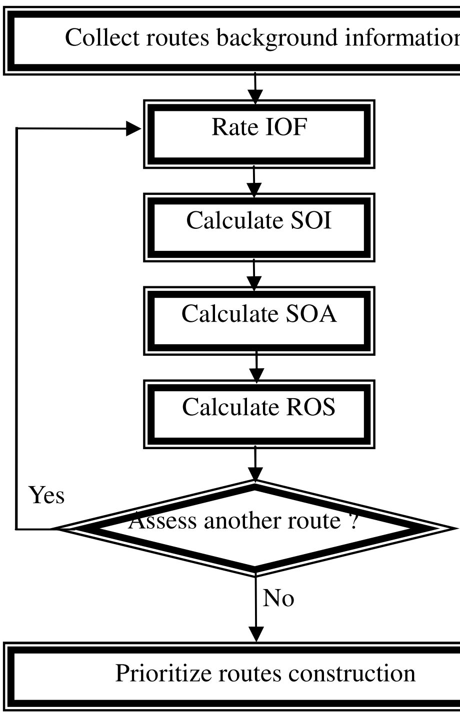


Fig. 5. Procedure of ranking the RCP in a CDN.

4) Calculate SOA

Raw Score of Aspect (RSOA) and Score of Aspect (SOA) can be calculated from (2), and (3), respectively. The weights of aspect, obtained by paired comparison method, are introduced to compute SOA.

$$RSOA = \Sigma(SOI)*(WOI)/5 \qquad (2)$$

$$SOA = WOA * RSOA \qquad (3)$$

Where: SOI = Score of Item, WOI = Weight of Item, WOA = Weight of Aspect.

5) Calculate ROS

Route Overall Score (ROS) is calculated to express the RCP. ROS can be obtained by utilizing (4).

$$ROS = SOA_{UA}+SOA_{IP}+SOA_{TC}+SOA_{LG}+SOA_{SC} \qquad (4)$$

Where: SOA = Score of Aspect.

6) Prioritize routes construction

Compare and analyze ROS of each route. Recommend the priority of route construction with integrated consideration of the situation of each route.

IV. APPLICATION OF THE PROPOSED MODEL

To demonstrate the developed model, this study analyzes and ranks the RCP of a six-route CDN located in northern Taiwan. The design team members of the assessment work. Since CDN plans are not decided by single authority, the assessment team needs to integrate the opinions of various CD related authorities to obtain a subjective and practical RCP assessment results. The assessment team should follow the procedure outlined in Fig. 5 and the corresponding results are shown in Table 3. Additionally, evaluators using the proposed assessment model should be aware that the bigger the impact of a particular PDV, the higher the IOF of that particular PDV. In PDV10 for example, because roadway pavement excavation necessary for repair or maintaining of existing pipelines will worsen already severe traffic congestion, building a CD significantly decreases the need for pavement excavation and thus minimizes traffic congestion. In other words, building a CD for a route characterized by heavy traffic congestion is necessary to improve traffic flow. As Appendix C illustrates, since all five routes face long term traffic congestion problems, the IOFs of long term traffic congestion for the five routes are rated 5, the highest rating.

The basic information of the routes in this particular CDN is listed in Table 4. The circumstances of all six routes are clearly similar. All six routes are located in the areas with high population density. The widths of the CDs are limited mainly because the existing roadways only have a width of 8-15 meters. To accommodate the above limitations, the CDs in most routes are designed to contain various cables. Considering the significant functional and structural differences between Main Duct and Cable Trench, including traffic impact of construction, work loading, and underground location, route 06 is excluded, and the remaining five routes are evaluated. Fig. 6 displays the cross-section of Route 06 while Fig. 7 presents the cross-section of the other five routes.

The assessment results were summarized in Table 5. Fig. 8 compares the assessment scores of the five routes. Fig. 9 displays the overall performance of the five routes from five aspects. The analysis of Table 5 reveals that aspect scores were evenly spread from approximately 71 to 82. Routes 02 and 03 all have overall scores of around 82, while routes 01 and 04 have scores of around 77. Route 05 had the lowest overall score of 71.76, and thus was the least favored among the five routes. Furthermore, route 03 had the highest construction priority while route 05 had the lowest. Fig. 10 shows that route 02 performed well in most aspects compared to the other five routes. For the present case, the authorities of the CDN may consider routes with the overall scores around 82. Therefore, route 03 is the preferred choice for a single route for the present CDN.

Table 4. Background information for various routes in the CDN.

Items\Routes	Route 01	Route 02	Route 03	Route 04	Route 05	Route 06
Width of existing roadway (m)	20	11	12~25	16	16	8~18
Up-to-date pavement restoration	Excavation (water agency)	Excavation (electricity agency)	Excavation (water agency)	Excavation (water agency)	Excavation (com-munication agency)	Excavation (electricity agency)
Estimated Budget costs (USD)	4.69 million	6.25 million	7.81 million	6.25 million	6.25 million	6.25 million
Distribution of budgeted costs	Proportion of pipelines	Proportion of pipelines	Proportion of pipelines	Proportion of pipelines	Proportion of pipe-lines	Proportion of pipelines
Frequency of pavement excavation	High	High	High	High	High	High
Number and types of pipelines accommodated	Cable trench	Cable trench	Cable trench	Cable trench	Cable trench	Main duct + Cable trench

Table 5. Route scores breakdown of the assessing CDN.

Routes \ aspects	Utility agency (SOA) (RSOA)	Traffic condition (SOA) (RSOA)	Local government (SOA) (RSOA)	Infrastructure project (SOA) (RSOA)	Site condition (SOA) (RSOA)	Route overall score (100%)	RCP
Route 01	0.1722 69.94	0.1821 88.71	0.1343 69.54	0.1998 (94.78	0.0854 59.02	77.38	3
Route 02	0.1934 78.53	0.1918 93.41	0.1435 74.33	0.1702 80.74	0.1141 78.88	81.30	2
Route 03	0.2207 89.64	0.1905 92.80	0.1435 74.33	0.1594 75.63	0.1073 74.18	82.14	1
Route 04	0.1990 80.80	0.1438 70.70	0.1258 65.17	0.1789 84.86	0.1236 85.44	77.11	4
Route 05	0.1996 81.06	0.1232 60.00	0.1460 75.63	0.1266 60.04	0.1222 84.51	71.76	5

Note: $WOA_{UA:TC:LG:IP:SC}$ = 0.246 : 0.205 : 0.193 : 0.211 : 0.145

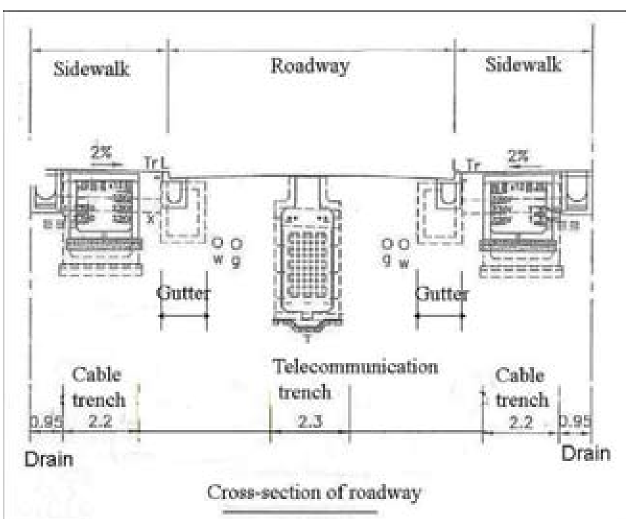


Fig. 6. Cross-section of the roadway for route 06. (T.Y. Lin International Taiwan [15])

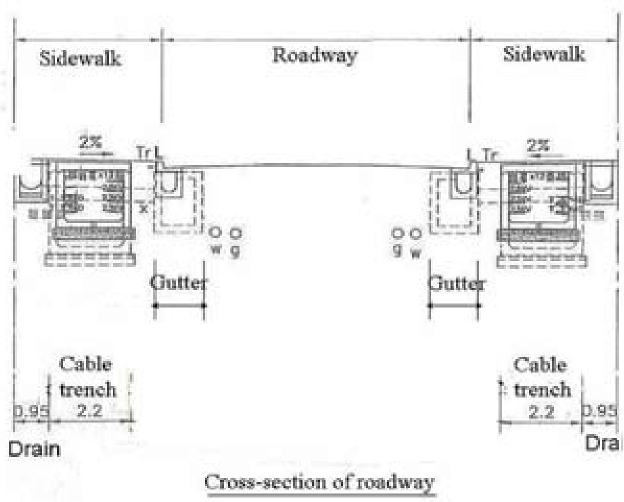


Fig. 7. Cross-section of the roadway for routes 01-05. (T.Y. Lin International Taiwan [15])

V. CONCLUSIONS

This study determines the critical variances for prioritizing route construction in a CDN based on expert interviews and questionnaire surveys. Factor analysis, paired comparison, and SWAM are employed to analyze the questionnaire data. An evaluation model is designed to assess and rank RCP in a CDN. The developed model is then applied to set the RCP of a six-route CDN located in northern Taiwan.

The assessment results of the proposed model can provide decision makers with an aid-based tool for prioritizing route construction. The approach used to build the proposed model

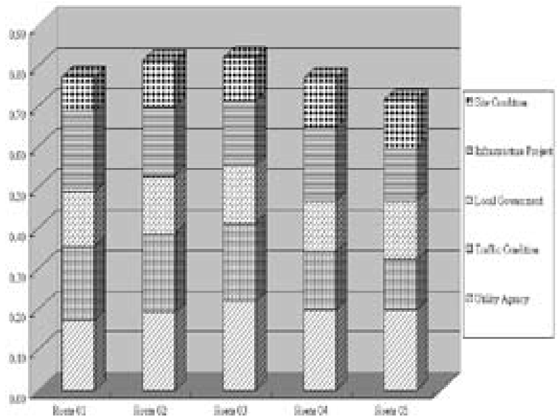


Fig. 8. Route-based total scores of the cumulated bar chart.

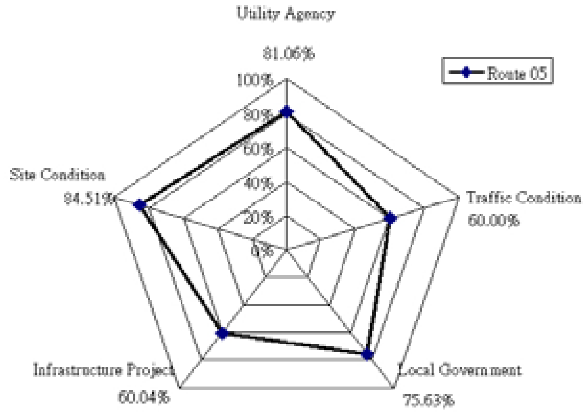
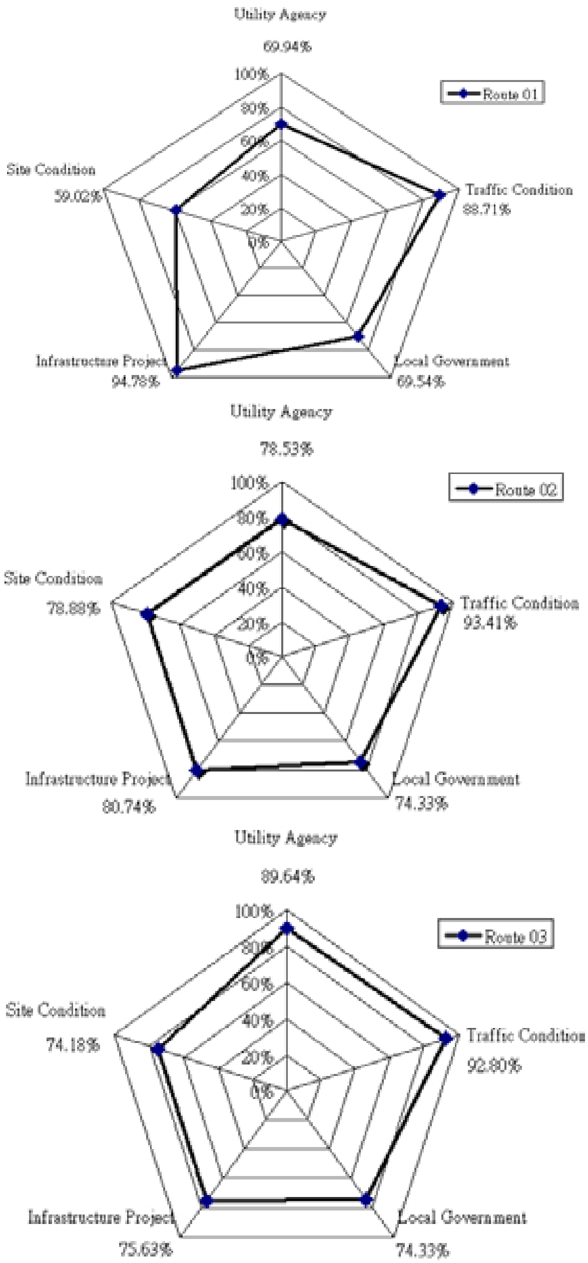


Fig. 9. Radar chart of each aspect for five routes.



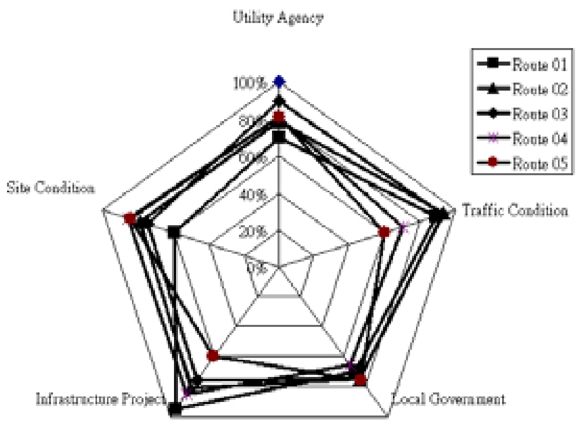


Fig. 10. Comparison of the aspect performance of the five routes.

can be applied to other fields to establish similar evaluation models. The findings of this study and suggestions regarding future research directions are as follows:

1. Various complex and interactive variables must be considered when prioritizing CDN route construction, and decisions regarding the implementation of such a plan cannot be made by any individual or single agency. Consequently, it is highly desirable to develop a systemic approach to gather various viewpoints and define the relationship of these viewpoints.
2. The proposed assessment model includes five aspects (utility agency, infrastructure project, traffic condition, local government, and site condition) and 24 evaluation items. Utility agency is the most important of the five aspects while construction site condition is the least important in terms of prioritizing route construction for a CDN. Notably, this is only a localized situation. In other countries, the aspects and evaluation items of prioritizing route construction may be completely different and the relative weights of assessment aspects and items may also vary.
3. The proposed model can be applied to prioritize route construction for other CDNs in Taiwan, and average scores can be obtained to provide the baseline values for priori-

tizing route construction.

4. Although the analytical methods used in this study are straightforward, the statistical analysis is relatively complicated. A computer-based assessment model can improve the effectiveness of model operation. In addition, numerical simulation methods may also be applied to rank RCP in a CDN as well.

Appendix A. List of NPDVs of the stage-one questionnaire.

No.	Description of NPDVs	Intensity of Importance				
		extremely important	important	neutral	unimportant	extremely unimportant
1	Collaboration of the high-volt electricity agency					
2	Collaboration of the low-volt electricity agency					
3	Collaboration of the communication agency					
4	Collaboration of the water supply agency					
5	Collaboration of the gas agency					
6	Collaboration of the sewage agency					
7	Collaboration of the oil supply agency					
8	Incorporation of the natural gas supply agency					
9	Incorporation of the waste collection agency					
10	Traffic congestion during particular holidays					
11	Route geology					
12	Extensive roadway needs in the near future					
13	Long term traffic congestion					
14	Traffic congestion during rush hours					
15	Desire to build CD of local government authority					
16	Corporation of the head of a subdivision of a city district					
17	Corporation from engineers in charge of the CD project					
18	Corporation of the comptrollers					
19	Correlation with the rural re-developed zones					
20	Correlation with the construction of rapid transit system					
21	Correlation with the construction of high speed railway					
22	Correlation with the construction within a re-developed zone					
23	Correlation with the construction of highway projects					
24	Complexity of existing underground pipelines					
25	Difficulty in performing construction work					
26	Aged pavement with poor condition on existing roadways					
27	Local residents' supporting of the CD project					

Appendix B. Paired comparison of PDGs of the stage-two questionnaire.

Scale of Importance / PDGs	5:1	3:1	1:1	1:3	1:5	Scale of Importance / PDGs
Utility agency	□	□	□	□	□	Site condition
Utility agency	□	□	□	□	□	Traffic condition
Utility agency	□	□	□	□	□	Local government
Utility agency	□	□	□	□	□	Infrastructure project
Site condition	□	□	□	□	□	Traffic condition
Site condition	□	□	□	□	□	Local government
Site condition	□	□	□	□	□	Infrastructure project
Traffic condition	□	□	□	□	□	Local government
Traffic condition	□	□	□	□	□	Infrastructure project
Local government	□	□	□	□	□	Infrastructure project

Appendix C. Rating the intensity of favorite for route 02.

Code	Description of Evaluation Items	Intensity of Favorite				
		5	4	3	2	1
UA1	Collaboration of the high-volt electricity agency	ˇ				

UA2	Collaboration of the low-volt electricity agency	ˇ				
UA3	Collaboration of the communication agency	ˇ				
UA4	Collaboration of the water supply agency			ˇ		
UA5	Collaboration of the gas agency			ˇ		
UA6	Collaboration of the sewage agency			ˇ		
UA7	Collaboration of the oil supply agency			ˇ		
TC1	Traffic congestion during particular holidays	ˇ				
TC2	Route geology	ˇ				
TC3	Extensive roadway needs in the near future	ˇ				
TC4	Long term traffic congestion		ˇ			
TC5	Traffic congestion during rush hours		ˇ			
LG1	Desire to build the CD of local government authority			ˇ		
LG2	Corporation of the head of a subdivision of a city district		ˇ			
LG3	Corporation from engineers in charge of the CD project		ˇ			
LG4	Corporation of the comptrollers		ˇ			
IP1	Correlation with the construction of rapid transit system	ˇ				
IP2	Correlation with the construction of high speed railway		ˇ			
IP3	Correlation with the construction within a re-developed zone	ˇ				
IP4	Correlation with the construction of highway projects				ˇ	
SC1	Complexity of existing underground pipelines			ˇ		
SC2	Difficulty in performing construction work		ˇ			
SC3	Aged pavement with poor condition on existing roadways	ˇ				
SC4	Local residents' supporting of the CD project		ˇ			

Note: For Intensity of Favorite, extremely favorable = 5, favorable = 4, neutral l = 3, unfavorable = 2, and extremely unfavorable = 1

Appendix D. Summary of the intensity of favorite for five routes.

Code	Description of Evaluation Items	R-01	R-02	R-03	R-04	R-05
UA1	Collaboration of the high-volt electricity agency	4	5	5	5	5
UA2	Collaboration of the low-volt electricity agency	5	5	5	5	5
UA3	Collaboration of the communication agency	4	5	5	3	5
UA4	Collaboration of the water supply agency	4	3	4	5	3
UA5	Collaboration of the gas agency	2	3	5	3	3
UA6	Collaboration of the sewage agency	2	3	5	4	4
UA7	Collaboration of the oil supply agency	3	3	2	3	3
TC1	Long term traffic congestion	5	5	5	3	3
TC2	Traffic congestion during rush hours	5	5	5	3	3
TC3	Traffic congestion during particular holidays	3	5	4	3	3
TC4	Route geology	5	4	5	5	3
TC5	Extensive roadway needs in the near future	4	4	4	4	3
LG1	Desire to build the CD of local government authority	3	3	3	3	4
LG2	Corporation of the head of a subdivision of a city district	3	4	4	3	4
LG3	Corporation from engineers in charge of the CD project	4	4	4	4	4
LG4	Corporation of the comptrollers	4	4	4	3	3
IP1	Correlation with the construction of rapid transit system	5	5	4	4	2
IP2	Correlation with the construction of high speed railway	5	4	4	5	2
IP3	Correlation with the construction within a re-developed zone	4	5	5	4	4
IP4	Correlation with the construction of highway projects	5	2	2	4	4
SC1	Complexity of existing underground pipelines	2	3	3	5	4
SC2	Difficulty in performing construction work	2	4	3	3	4
SC3	Aged pavement with poor condition on existing roadways	3	5	4	4	5
SC4	Local residents' supporting of the CD project	5	4	5	5	4

Appendix E. Demonstration of various scores for route 02.

Code	Description of Evaluation Items	Score of Favorite (SOF)	Weight of Item (WOI)	Score of Item (SOI)	Raw Score of Aspect (RSOA)	Score of Aspect (SOA)
UA1	Collaboration of the high-volt electricity agency	5	0.1587	0.7935	0.7853	0.1934
UA2	Collaboration of the low-volt electricity agency	5	0.1491	0.7457		
UA3	Collaboration of the communication agency	5	0.1555	0.7776		
UA4	Collaboration of the water supply agency	3	0.1491	0.4474		
UA5	Collaboration of the gas agency	3	0.1383	0.4149		
UA6	Collaboration of the sewage agency	3	0.1262	0.3786		
UA7	Collaboration of the oil supply agency	3	0.1230	0.3690		
TC1	Long term traffic congestion	5	24.09	1.2047	0.9341	0.1918
TC2	Traffic congestion during rush hours	5	22.51	1.1256		
TC3	Traffic congestion during particular holidays	5	20.47	1.0233		
TC4	Route geology	4	17.40	0.6958		
TC5	Extensive roadway needs in the near future	4	15.53	0.6214		
LG1	Desire to build the CD of local government authority	3	28.33	0.8499	0.7433	0.1435
LG2	Corporation of the head of a subdivision of a city district	4	23.96	0.9586		
LG3	Corporation from engineers in charge of the CD project	4	25.87	1.0347		
LG4	Corporation of the comptrollers	4	21.84	0.8735		
IP1	Correlation with the construction of rapid transit system	5	25.58	1.2792	0.8074	0.1702
IP2	Correlation with the construction of high speed railway	4	24.31	0.9724		
IP3	Correlation with the construction within a re-developed zone	5	26.11	1.3057		
IP4	Correlation with the construction of highway projects	2	23.99	0.4798		
SC1	Complexity of existing underground pipelines	3	28.15	0.8446	0.789	0.1141
SC2	Difficulty in performing construction work	4	25.12	1.0047		
SC3	Aged pavement with poor condition on existing roadways	5	22.55	1.1273		
SC4	Local residents' supporting of the CD project	4	24.18	0.9673		
Route Overall Score						81.30

Note: (4)=(2)*(3); (5)=(4)/5; (6)=(5)*(WOA); $WOA_{UA:TC:LG:IP:SC}$ = 0.246 : 0.205 : 0.193 : 0.211 :0.145

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