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# A FRAMEWORK TO EVALUATE URBAN UNDERGROUND UTILITY COMPLEXITY INDEX USING THE DELPHI METHOD AND ANALYTIC HIERARCHY PROCESS

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**Abstract:** Urbanization is rapidly increasing for a few years. Worldwide rapid and unplanned urban growth has threatened sustainable development as basic infrastructure facilities are unable to cope up with the rising urbanisation. Modern cities depend on complex network of utilities. The complex underground utility networks leads to delaying of new infrastructure projects and create hygiene problems. Underground utility network complexity evaluation is a critical task in subsurface utility engineering because of its dynamicity. The dynamicity is due to the rising urbanism, demanding infrastructure facilities thereby creating a web of cables and pipes under the ground. Therefore, a lot of complexity arise and exist in an excavated pit particularly in urban area. However, the complexity level cannot be easily measured due to its qualitative nature and it varies from one pit to another. In this connection, this study presents a framework of prioritizing, analysing and evaluating the urban underground utility complexity index (UUUCI) using analytic hierarchy process (AHP) and weighted sum method (WSM). The casual and its categorical factors are selected based on the literature review and finalized by using the Delphi method. To validate this study, 40 pit samples have been collected and their UUUCI are computed. The values of UUUCIs follow the normal distribution curve. Thus UUUCI is able to represent the complexity level of a pit. The UUUCI will be useful to measure and differentiate the complexity level of pits. The impact of complexity level of a pit on traffic flow, environment and other managerial aspects can be studied by correlating the UUUCI.

## 1 INTRODUCTION

Underground infrastructures support a strong urban economy and high quality of life. Due to rapid increasing the use of urban underground space, city growth and urban planning cause scarcity of underground space for utility placement (J. Curiel-Esparzaa and J. Canto-Perellob 2013).However, underground utility complexity identification and its assessment is an unfamiliar term in Subsurface Utility Engineering (SUE). Complexity means any level of difficulty hindering the task completion. This level of difficulty may be due to several tangible or intangible factors. Hence, the estimation of complexity level at the project site is essential to be considered for all ongoing, old or maintenance works related to utilities. However, the two main difficulties to quantify the complexity are the selection of potential and their categorical factors as well as the evaluation method of the complexity level of the utility projects. Construction professionals express utility complexities in qualitative terms only and are also unaware of the evaluation process in the presence of both tangible and intangible factors. Thus, the evaluation of utility network complexity level is a multi-criteria decision-making problem. This study uses analytic

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hierarchy process (AHP) which is used to structure a large number of complexity factors associated with the utility projects. The proposed methodology incorporates knowledge and experience acquired from many experts of the related field. All of the categorical factors are expressed on the quantitative scale using normalisation strategy and later incorporated with AHP to achieve an urban underground utility complexity index (UUUCI), by adding all the weighted complexities associated with individual factors. Later, 40 samples of utility networks were collected along different road sections from ongoing infrastructure projects in Surat city, India to validate the study.

## 2 OBJECTIVE OF THE STUDY

The objectives of this study are to: (1) determine the important complexity factors in typical utility projects and their categorical factors, (2) prepare the framework to evaluate the utility project complexity level, (3) formulate and present the UUUCI to evaluate the complexity level of a utility project, (4)and validate the UUUCI.

## 3 LITERATURE REVIEW

There are several factors which affect the underground utility network complexity. Therefore, there was a need to identify the most influential factors affecting UUUCI. A literature review has helped in recognising the imperious factors. Existing literatures include; a) standards and codes available in India related to any underground utility as shown in Table 1 and b) standards papers different journals such as journal of computing in civil engineering, b.2) journal of infrastructure systems b.3) journal of urban planning and development, b.4) journal of construction engineering and management, b.5) journal of surveying engineering, b.6) journal of water resource planning and management, c) experts' opinions and d) project reports and case studies. Following complexity factors as shown in Table 1 may be considered for this study.

Table 1 *:* Potential complexity factors

| Complexity Factors | Definition | References | Categorical factors |
|---|---|---|---|
| Width of the Urban Road | Right of Way | Indian Road Congress (IRC)- 69-1977 Space Standards for Urban Roads | Express Way-(50-60)Meters |
| | | | Arterial Street-(40-50)Meters |
| | | | Sub Arterial Street-(30-40)Meters |
| | | | Collector Street-(20-30)Meters |
| | | | Local Street-(10-20)Meters |
| Type of Utility based on function | Various service types of buried utilities. Based on possibility of hitting …Less the depth higher the chance of hitting. | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Drinking Water |
| | | | Storm water |
| | | | Sewage |
| | | | Gas |
| | | | Electrical |
| | | | Optical Fibre Cable |
| | | | Dead pipes |
| | | | Others |
| Density of Utility | Number of buried utilities per roadway cross section that are expected to be encountered on any project | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Low(One pipe/roadway cross- section) |
| | | | Medium(Two or three pipes/roadway cross- section) |
| | | | High(More than three pipes/roadway cross- section and unknown) |

Table 1 (continued)

| Complexity | Definition | References | Categorical factors |
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| Factors | | | |
|---|---|---|---|
| Material of Utility | Material types of buried utilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Rigid(Concrete, Cast Iron, Ductile Iron) |
| | | | Flexible(PVC,HDPE) |
| | | | Brittle(Clays, Unknowns) |
| Depth of Utility | Vertical distance from top of road surface to centre of utility pipeline | Indian Road Congress (IRC) 98-1997 | Shallow(0 to 0.5m) |
| | | | Very Low(0.5 to 1 m) |
| | | | Low(1 to 2m) |
| | | | Medium(2 to 3m) |
| | | | High(3 to 4m) |
| | | | Very High(4 to 6m) |
| Pattern of Utilities | Configuration of buried utilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Simple (One Parallel and /or one crossing Utility) |
| | | | Medium(Two Parallel and/or two crossing Utilities) |
| | | | Complex(More than two parallel and/or crossing Utilities) |
| Access to Utilities | Difficulty or ease of access to buried utilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Easy(Open Land) |
| | | | Medium(Few Light Structures, Pavements, Medians) |
| | | | Restricted(Bridge Pier, Other Large Structures) |
| Age of Utilities | Reveal the type of material and the physical condition of utility | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | New(Less than 10 years) |
| | | | Medium(10 to 25 years) |
| | | | Old(Greater than 25 years) |
| Utility relocation Cost | Cost incurred in the adjustment, replacement and relocation of utility facilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Low (Less than or equal to 2% of total project Cost (Design and Construction Cost)) |
| | | | Medium (Between 2% and 5% of total project cost (Design and Construction Cost)) |
| | | | High(Greater than 5 % of total Project cost(Design and Construction Cost)) |
| Estimated Project Traffic Volume | Average daily traffic volume per lane | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Low(Less than or equal to 1500 ADT per lane) |
| | | | Moderate(Greater than 1500 and less than or equal to 6000ADT per Lane) |
| | | | High (Greater than 6000 ADT per lane) |
| Project Time Sensitivity | Project schedule in order to avoid delays | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Low(Project is not time sensitive) |
| | | | Medium(Some Flexibility in Schedule) |
| | | | High(Very Tight schedule- no time extension) |
| Project Area Description | Location or nature of the project | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Rural(Areas with lot of open areas) |
| | | | Sub-Urban(Areas with few businesses and residences) |
| | | | Urban(Areas with numerous business and residences) |

Table 1 (continued)

| Complexity | Definition | References | Categorical factors |
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| Factors | | | |
|---|---|---|---|
| Type of Project/Section/Location | Project location specifically the section of construction reveal the traffic volume ,accessibility and possibilities of accidental damages to the utilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Simple(Without excavation. i.e., widening, and /or other minor construction works) |
| | | | Moderate (Shallow Excavation. i.e., Guide Rail, low depth pipe replacement, traffic light post, shoulder cutting, and/or minor drainage.) |
| | | | Complicated (Deep excavation, i.e., new construction, full depth re-construction, bridge foundation, deep-depth pipe replacement, etc.) |
| Quality of Utility record | Reliability of existing record on utilities | Norms as per Common Wealth of Pennsylvania (Department of Transportation) | Good(Very accurate record of utilities) |
| | | | Fair(Not very good record of utilities) |
| | | | Poor(Utilities information /data are not accurate) |
| Burial Methods | Laying condition of the pipelines | Site observation | In trench |
| | | | Trenchless |
| Distance from Road edge | Distance from the road edge to the centre of the utility line | IRC 98-1997 | Very Near(0 to 1 m) |
| | | | Near(1-3m) |
| | | | Mid way(3-5m) |
| | | | Far(5-7m) |
| | | | Very Far(>7m) |

### 3.1 Frame Work For Evaluation Of Underground Utility Complexity Networks

This study formulates an UUUCI that represents the complexity level of a typical underground utility project. The evaluation of UUUCI is considered to be a multiple-criteria decision making (MCDM) problem. A hierarchical framework to develop the UUUCI has been constructed as shown in Figure 1. It is assumed that the complexity level of any underground utility network depends on the potential factors as identified through the literature review. Each of these factors is characterised by its categorical factors. The complexity factors and their categorical factors are shown at level 2 and level 3 respectively in Figure 1; whereas the underground utility network complexity is measured by the UUUCI at level 1 in Figure 1.

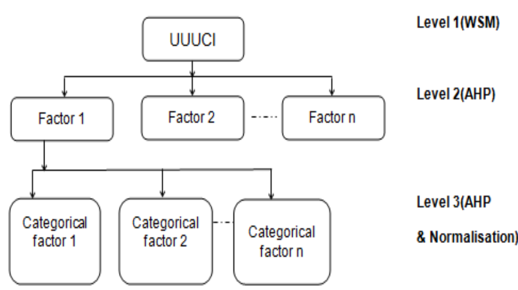


Figure 1: Framework for evaluation of underground utility complexity level

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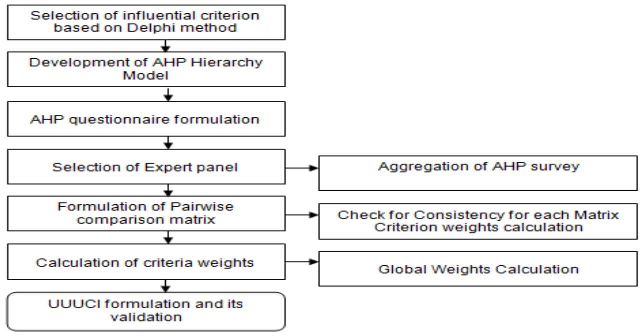


Figure 2: Research Methodology

The MCDM approach has mainly four parts: (1) alternatives, (2) categorical factors, (3) weight of relative importance of each categorical factors, (4) measure or performance of alternatives with reference to the categorical factors.

### 3.2 Research Methodology

As shown in Figure 2, a research methodology was outlined to achieve the objectives. To select the factors related complexity of urban ground utilities, the Delphi method was used. The selection criteria for experts, number of rounds, etc., guidelines were decided as shown in Table 2. Then, analytic hierarchy process (AHP) was used to evaluate and decide the relative importance of each utility complexity factors.

Table 2: Selection criteria for expert panel

| **Characteristics** | **Minimum Requirements suggested by Hallowell and Gambatese (2010)** | **Modified guidelines for this study** |
|---|---|---|
| Identifying potential experts | Membership in a nationally recognized committee in the focus area of the research | Working professional (as civil engineer, utility engineer etc.) |
| | Primary writer of publications in ASCE journals | |
| | Known participation in similar expert-based studies | Academician (research scholar, data scientist etc.) |
| Qualifying panellists as experts | Experts must satisfy at least four of the following criteria in the topics related to the research: | Experts must satisfy the following criteria: |
| | Primary or secondary writer of at least three peer-reviewed journal articles | |
| | Invited to present at a conference | Graduate in civil engineering |
| | Member or chair of a nationally recognized committee | Employee in Government /Public Limited companies |
| | At least 5 years of professional experience in the relevant industry | |
| | Faculty member at an accredited institution of higher learning | Minimum 5 years of experience in the relevant industry |
| | Writer or editor of a book or book chapter on the topic of construction safety and health, or risk | |
| | Advanced degree in the field of civil engineering | |
| | Professional registration such as Professional Engineer | |

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Table 2 (continued)

| Characteristics | Minimum Requirements suggested by Hallowell and Gambatese (2010) | Modified guidelines for this study |
|---|---|---|
| Number of panellists | 8 to 12 | 7 to 10 |
| Number of rounds | 3 | Minimum two rounds of survey is required In this study, concise result was obtained after second round of survey. |

In order to qualitative measures of some categorical factors such as width of the road, depth of utility, distance from road edge, and their weights can be normalized and calculated. Besides, categorical factors of some factors such as density of utility, patterns of utility, and access to utility are decided based on equal distribution of the score where maximum being 1 and least being 0 among all its categorical factors. The weightage sum method (WSM) is the simplest but most widely used multi attribute decision making method (Mitropoulos and Prevedouros 2016). In this method, each complexity factors is assigned a weight, and the sum of all weights must be 1. Referring Figure 1, the UUUCI is at the first level in hierarchy and it can be obtained by using WSM that integrates the score of each complexity factors. In nutshell, the overall or composite performance score of the underground utility network can be obtained and calculated using .Eq. 1.

$$[1]\ \mathrm{Pi} = \sum_{\mathrm{J}=1}^{\mathrm{h}} \mathrm{Wj}(\mathrm{hij})$$

Where $h_{ij}$ represents the normalised value of categorical factors, and $P_i$ is the overall or composite score of the alternatives. The underground utility network with highest value of $P_i$ is considered as the most complex network. Thus, at this level, using Eq. 2, overall network complexity value is computed through an operation of WSM that integrates the score of each complexity factors.

Thus, for this study, the final value of the UUUCI can be calculated as:

$$[2]\ \ UUUCI_i = W_1.h_1 + W_2.h_2 + \ldots\ldots\ldots\ldots +. W_n.h_n$$

Where UUUCI, is the numerical value of the complexity level of an underground utility network for any sample say i based on n number of factors ($W_n$) and its categorical factors ($h_{in}$).

## 4. DATA COLLECTION

A Delphi questionnaire survey has been conducted to shortlist ten typical complexity factors out of the identified complexity factors as mentioned in Table 1 based on experts' opinions. Seven experts belonging to the different construction companies and institutes were selected as per the panellist selection criteria as mentioned in Table 2. They were interviewed and asked to evaluate and rank the 16 factors on the scale of 1 to 5, where 5 being very significant and 1 being not significant in the first round of their interviews. In the second round of Delphi survey, the findings of the first round of interviews were presented to the experts. Again experts were asked to evaluate the importance of the complexity factors on the same scale used in the first round. The objective is to verify the consensus of the utility experts and the reliability of the categorical factors for each complexity factor. According to Gambatese (2010), there is no standard for the consensus check; however, he had used the standard deviation (SD) and geometric mean (GM) as the main parameters to judge the consensus. Therefore, in this study, these two parameters (SD and GM) are used for consensus check.

At the end of each round of interview, statistical parameters i.e. geometric mean and standard deviation were computed. The factors were then ranked based on descending values : type of utility(1), width of the

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urban road(2), access to utilities(3), estimated project traffic volume(4), burial methods(5), distance from road edge(6), density of utility(7), pattern of utilities(8), depth of utility(9), material of utility(10), quality of utility record(11), type of project/section/location(12), project area description(13), age of utilities(14), involvement of different agencies(15) and project time sensitivity (16). Thus, in the final Delphi round, it resulted into ten complexity factors which are used to formulate UUUCI. Later it was realised that the factor “Estimated project traffic volume” does not affect the utility network complexity directly. Hence it was removed and in the second phase further analysis was carried out with the remaining nine factors as: Type of Utility based on functions (F1)[ Drinking Water, storm water, sewage, gas, electrical, optical fibre cable(OFC), Dead pipes, and others], Width of the Urban Road(F2)[ Express Way(50-60)Meters, Arterial Street(40-50)Meters, Sub Arterial Street(30-40)Meters, Collector Street(20-30)Meters, Local Street(10-20)Meters], Access to Utilities(F3)[ Easy(Open Land), Medium(Few Light Structures, Pavements, Medians), Restricted(Bridge Pier, Other Large Structures)], Burial Methods(F4)[ In Trench, Trenchless], Distance from Road edge(F5)[ Very Near(0 to 1 m) , Near(1-3m), Mid way(3-5m), Far(5-7m), Very Far(>7m)], Density of Utility(F6)[ Low(One pipe/roadway cross- section), Medium(Two or three pipes/roadway cross- section), High(More than three pipes/roadway cross- section and unknown)], Pattern of Utilities(F7)[ Simple (One Parallel and /or one crossing Utility), Medium(Two Parallel and/or two crossing Utilities), Complex(More than two parallel and/or crossing Utilities)], Depth of Utility(F8)[ Shallow(0 to 0.5m), Very Low(0.5 to 1 m), Low(1 to 2m), Medium(2 to 3m), High(3 to 4m), Very High(4 to 6m)], Material of Utility(F9)[ Rigid(Concrete, Cast Iron, Ductile Iron), Flexible(PVC,HDPE), Brittle(Clays, Unknowns)].

Afterwards, weights of the factors and their categorical factors were evaluated. As shown in Figure 1, in the second and third level of the MCDM hierarchy, it is to assign weights to the factors and their categorical factors using AHP. The questionnaire survey was conducted to obtain the necessary data to determine the weights of factors and their categorical factors. The questionnaire consists of 3 sections for allocation of following details respectively: 1) experts’ brief profile, 2) weight of complexity factors and 3) weight of categorical factors.

The experts were asked to rate the importance of the nine complexity factors and their categorical factors on the Likert scale of 1-9, where 1 stands for equal importance of factor/categorical factor, 3 stands for weak importance of one factor/ categorical factor over the other, 5 stands for essential or strong importance of one factor/ categorical factor over the other, 7 stands for demonstrated importance of one factor/ categorical factor over the other, 9 stands for absolute importance of one factor/ categorical factor over the other and 2,4,6,8 stands for intermediate values between two adjacent adjustments. The questionnaire survey was conducted to obtain the opinions of professionals and academicians belonging to subsurface utility engineering and urban planning industry. The professionals and academicians were selected based on their experience (not less than five years) and relevancy of expertise (mainly in underground utility management, city network planning, infrastructure, network designing, etc.). A total of seven experts gave their timely response through emails.

After the aggregation of the responses of experts, the AHP generated a weight for each factor according to the pairwise comparisons of the nine factors. A pairwise comparison matrix of order 9X9 was formed and solved for determining the weights of the nine complexity factors (F1 to F9). The AHP assigned a score to each factor according to the decision maker’s pairwise comparisons of the factors. As the AHP analysis purely relies on expert’s inputs, there may be some inconsistencies in the pairwise comparison matrix. Thus, a consistency check for matrix is necessary. Consistency Index (CI) and Random Index (RI) are the two parameters which have been used in this study to check the consistency of the pairwise comparison matrix. The value of CI should always be equal to zero but small values of inconsistency may be tolerated (Saaty 1980). Thus, it is $CI/RI \leq 0.1$. In this study, the factor pairwise comparison matrices generated a scored $CI/RI \leq 0.1$. Similarly, the weights for all the categorical factors for factor F1 (type of utility based on function), F4 (burial method) and F9 (material of utility) were also determined by following the same procedure and checks for AHP.

Finally, the AHP combines the factor weights referred as AHP matrix weight and the categorical factors’ scores, thus determining a global score for each factor and its categorical factors. The global score for

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factors is same as its AHP matrix weight but for categorical factors global score it is the product of AHP matrix weights for categorical factors and its respective factor.

## 5. DEVELOPMENT OF URBAN UNDERGROUND UTILITY COMPLEXITY INDEX (UUUCI)

The weightages were extracted for the second and third level of hierarchy as shown in Figure 1. Now based on WSM, the UUUCI can be computed as shown in Eq. (3). The values of categorical factors can be evaluated for a sample (pit) by the predetermined values of global weights obtained as follows:

Table 3 AHP Matrix Weights and Global Weights

| Complexity Factors and its categorical factors | AHP Matrix Weights | Global Weights |
|---|---|---|
| **Type of Utility based on functions(F1)** | **0.07** | **0.070** |
| Drinking Water($h_{11}$) | 0.07 | 0.005 |
| Storm water($h_{12}$) | 0.07 | 0.005 |
| Sewage($h_{13}$) | 0.21 | 0.015 |
| Gas($h_{14}$) | 0.31 | 0.022 |
| Electrical($h_{15}$) | 0.15 | 0.010 |
| Optical Fibre Cable($h_{16}$) | 0.08 | 0.006 |
| Dead pipes($h_{17}$) | 0.05 | 0.003 |
| Others($h_{18}$) | 0.06 | 0.004 |
| **Width of the Urban Road(F2)** | **0.11** | **0.110** |
| **Access to Utilities(F3)** | **0.09** | **0.090** |
| **Burial Methods(F4)** | **0.13** | **0.130** |
| In Trench($h_{41}$) | 0.15 | 0.020 |
| Trenchless($h_{42}$) | 0.85 | 0.111 |
| **Distance from Road edge(F5)** | **0.10** | **0.100** |
| **Density of Utility(F6)** | **0.12** | **0.120** |
| **Pattern of Utilities(F7)** | **0.11** | **0.110** |
| **Depth of Utility(F8)** | **0.12** | **0.120** |
| **Material of Utility(F9)** | **0.14** | **0.140** |
| Rigid($h_{91}$) | 0.49 | 0.069 |
| Flexible($h_{92}$) | 0.42 | 0.059 |
| Brittle($h_{93}$) | 0.09 | 0.013 |

Normalised Weight of quantitative factor's categorical factors obtained as follows: Width of the Urban Road(F2) [Local Street(1.000), Collector Street(0.800), Sub Arterial Street(0.600), Arterial Street(0.400), Express Way(0.200)], Density of Utility(F6) [Low(0.333), Medium(0.667), High(1.000)], Depth of Utility(F8) [Shallow(0.083), Very Low(0.167), Low(0.333), Medium(0.500), High(0.667), Very High(1.000)], Pattern of Utilities(F7) [Simple(0.333), Medium(0.667), Complex(1.000)], Access to Utilities(F3) [Easy(0.333), Medium(0.667), Restricted(1.000)], Distance from Road edge (F5) [Extremely Near(1.000), Very Near(0.750), Near(0.580), Mid way(0.420), Far(0.250), Very Far(0.080)].

Eq [3] $UUUCI_i = W_1.h_1 + W_2.h_2 + \ldots\ldots\ldots + W_9.h_9$

$$= 0.07.h_1 + 0.11.h_2 + 0.09.h_3 + 0.13.h_4 + 0.10.h_5 + 0.12.h_6 + 0.11.h_7 + 0.12.h_8 + 0.14.h_9$$

$$= 0.07\,.(h_{11} + h_{12} + h_{13} + h_{14} + h_{15} + h_{16} + h_{17} + h_{18}) + 0.11.h_2 + 0.09.h_3 + 0.13.h_4 + 0.10.h_5 + 0.12.h_6 + 0.11.h_7 + 0.12.h_8 + 0.14.(h_{91} + h_{92} + h_{93})$$

The UUUCI is a function of nine complexity factors and their categorical factors. Its value varies from 0 to 1, where 0 and 1 conditions are practically hypothetical as 0 indicates "no complexity" and 1 indicates

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“highest complexity”. Both the extreme conditions are not feasible as 0 means “there is no utility line below the ground” and 1 means “highest complexity due to violation of practice code or design failure”.

While computing UUUCI, these points should be considered: (1) for the factors “utility type based on function (F1)” and “ material of utility (F9)”, there may be more than one utility in a pit, in this case, there is a need to sum of all values assigned to all different utility types. (2) The underlying depth of utility is considered for the most lowered utility in a pit. ‘Distance from road edge’ is considered for the utility line nearest to the road edge

For the practical validation of the study, 40 random samples (pits) of ongoing utility projects at different locations were collected from urban area of Surat city (India). The normal distribution for these 40 samples was plotted using Statistical Package for the Social Sciences (SPSS 20) statistical tool. A null hypothesis is formulated: “UUUCI of 40 samples is not normally distributed”. This hypothesis has been tested by the Shapiro-Wilk Test as it is more appropriate for small sample sizes (< 50 samples). The significant value of the Shapiro-Wilk Test (0.734) is greater than 0.05, it shows that the data is normal. Further normality has been checked graphically by plotting Q-Q graph. Data was found normally distributed as the data points were close to the diagonal line. The derivatives of the normal distribution curve were computed. The mean value of UUUCI for the 40 pits is 0.405, with the range of 0.360 between the extreme end limits of 0.220 to 0.580. The median value equals to 0.414 and the standard deviation for the data set of UUUCIs for 40 pits is 0.084 with a low variance of 0.007. The 5 % trimmed values represent the outliers which are not falling in confidence interval. Thus, the assumed null hypothesis is not accepted. Therefore, UUUCIs of 40 pits (samples) are normally distributed. Hence, the variability in UUUCI estimation can be very well taken care of by the formulated framework.

## 6. SUMMARY AND CONCLUSIONS

UUUCI represents complexity level of a pit while executing and rehabilitation of underground networks of utilities. To compute the UUUCI, this study primarily focused on developing a framework for evaluation of complexity level of a pit. First, 16 factors and their categorical factors were determined by rigorous literature review and interactions with professional experts. By using the Delphi method, out of 16 factors, nine factors with their categorical factors were finalized to find out their weightage. Weightage of nine factors and their categorical factors were found by using the AHP method and normalisation equation. Later, a formula was presented to compute UUUCI by using WSM. Afterwards UUUCI values for different 40 pits were evaluated to study their complexity level. The normality of 40 UUUCI values for 40 different pits was examined and they found normal. Five experts were requested to evaluate the complexity level of the same 40 pits by their experiences and cognition and found that their judgments are matching with UUUCI. It means that UUUCI is able to represent a real picture of the complexity level of any pit and makes it applicable to the entire set of pit population due to its probable behaviour towards normality.

In urban area, it is quite difficult to quantify and present the complexity level of underground utilities in a pit. However, the developed UUUCI can help in quantification for an ordinal parameter of complexity which would provide base for the profound time and cost analysis of any utility project. UUUCI describes the pit complexity in numeric terms. Thus, it becomes easy for the professional to quantify the problems associated with the utility works depending on its network complexity such as utility relocation cost, utility shifting time, utility risk assessment, project delay cost etc. Researchers can further estimate the ambiguous impacts of the utility works by assessing its complexity. The various equivocal affects arising of the utility works are traffic delays, social and environmental interruption, the users’ disruptions, loss of economic activities nearby the project area and so on.

UUUCI can also be used as a performance indicator of the underground utility networks. The lower the UUUCI value, the least is the complexity of the network and hence it is expected to have less execution cost, completion time, risk/causalities etc., of the project. Thus, thoughtful decisions can be taken based on UUUCI values, for example, if the UUUCI value is very high, then it will lead to adverse impacts on surrounding traffic, environment, safety of workers and urban dwellers. In this connection, adequate remedial measures can be taken to minimize their adverse effects. UUUCI may be used to assess the

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performance and accuracy of configurations of modern techniques adopted for determining the underground utility network such as digital mapping, geographic information system (GIS) etc. However, a comparison between the UUUCI values for the current utility laying practices and the modified or smart underground utility laying practices can be helpful to differentiate them in future. Thus it will be beneficial to state the check of the impartibility of modern measures over the conventional measures.

In limitations of this study, there is a scope to add or remove underground complexity factors and their categorical factors in a framework of the study. The IRC 98-1997code gives utility laying standard along the roads but fails to explain the utility clashes at junction as there is no specific norm for utilities at junction. Thus, it needs to be incorporated and revised in further study. It needs to specify a code exclusively for lying of different utilities with their detailed specifications too. With the growing urbanization and demand for good infrastructure government needs to take necessary measures to improve the quality of city infrastructure especially the utility services. The purpose of this study was to fill in the gap by formulating a methodology for quantifying the complexity level of underground utility network which often adds to work delays, cost escalation for major infrastructure projects in urban areas now a days.

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