Evaluation of Proposed Highway Routes Based on the Existing Utilities: A Cost Estimate Framework

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Abstract

Early identification of utility conflicts and planning for addressing them is critical for controlling time and cost overruns in highway projects. This study introduces a framework for the evaluation and selection of highway routes based on existing utilities in the vicinity of the proposed routes. As a way for comprehensive consideration of utility conflicts early in the planning stage of highway projects, the framework identifies and classifies conflicts, calculates their estimated direct and indirect resolution costs, and ranks the proposed routes based on their costs related to these conflicts. The study introduces a *conflicts classification* system that incorporates conflict resolution actions (e.g., utility relocation) and the probabilities of the application of these actions in order to determine conflict cost estimates. The framework was implemented using an ArcGIS Model that examines the GIS data related to existing utilities, and analyzes conflicts with predetermined proposed highway routes. The model also analyzes the impact of conflicts on neighboring facilities. A case study is introduced to demonstrate and validate the proposed framework. Sensitivity and uncertainty analysis showed that the utility line length, utility material, and the average annual daily traffic (AADT) of the proposed route are the most significant variables in the cost estimates.

INTRODUCTION

Addressing utility conflicts is a challenge in highway construction, and has a significant impact on the cost and the time duration of the project. Utility conflicts can sometimes be identified during the design either when the existing utilities are in conflict with a new highway route, other utility facilities' installation, or when the existing utilities are not in compliance with Utility Accommodation Policies. When such conflicts take place, they are often resolved by relocating existing utilities, realigning highway routes, protecting the utility in-place, or other means, such as engineering solutions (Kraus, et al. 2007). A survey of state departments of transportation, highway contractors, and design consultants conducted in 2002 identified utility relocation as the most frequent cause of delay in highway construction projects (Ellis and Thomas, 2002). The delays associated with utility conflicts can extend the duration of the project and cause cost overrun due to higher bids, changes in orders, damage or delay claims, redesign, and/or litigation by utility owners (Quiroga, et al. 2012).

Early involvement of utility conflicts in the design of highway construction projects reduces the delay and the cost of the project. A study conducted in 2000 for the FHWA in regards to cost savings on highway projects by utilizing Subsurface Utility Engineering (SUE)—an engineering process that aims to accurately locate and identify exiting utilities prior to construction—found that every $1 spent on SUE resulted in an average of $4.62 in savings in the overall project's cost as a result of reducing the costs related to utility conflicts (Lee, 2000). When considering utility conflicts early in the design phase, unnecessary utility relocations can be avoided by implementing other resolution strategies such as modifying the highway design or protecting the utilities in-place (Quiroga, et al. 2014).

The process for addressing utility conflicts in traditional design-bid-build (DBB) projects (Quiroga, et al. 2014) assumes that a highway route has already been chosen, and hence the utility conflicts are not investigated until the preliminary design phase. However, there is an opportunity for cost reduction and time saving by considering the utility conflicts at earlier stage of planning, when the highway route choice process is being undertaken. This study introduces the idea of including utility conflicts as a factor in a further-evaluation step that evaluates suggested possible routes for the highway. By considering utility conflicts at this stage, the cost and the time that is expected to be spent to resolve these conflicts will play a role in deciding which route is more economically suitable.

Figure 1 explains this concept by introducing two components to the traditional utility process. The first component (denoted by 1 in the figure) assumes that the highway route has not been chosen yet. Instead, there is a set of proposed routes for the same highway that are identified by the highway planners as suitable routes that satisfy the planning objectives. The second component (denoted by 2 in the figure) is an evaluation step that estimates the severity of utility conflicts for each proposed route and selects the most suitable route to complete the process with. The preliminary utility investigation step—which is usually completed during the preliminary design stage—is moved to the planning stage, where the available data about existing utilities are collected for all proposed routes to be used as inputs for the evaluation of routes.

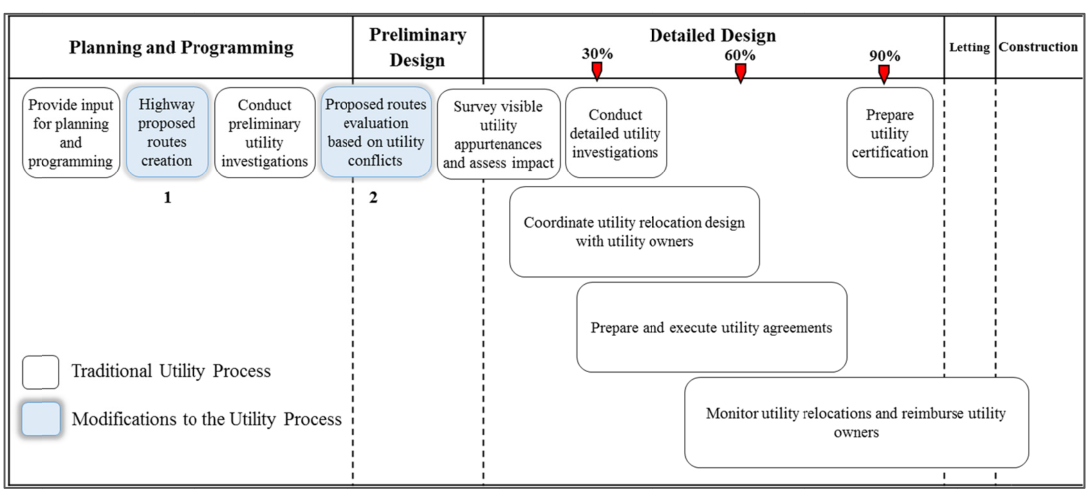

Figure 1. The Modifications to the Traditional Utility Process in DBB
(Adopted from: Quiroga, et al., 2014)

The main objective of this study is to develop a framework that evaluates and ranks proposed highway routes based on the severity of their conflicts with existing underground utilities. Above-ground utilities are not considered in this study. The framework deals with linear utility facilities that exclude point utility components such as manholes and valves. The proposed route evaluation is based on the estimated direct and indirect costs of conflicts resolution, and assumes that other factors for routing (such as environment, development, economic factors, or safety) have been already considered in the process of creating the proposed routes.

LITERATURE REVIEW

Many studies have been conducted in order to identify an optimal route for utility line projects. Utility line route evaluations and selections share similar concepts with the highway route evaluations, which are the objective of this study. Cheng and Chang (2001) used a GIS-based network analysis to develop an automated system for selecting optimal routes for an electric utility line. Their method identifies route alternatives along existing roads, determines the optimal route that has the least influence on existing utilities and roads, and identifies the conflict between the optimal route and existing utilities. The authors used Analytical Hierarchy Process (AHP) for evaluating the alternative routes and determining the optimal one. However, by using deterministic values for weighting the factors in the AHP analysis, the system limits the variation of the results of the route selection.

Luettinger and Clark (2004) presented a GIS-based process for a large-diameter transmission pipeline route selection in Utah. The selection process was completed in two stages, where the first stage eliminates the possible routes based on the construction costs, and the second stage eliminates the remaining routes based on non-cost issues, such as constructability, utility conflicts, community disruption, environmental concerns, and traffic. However, assessing the non-cost issues was based on experts' opinions and was applicable only to the project at hand, not applicable for general cases. Also, the cost of the final selected route includes only the cost of construction while the non-cost issues are only presented using a rating scale. Osman and El-Diraby (2006) developed a web-based GIS tool portal to check the compliance of new utility line routes, with design constraints regarding existing utilities. The method does not compare different routes in order to select the most suitable one and does not address the severity of conflicts or their resolving costs.

Moore, et al. (2002) used a GIS model for optimal routing for new pipelines, where four categories of influencing factors were considered (costs, environmental characteristics, land ownership, and topography). The model utilizes an ArcGIS extension—called Spatial Analyst Extension—which uses a weighting method similar to AHP to assess the influence of factors on the route selection. However, this method is subjective and its ranking system (from 1 to 9, where 1 represents a lower influence on the pipeline route and 9 indicates maximum influence) limits the variation of the different situations of the conflicting features.

METHODOLOGY

Figure 2 explains the steps of building the proposed routes' evaluation tool based on the conflicts with existing utilities. Two components were established as the basis of the evaluation tool. The first component (Box A) is a method for classifying utility conflicts based on their criticality and severity. The second component (Box B) establishes a set of considered resolution actions for each conflict class. By examining the conflict types and the considered resolution actions, a set of cost items was assigned to each conflict type. In addition, ranges of probabilities of applying resolution actions were established to assess the uncertainty of the resolution-action decision making. After this step, the equations for calculating costs and the probabilities of resolution actions are used to evaluate any proposed route after identifying and classifying its conflicts using a GIS tool.

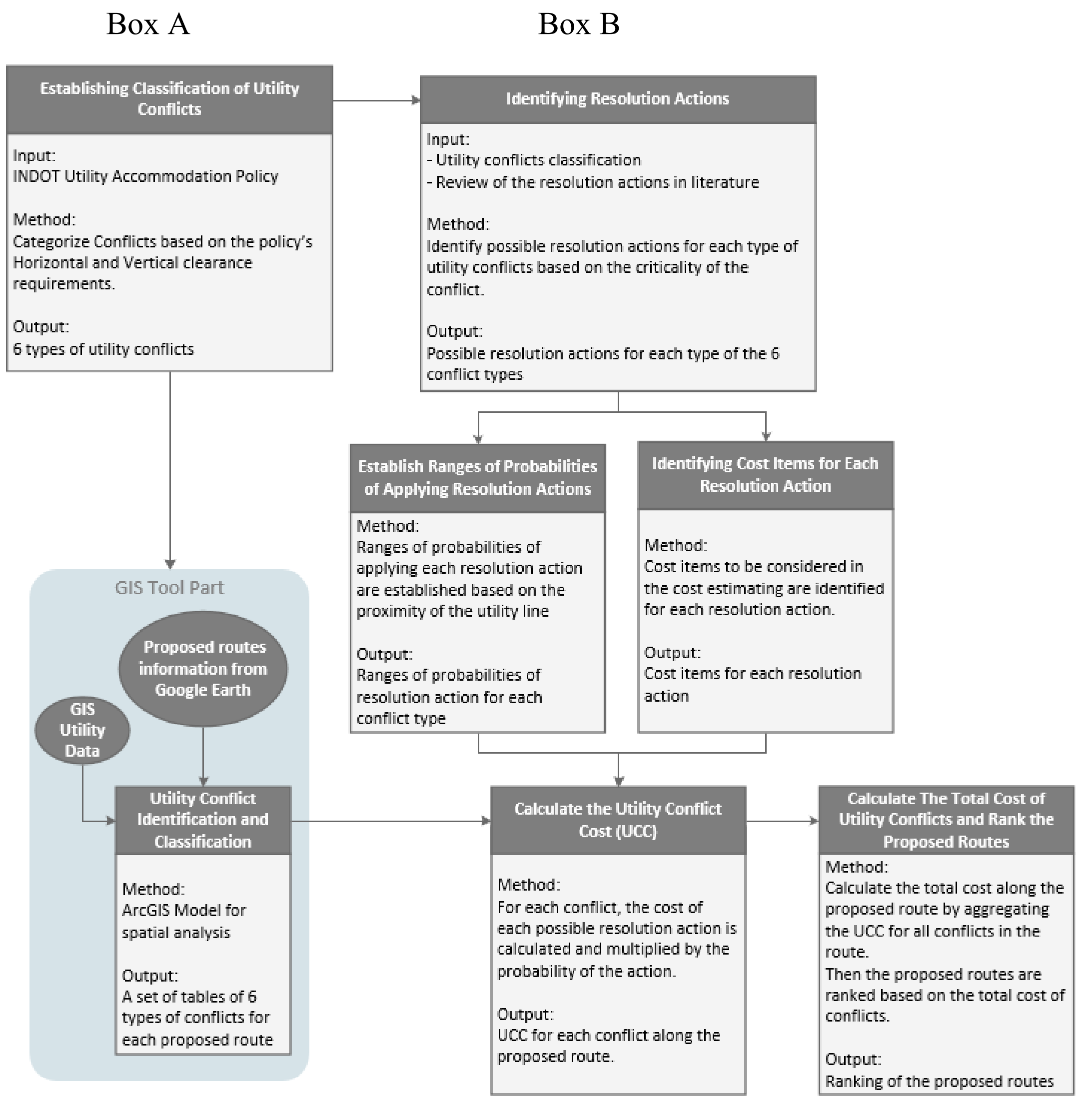

Figure 2. Framework Used in This Study; Utility Conflicts Classification

The Indiana Department of Transportation (INDOT) Utility Accommodation Policy (2013) is used to establish three horizontal zones in the right of way (ROW) of the new highway where the existing utility line might be located:

- Zone 1: Under Pavement
- Zone 2: Within 5 feet from the pavement edge
- Zone 3: Not within 5 feet from the pavement edge

The policy requires different minimum depths of cover for each horizontal zone. Based on the horizontal zone and the minimum required depth of cover of the existing utility line, the utility conflicts are classified into six types, as shown in Table 1. In addition to the minimum required depth, the consequences of the conflict in each zone have also been considered when classifying the conflicts.

Table 1. Utility Conflicts Classification

Minimum required cover	Under pavement	Within 5 ft from the pavement	Not within 5 ft from the pavement
Does not satisfy	**Type 1**	**Type 2**	**Type 3**
Satisfies	**Type 4**	**Type 5**	**Type 6**

Calculating the Utility Conflict Cost (UCC)

The UCC is the sum of the estimated direct and indirect costs of the conflict resolution, and is calculated for each utility conflict along the proposed route. Alternative resolution actions are determined based on the criticality of the conflict. For each alternate action, cost items are identified to estimate the cost of the alternative. When the conflict can be resolved by one of many possible alternative actions, the probability of each action is estimated and considered in the UCC estimate. Table 2 shows the three resolution actions that have been considered in the study and their associated cost items. Although other resolution actions could be considered, such as protecting the utility in-place or other engineering solutions, they are either applicable for conflicts during the construction—not permanent conflicts—or they are applied rarely in special situations (e.g. when utilities are attached to a bridge or when the utility requires special encasement). Table 3 summarizes the UCC estimates for the six conflict types that were introduced in Table 1. To estimate the probability of relocating the existing utility (p_R), which applies to conflict Type 1, Type 2, and Type 3, the ratio of d_i (the offset of the utility line from the most critical point in the zone) to D_i (the total width of the zone) is calculated to represent how far the utility line is within each zone. In the pavement zone, the most critical point is the centerline of the highway. In the other two zones, the most critical points are the nearest points to the pavement edge. This method of estimating the probability of relocation is based on the assumption that the closer the utility line to the centerline of the route, the greater the alignment change needed to avoid the conflict as well as a higher probability of relocation. For each one of these three zones, a range of probability of relocation is pre-identified, starting from a range of higher values of p_R for Zone 1 (under-pavement) to a range of lower values for p_R for Zone 3 (not-within-5ft). The distance ratio (d_i /D_i) is used to assign a probability value for the probability range for each zone, as shown in Table 3. The same method is also used to estimate the probability of traffic disruption in Type 5 conflicts.

Table 2. The Resolution Actions and their Cost Items

Resolution Actions	Cost Items
Utility Relocation	- Relocation Cost, R - Risk on Project Schedule, D - Impact on Nearby Facilities, N
Route Realignment (Design change)	None
Leave the utility in-place (Future conflict with utility maintenance and repairs)	- Impact on Traffic, T - Impact on Nearby Facilities, N - Impact on Pavement Service Life, P

The cost items were estimated using RSMeans cost data and published estimation models from literature, with some assumptions that are appropriate for the context of utility conflicts. The relocations cost—R—includes the earth work as well as the utility line installation. A rating of the impact of utilities on the project schedule for different types of utilities (Goodrum et al. 2006) is used to estimate the risk on project schedule—D—by assuming that each increment increase in the rating scale equals to 10% increase in relocation costs. Neighboring facilities include public facilities such as hospitals, schools, government services, libraries, and parks that are within 2,000ft from the conflict. A cost is assigned to each facility as a percentage of either the relocation cost or the traffic disruption cost—as applicable—in addition to the consideration of the proximity of the facility to the conflict within the 2,000ft circle. The cost of traffic disruption, T, due to the future maintenance of the utility line that has been left in-place is calculated using a set of equations provided by Tighe et al. 1999, where the user delay cost is estimated using the expected AADT of the new road. As for the impact on pavement service life, P, of the new highway due to excavations of future maintenance of the utility line, the cost is calculated using an average value of ($110/m) as a rough estimate for the reduction in road surface value, as suggested by Kolator (1998) (Matthews, et al. 2015).

Sensitivity and Uncertainty Analysis of UCC Calculation

Tornado diagrams were used to investigate the impact of variables in the UCC equations. There are three general equations that have been analyzed: (1) the first equation represents Type 1, Type 2, and Type 3 criticalities that share the scenario of utility relocation; (2) the second equation represents Type 4 criticalities; (3) and the third equation represents Type 5 criticalities (refer to Table 3). For type 1, 2, and 3 conflicts, the utility line length has the most significant impact on the uncertainty of the UCC. The utility material—the installation unit cost—and the probability of relocation have similar moderate impact, whereas the other factors have negligible impact on the UCC. For type 4 criticalities, the utiltiy line length is also the most significant variable, followed by the utility material. The AADT (which was not included in the first equation) is found to be the third most singnificant variable on the uncertainty of the UCC estimation found in the second equation. For Type 5 criticalities, the UCC is driven by the AADT. The other factors have limited to no impact on the equation results. The AADT significantly influences the UCC because it has an exponential relationship with the traffic impact cost (Tighe et al. 1999). Even though the AADT is included in Type 4 criticalities, its influence was less significant because the probability of traffic disruption decreases as traffic delay cost increases.

Table 3. Summary of Utility Conflict Cost Estimates

Conflict Criticality	Resolving Action Considered	Cost Items included in UCC estimating	Factors considered	Estimating Equation
Type 1: Critical Conflict	Existing utility relocation	R, D, N	Probability of Relocation, p_R High (80%-100%)	$UCC = \left(1.0 - \left[\left(\frac{d_1}{D_1}\right)(1.0 - 0.8)\right]\right)(R + D + N)$
Type 2: Moderate Conflict	Existing utility relocation Or **Major** route design change	R, D, N	Probability of Relocation, p_R Medium (40%-70%)	$UCC = \left(0.7 - \left[\left(\frac{d_2}{D_2}\right)(0.7 - 0.4)\right]\right)(R + D + N)$
Type 3: Non-Critical Conflict	Existing utility relocation Or **Minor** route design change	R, D, N	Probability of Relocation, p_R Low (10%- 30%)	$UCC = \left(0.3 - \left[\left(\frac{d_3}{D_3}\right)(0.3 - 0.1)\right]\right)(R + D + N)$
Type 4: Future critical conflict	Existing utility relocation Or No action, Future conflict with utility maintenance	Scenario 1: R, D, N Scenario 2: T, N, P	Probability of scenario 1, p_1 Probability of scenario 2, $1 - p_1$	$UCC = p_1 (R + D + N) + (1 - p_1)(T + N + P)$ $p_1 = \left(1 - \frac{Cost\ of\ Scenario 1}{Total\ Cost\ of\ both\ Scenarios}\right)$
Type 5: Future Moderate Conflict	No action, Potential Future conflict with utility maintenance	T, N	Probability of traffic disruption, p_{TN} (20%-80%)	$UCC = \left(0.8 - \left[\left(\frac{d_1}{D_1}\right)(0.8 - 0.2)\right]\right)(T + N)$
Type 6: No conflict	No action	None	None	UCC = zero

IMPLEMENTATION

The methodology was implemented in two steps for each proposed route: (1) GIS-based conflict identification and classification; and (2) Calculation of the UCC for conflicts using an Excel calculation sheet. A GIS tool with ArcGIS ModelBuilder was built in order to identify conflicts, classify them, and perform all spatial calculations and analysis. The GIS model analyzed two main inputs: (1) the proposed route information as a path created and saved by the user as .KML file in Google Earth; and (2) the existing utility geodatabase. In addition, the nearby facilities' geodatabase was also provided to the model in order to assess the impact of conflicts on these facilities. The model examined the input data and performed a horizontal check that identified the utilities in the three horizontal zones, followed by a vertical checking that further divided these three groups into six subgroups representative of the six conflict types. The model then calculated the utility line offset from the most critical point in its zone. Lastly, the model identified affected nearby facilities within 2,000ft from the conflict and calculated the distance between each affected facility and the conflict. The utility geodatabase (GIS data) included information about the utility type, diameter, line length, and depth of cover in addition to the utility material. UCC calculations for each type of conflict were performed in Excel. The Total Cost of Conflicts for the proposed route was calculated by aggregating the UCC of all conflicts along the route.

Case Study

A case study was used to demonstrate the viability of the ArcGIS Model and the Excel UCC calculations. The case study evaluates a scenario of three proposed routes for a new highway in Anderson County, Kentucky. The data was used in this study includes: sewer lines' GIS data, waterlines' GIS data, hospital locations' GIS data, and school locations' GIS data. The GIS data was edited and reasonable assumptions were made for missing attributes from the obtained data. Edits and assumptions include: (1) reasonable depths were given to the utility lines, (2) new facilities—such as hospitals and schools—were added to the original data, as were other assumptions for the proposed highway, such as the pavement width, ROW width, and the AADT (7,000 vehicle/day).

Table 4 shows the summary the case study's results. The number of conflicts and their total estimated cost are shown for each conflict type. The last two rows in the table show the final outputs: (1) the Total Cost of Conflicts for all conflicts along the proposed route, and (2) the ranking of the routes with 1 representing the route that has the lowest Total Cost of Conflicts. From Table 4, Route 3 has the lowest cost of utility conflicts among these three proposed routes. Route 3 is less costly than Route 2, even though the number of conflicts is greater in Route 3. It is partially because Route 2 has a very long utility line (>10,000 ft) under Type 4 that is not in conflict with Route 3, and as discussed earlier, the line length has a significant impact on the UCC. The case study would have slightly different results if the ArcGIS Model was capable of assigning the resolution action to only the segments of the utility line that are in conflict with the route. Also, changing the AADT to a lower value (e.g. 3,000 vehicle/day) would have an impact on the results of the evaluation since the AADT has a significant impact on the UCC.

Table 4. Summary of Case Study Results

		Route 1	Route 2	Route 3
Type 1	Number of conflicts	48	18	34
	Total UCC	$400,332	$201,017	$264,307
Type 2	Number of conflicts	3	4	5
	Total UCC	$4,348	$57,025	$40,645
Type 3	Number of conflicts	1	0	0
	Total UCC	$4,348	$0	$0
Type 4	Number of conflicts	9	2	1
	Total UCC	$212,080	$192,490	$39,696
Type 5	Number of conflicts	2	0	2
	Total UCC	$68,444	$0	$71,115
Type 6	Number of conflicts	8	4	3
	Total UCC	$0	$0	$0
Total Cost of Conflicts		**$685,609**	**$450,533**	**$415,764**
Ranking		3	2	1

CONCLUSION

The framework described in this study assesses utility conflicts in a comprehensive way during the early stages of planning and design phases. The case study demonstrates that the number of conflicts cannot alone be used to evaluating routes. Rather, the assessment should include considerations on the severity of the conflicts as well. When including the utility conflict costs in the route choice process, some alternatives that were eliminated at earlier stages due to cost issues can be reconsidered, since they might become more economical. The discussed framework can assist highway planners in order for them to easily examine the utility conflicts on proposed routes with minimal required design information. However, the level of confidence in the evaluation and ranking decision depends on the level of quality of the utility GIS data. More detailed analysis of the conflicts in the chosen route is important to confirm the conflicts, recheck their severity, eliminate them, or identify new conflicts in order to estimate more accurate relocation costs.

Although the framework is developed for new highway projects with some modifications and assumptions, it can be used for other types of transportation projects, such as railroads, metro lines, and highway widening projects. The direct costs considered in the study are mainly incurred by the transportation agency and/or the utility owners. However, the framework is applicable even if the cost is incurred by other entities. The framework can also be adjusted to adopt the cost data of any company or agency that uses their own cost data for estimation. Although the utility conflict classification is based on the INDOT Utility Accommodation Policy, it can be modified to address the needs that are listed in the utility policies of other states. For example, the Utilities & Rails Guidance Manual of the Kentucky Transportation Cabinet specifies different minimum required depths for only two zones within the ROW. This difference would be addressed in the framework by establishing four types of conflicts instead of six types. However, the aim of this paper was to demonstrate the methodology that could be used, irrespective of the location of the project. The results of the GIS model include GIS data for the conflicts that can be used to identify the locations that require more accurate and detailed utility line investigation. The method used in this study can be further enhanced to generate highway route alternatives using an automated process or it can be included as a criteria in established route optimization algorithms.

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