DESIGNING A DECISION SUPPORT PROCESS AND MODEL FOR COMBINED TRANSPORTATION AND UTILITY CONSTRUCTION PROJECTS

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ABSTRACT

In highly developed metropolitan areas, there are more and more highway projects that require adjacent utilities to be relocated in order to make room for new highway facilities. Traditionally, utility companies are responsible for their own relocations prior to highway construction. However, recent research has identified that the utility relocation delay is the root cause for delays in highway construction. One major strategic approach over the last 15 years among state Departments of Transportation (DOTs) is to combine utility relocation work with the highway contractor's scope of work, thereby reducing project duration and minimizing complications and risks. While many benefits can result from this combined approach, it does have its disadvantages and own set of challenges. Hence, in the highway planning and design phase, a decision support tool for Combined Transportation and Utility Construction (CTUC) projects was developed to provide guidance to both DOT and utility decision makers as to how the combined approach could be applied. This paper discusses the decision support process and model embedded in this CTUC decision support tool.

KEY WORDS

Decision Support System, Combined Transportation and Utility Construction, Utility Relocation, Highway Planning and Design, Computer Supported Collaborative Work.

INTRODUCTION

In highly developed metropolitan areas, there are more and more highway projects that require adjacent utilities to be adjusted in order to make room for new or expanded highway facilities. Traditionally, utility owners are responsible for their own adjustments prior to highway construction. In this paper, this method is referred to as the "Conventional Approach." Since utility owners may not have enough resources during the time of utility

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adjustment work requested from DOT, recent research papers have tended to show that the delay resulting from utility adjustments is the root cause for delays in highway construction (Ellis et al. Thomas 2003) (GAO 1999). One major strategic approach over the last 15 years among DOTs is to combine utility adjustment work with the highway contractor's scope of work, thereby reducing the project duration and minimizing complications and risks. This approach is referred to as the CTUC approach. Nevertheless, utility owners' concerns such as the highway contractor's adjustment quality and limited warranty, and utility owners' non-transferable liabilities are likely to frustrate a highway project with the use of CTUC. Further, since current practices regarding communication patterns and coordination steps in CTUC decision-making can only ameliorate a small part of problems, an easy-to-follow process is required so that a systematic and transparent method for all parties involved can be developed to exchange information and to reasonably make the CTUC decision. All in all, there is a need to design a decision support process and model in order to provide recommendations for DOT and utility owners' decision makers as to whether or not the CTUC approach should be applied.

RESEARCH METHODOLOGY

This research is divided into 6 major steps: (1) Conduct literature review and preliminary interviews, (2) Identify and analyze CTUC decision variables, (3) Design CTUC decision support process, (4) Design CTUC decision support architecture and model, and (5) Develop CTUC decision support tool, and (6) Validate CTUC decision support model and tool. The ensuing sections will provide in-depth descriptions for each of the aforementioned steps.

LITERATURE REVIEW AND CHARACTERISTIC ANALYSIS OF CTUC DECISION-MAKING

Past research studies have indicated that in the conventional approach, delays to highway construction projects caused by utility adjustments result in longer completion times and increased costs (GAO 1999). Other research projects have also documented the CTUC approach as the next logical solution to the problems occurred in the conventional approach (AASHTO 2004). However, none of these research studies discuss why utility owners do not want to use the CTUC approach. In other words, most research projects focus on the problems of the conventional approach and implementation details of the CTUC approach. Hence, in this research, utility owners' opinions, as well as DOTs', will be extracted first through literature review and interviews. Then, identification of CTUC decision variables along with characteristic analysis of CTUC decision-making will be performed so that the proper decision support techniques can be selected and applied. Due to page constraints, only some CTUC decision variable descriptions are listed in this paper, and the main characteristics of CTUC decision-making are described as follows:

CTUC Is a Concurrent Decision

The CTUC decision is about whether or not the CTUC approach should be applied in the given utility adjustment project. Since each utility adjustment project in a highway project may have distinct requirements, the number of CTUC decisions shall be equal to the number of utility adjustment projects in a highway project. In addition, these decisions may be made at different timeframes, mostly within the highway design phase. Complication can arise when two simultaneous decisions influence each other, which causes one or both to take more time than would be required in a serial context. Past research also indicated that the DST (Decision Support Tool) supporting decision-making in a concurrent context should aid the decision maker's efforts to gain the benefits of concurrency or avoid its drawbacks by assisting in coordination and promoting synergy (Holsapple et al. 1996).

CTUC Is a Multi-Party Decision

In a typical highway project with at least two utility adjustments, it is ordinary that coordination between utility owners is complex not only because they may share some facilities that need to be adjusted in a special sequence, but more importantly because unknown physical conflicts may exist among the facilities. CTUC is certainly a multi-party decision where consideration must be given to DOT and the corresponding utility owners. Thus, any decision information related to the other parties might need to be transferred on demand.

CTUC Is a Negotiation Decision

CTUC is not a unilateral decision because no single party can enforce the other party to use CTUC. Although DOT may have more authority and resources than other parties, DOT still has to negotiate with utility owners involved in order to reach consensus. A negotiation decision is a give-and-take interchange with other parties until all agree on a particular alternative (Holsapple et al. 1996). This implies that a significant portion of CTUC DST may have to provide decision recommendations instead of numerical decision results. In other words, CTUC DST should serve as a means to facilitate the decision process dialogue, rather than calculating an answer.

CTUC Is a Repetitive Decision

Since there are more and more modern highway projects involve utility facilities to be adjusted, it is obvious that CTUC is not a one-shot decision. Research has shown that development of routine decisions allows decision makers to maintain mastery of the situation. Once a behavioral solution from experts to a decision problem has been learned and documented, individuals can use this knowledge when they reencounter the same kind of problem (Holsapple et al. 1996).

CTUC Decision Lacks Quantitative Data

Most CTUC decisions are made based on project stakeholders' experience. Though Subsurface Utility Engineering (SUE) can provide plenty of numeric, accurate data regarding position of underground utility facilities, the data only contribute the portion of utility conflict information to CTUC decision makers. Another possible quantitative data source is the database recording utility permits, e.g., ROWIS in TxDOT. Since it only stores TxDOT's managerial data, other relevant decision information may need to be developed.

The project stakeholders who have extensive experience of utility adjustments have been immersed in such environments for many years, and they know whether CTUC is the best approach as long as they can correctly perceive the current project circumstances. However, it is very difficult to represent knowledge or experience in quantitative formats, although experts' experience can be acquired and documented in knowledge management systems. Overall, lack of quantitative data would impose the requirement that CTUC decision support model shall incorporate more qualitative data from experts in this field. In addition, CTUC DST should provide transparency in invoking decision makers' judgment on relative importance of decision variables, as well as help decision makers sort out what decision variables drive or impede the use of CTUC on the project under consideration.

CTUC Decision Is In a Dynamic Environment

CTUC decision-making is actually in a dynamic environment. The decision made at the earlier time may assume some conditions, which may be changed at the latter time. Therefore, CTUC DST should provide a persistence service to store the history of all assumptions made so that decision makers can revisit and examine them at any time.

DESIGNING CTUC DECISION SUPPORT PROCESS

Figure 1 shows the proposed CTUC decision support process. Each rectangle represents an activity and contains a description of that activity. The bottom portion of the rectangle indicates which party is responsible for each activity. The two actual meetings for CTUC decision making purposes (Activities #1 and #4), in which CTUC DST will be used, are indicated with bold rectangles (Goldman 2005).

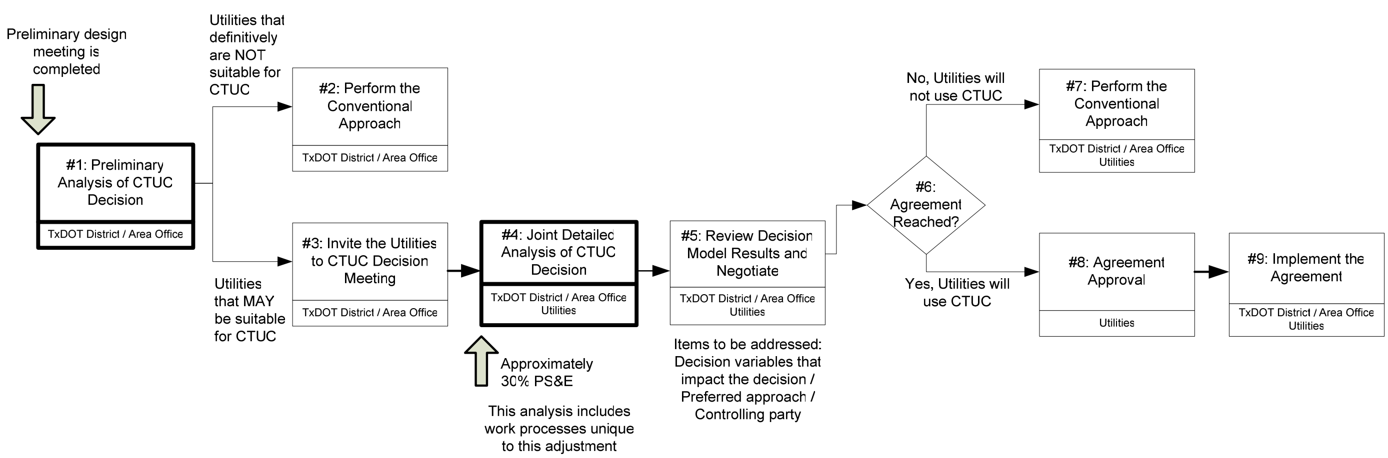

Figure 1: CTUC Decision Support Process

The goal of Activity #1 is to separate utility owners that are definitely not suitable for CTUC from those which may be appropriate for CTUC (Goldman 2005). From DOTs' perspective, the earlier they can separate the utility owners into two groups, the fewer efforts are necessary for utility coordination. The complexity resulting from concurrence of multiple CTUC decisions can be also alleviated because fewer CTUC candidates exist in the latter phase.

The joint detailed analysis is performed as a combined effort by DOT and the utility owners. They provide information as prompted by CTUC DST. As indicated by the name, the joint detailed analysis decision activity requires more comprehensive information input from the stakeholders than the preliminary phase, and is thereby able to produce a more thorough result. Once the tool has gathered the necessary project-specific information from each party, it will exchange and integrate collected information, and provide outputs to serve as guidance for DOT and each utility regarding whether or not the CTUC approach would be beneficial for the given adjustment (Goldman 2005).

Following Activity #4, each utility owner will meet with DOT in order to "Review Decision Model Results and Negotiate" (Activity #5). This activity provides the utility owners and DOT the opportunity to discuss potential project-specific challenges that can be simplified through effective coordination, as well as to rectify possible concerns associated with the CTUC approach and to suggest or consider procedural changes that could result in a more effective adjustment process (Goldman 2005). Since DOT can know each utility owner's stands in advance through the use of CTUC DST, coordination and negotiation will be simpler, and DOT can have more time to deliberate the proposed approach instead of making the decision on-the-fly.

SELECTION OF CTUC DECISION SUPPORT TOOL ARCHITECTURE

Since DST technologies are widely used in almost every business domain, providing better CTUC decision recommendations may need to reuse or integrate current DST technologies. Hence, the architecture of each major DST is discussed first so that the appropriate architecture of DST can be defined and developed further.

In model-driven DST, decision analysts (i.e. professionals who do not have domain knowledge but have the ability to perform decision analysis) examine data, identify decision variables, and develop a mathematical model to best describe the problem domain. Model-driven DST can then use the model to perform simulation under varied events in order to aid decision makers (i.e. professionals who have domain knowledge and are primary users of DST) in analyzing a situation (Holsapple et al. 1996). However, since there are not enough quantitative data to formulate a mathematical CTUC model, nor is the computation task of model simulation expected, the architecture of model-driven DST doesn't fit CTUC decision requirements. In order to find out CTUC decision core tasks, the general human decision-making process model is introduced as follows (Holsapple et al. 1996):

(1) Intelligence: Observe reality. Gain problem understanding. Acquire needed information.
(2) Design: Develop decision criteria. Develop decision alternatives. Identify relevant events. Specify the relationships between criteria, alternatives, and events.
(3) Choice: Logically evaluate the decision alternatives. Develop recommended actions that best meet the decision criteria.
(4) Implementation: Develop an implementation plan. Secure needed resources. Put implementation plan into action.

Thus, a CTUC decision may need DST to primarily assist its decision makers in the Intelligence and Design phases because the Choice phase is in fact a very human negotiation process in CTUC, which is covered in Activity #5 in Figure 1. In Executive Information System (EIS), a time-series of data exists and will be automatically organized into specified board categories, which are defined by decision analysts and decision makers. The decision maker will then view (slice or dice) the data from interesting perspectives (Holsapple et al. 1996). The EIS directly supports the Intelligence stage; however, CTUC may not have so many data to be analyzed. In Machine Learning System (MLS), the computer system will simulate learning, organize problem data, and structure the learning model. The decision makers can then reuse the model provided by MLS (Holsapple et al. 1996). Hence, it is not the type of DST that can be applied in CTUC because CTUC needs a mechanism to collect each party's opinions in advance and if possible, to compare each party's opinions to the opinions from CTUC experts so that decision makers will know the right direction they should follow, just like the way EIS provides to its managers. The decision analyst will identify several potential decision variables, and then EIS will use a lot of real data to perform the trend analysis, eliminate unimportant variables, and finally show the net effect of these important variables. While in CTUC, if the real data can be replaced by experts' opinions, and parties' opinions can be seamlessly exchanged, CTUC DST can be said as an integrated system that has group communication and EIS functionalities.

In addition, since some of CTUC decision makers may be novices, it would be better to let decision makers just identify current project circumstances and make simple predictions of future project states. Assessing the impact on the CTUC decision and defining corresponding recommendations pertaining to each project circumstance should be delegated to CTUC experts to evaluate in a project-independent context.

DESIGNING CTUC DECISION SUPPORT MODEL

Decision Variable

A CTUC decision variable is a variable that drives the CTUC decision. The variable may be **certain** before the CTUC decision is made, or **uncertain** (also known as "State Variable") with probabilities associated with each possible value or option. There are two data types in the values of CTUC decision variables, i.e., **nominal** or **numeric**. Since the CTUC decision does not have many quantitative data, most CTUC decision variables' values are nominal. For example, "Lane Closures" is an uncertain CTUC decision variable with three possible, nominal values: *1) CTUC requires substantially fewer lane closures than the Conventional approach during the project execution, 2) the Conventional approach requires substantially fewer lane closures than CTUC during the project execution, and 3) the number of lane closures in both approaches is about the same.* "Lane Closures" is uncertain because it represents a future traffic state of the project when CTUC or the conventional approach will be used. CTUC decision makers just select the most possible value based on current project circumstances, and CTUC DST will show the impact level and recommendations of this value from experts' opinions.

"Eligibility" is a certain CTUC decision variable with numeric values. The value of "Eligibility" represents a numeric ratio of the amount of one utility adjustment project costs that DOT has to pay. It will influence the CTUC decision because experts indicated that utility owners will be willing to pursue CTUC if DOT pays all utility adjustment costs. In addition, "Eligibility" is a certain decision variable because most DOTs determine this ratio before approaching the CTUC approach. However, if an extraordinary event happens such as the utility owner loses the documents of the prior right, this ratio may be changed. Hence, certain variables, like uncertain ones, become changeable under some uncommon situations, and each value of the variable should have the corresponding occurrence probability.

It should be noted that all values of one decision variable should be unique, and the set of all values should include all potential states of this decision variable. Furthermore, if the value belongs to an uncertain decision variable, the description defined in this value must imply that either CTUC or the conventional approach will be used, as shown in "Lane Closures" values' descriptions.

Decision Context

Theoretically, the relationship between CTUC decision variables is assumed to be fixed and should be identified and depicted in an influence diagram. However, the CTUC decision is so complicated that even the relationship between decision variables is not constant, and will be changed according to other decision variables' values. For example, "Unacceptable Specifications" usually means that utility owners cannot provide a set of specifications that is acceptable to DOT in terms of assignment of responsibility, liability, and risk. Hence, it is usually Anti-CTUC and has a high impact on the design aspect of the project. However, if the utility owner is a public utility and has a good relationship with its DOT (another two decision variables), the above situation become CTUC-neutral because the public utility is willing to let DOT manage the utility adjustment project, including hiring utility adjustment design consultants to develop the specifications.

Since the CTUC decision is in a dynamic environment, in order to simplify it, each decision variable is assumed to be independent. If all relevant decision variables can be identified, and if each party's opinions can be collected and integrated seamlessly, it is believed that CTUC decision makers can negotiate with each other and select the best approach regardless of whether or not the correct relationships between decision variables are defined.

Although the assumption of independence can be made between most decision variables, there are still some decision variables that have profound impacts on all decision variables, but only have indirect influence on the CTUC decision. They are all certain decision variables. For example, the type of a project stakeholder (DOT or utility owner) influences almost all CTUC decision variables. It cannot be said that if the user belongs to DOT, the CTUC approach is preferred. However, it can be said that if the project stakeholder is DOT, "Lane Closures" is a very serious issue while a utility owner may not agree. The type of project stakeholders is thus defined as a "Decision Context."

"Past CTUC Experience" is another CTUC decision context. Again, having good CTUC experience in the past can not always imply use of CTUC, yet it indeed influences other decision variables. Having no CTUC experience can not preclude the utility owner from joining CTUC in the future.

Measurement of Impact Level

The basic elements of each CTUC decision variable in the proposed model are described as follows:

(a) Decision Variable Name: The name of the decision variable. For example, Schedule Pressures.

(b) Possible Value (or Option): A decision variable may contain several possible options. An option may be a number or a statement that describes a hypothetical project circumstance. For example, in Schedule Pressures, they are: 1) the project has severe schedule pressures, and the utility adjustment scope can be well defined before 60% PS&E, 2) the project has severe schedule pressures, and the utility adjustment scope cannot be well defined at approximately 60% PS&E, 3) the project does not have severe schedule pressures, 4) don't know, and 5) this question is not applicable in this project. Note that the last two options are added automatically for each decision variable.

(c) Pro/Con: The preferred approach for each value of the decision variable. There are five possible choices of Pro/Con, namely: 1) Pro-CTUC only, 2) sometimes Pro-CTUC and sometimes Neutral, 3) Neutral, 4) sometimes Anti-CTUC and sometimes Neutral, and 5) Anti-CTUC only.

(d) Impact Level: How much benefit to the project from the project stakeholder's view; in other words, the impact on the CTUC decision. When Pro/Con is "Pro-CTUC" or "Pro-CTUC or Neutral," the possible impact levels would be: High, Medium, Low, or No Impact. When Pro/Con is "Anti-CTUC" or "Anti-CTUC or Neutral," the possible impact levels would be: Show-Stopper, High, Medium, Low, or No Impact. Note that Show-Stopper should be marked only when the circumstance precludes further analysis of CTUC. In other words, the conventional approach would definitely be used for the project.

(e) Situation Resolvable: Whether or no the situation can be changed to facilitate CTUC. It indicates the controlling party responsible for possible process changes to facilitate CTUC. As mentioned before, since the CTUC decision is the result of a series of negotiation activities, decision makers need to know whether or not the value of this decision variable can be switched to the other value. If the project circumstance can be changed so that "Anti-CTUC" can become "Neutral" or "Pro-CTUC", or "Low Impact" of "Pro-CTUC" can become "High Impact," the efforts to make the change should be persuaded. The possible answers are: "Yes, the process can be changed, but the responsible party is unknown"; "State DOT is responsible for the process change"; "Utility is responsible for the process change"; "Other parties are responsible for the process change"; "No, there is no chance to change the process to facilitate CTUC."

(f) Confidence Level: How confident the decision maker feels about this answer. The possible choices are: "Certainly True Option"; "Probably True Option"; "Impossible Option."

Analysis of Impact Type

It is obvious that not all values within one CTUC decision variable influence the decision in the same direction. Some values may be Pro-CTUC, while the others may be Anti-CTUC or Neutral. Figure 2 shows a hypothetical DOT expert's opinions regarding the decision variable of Schedule Pressures. Note that CTUC experts are expected to assess Pro/Con, Impact Level, and Situation Resolvable for each value, while CTUC DST users (or project stakeholders) are expected to evaluate or predict the option that can best describe the current project, and indicate the confidence level.

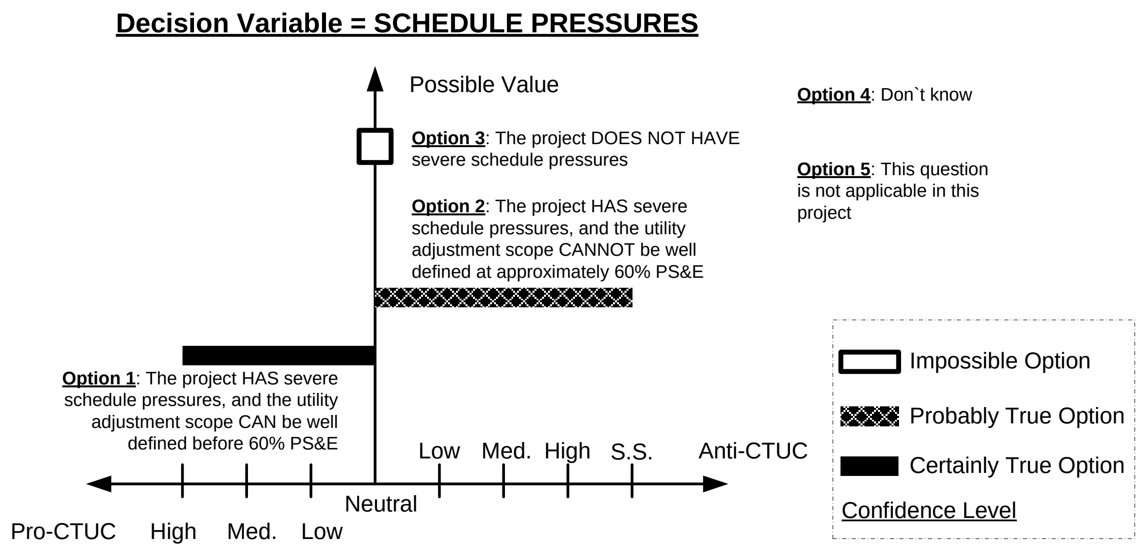

Figure 2: Three Impact Types of a CTUC Decision Variable's Value

CTUC Decision Support System

CTUC DST based on the proposed model is being developed. When CTUC decision makers use the system, the first thing is to select the correct value of each decision variable that can best describe their specific project circumstance. Then, they evaluate the confidence level of this answer. The system will show Pro/Con-CTUC, Impact Level, and Situation Resolvable from previous assessment results from experts. CTUC decision makers can therefore review these data and may make adjustments to the above elements based on specific project conditions. As discussed before, the assessment results from experts are in the general context. Decision variables may behave differently depending on the value of the other decision variables.

The major report of the system is shown in Figure 3. Figure 3 summarizes the results from a DOT and a utility owner for the CTUC decision on a hypothetical utility adjustment. The top 6 Pro-CTUC and Ant-CTUC decision variables from DOT's perspective are displayed, compared with Utility ABC's perspective. DOT and Utility ABC may have different impact levels, e.g., both DOT and the Utility ABC think "Specification Consistency = High" is Pro-CTUC; however, DOT thinks it has high impact while Utility ABC thinks it has low impact on the CTUC decision. Sometimes DOT and Utility ABC don't have the same opinion on the same decision variable. For example, DOT thinks "HAZMAT = only on utility" while Utility ABC thinks "HAZMAT = on both sides." In this case, further clarification and negotiation activity is necessary because both parties may have different understandings on the same issues.

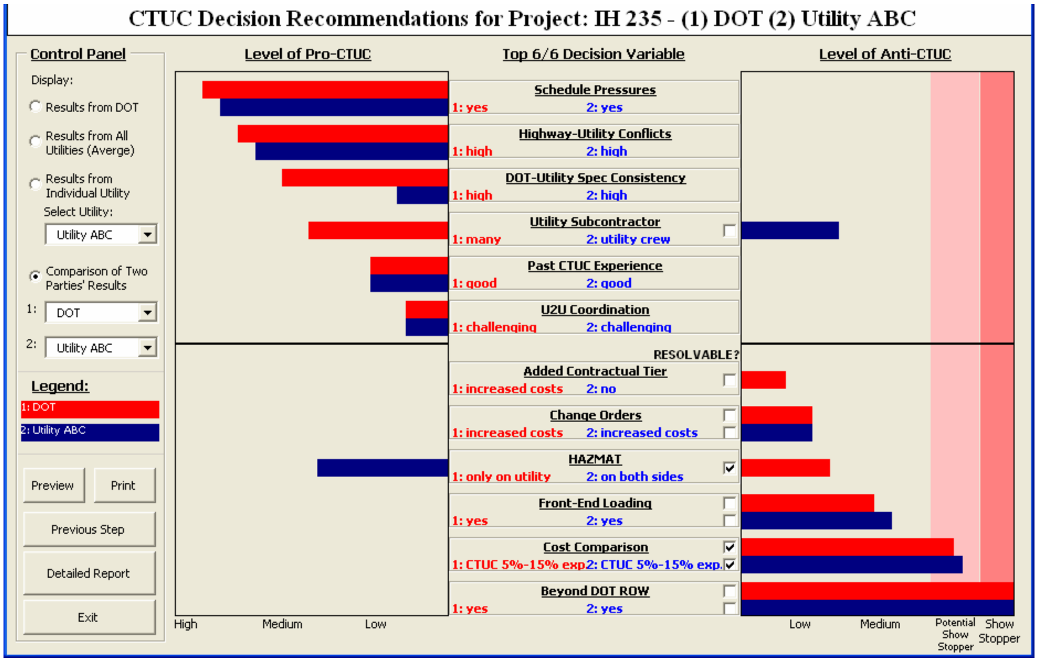

Figure 3: Graphical Results of a DOT and a Utility Company

CONCLUSIONS

Successful implementation of the CTUC approach requires systematic analysis and early decision-making based on CTUC decision variables. Both the conventional approach and the CTUC approach should be treated without bias. The CTUC decision support model was designed to capture project circumstances and to highlight the factors that impact the decision on the most appropriate project delivery method for a given utility adjustment. The system itself serves as an intelligence tool that assists decision makers in capturing and evaluating the project circumstances in a systematic way.

REFERENCES

AASHTO. (2004). *Right of Way and Utilities: Guidelines and Best Practices*, American Association of State and Highway Transportation Officials, Washington, D.C.

Ellis, R.D., and Thomas, H.R. (2003). "The Root Causes Of Delays in Highway Construction." *82nd Annual Meeting of the Transportation Research Board*, Transportation Research Board, Washington, D.C.

GAO. (1999). "Transportation and Infrastructure: Impacts of Utility Relocations on Highway and Bridge Projects." *GAO/RCED-99-131*, United States General Accounting Office, Washington, DC.

Goldman, G. (2005). "Combined Transportation and Utility Construction: Analysis of Approach." *M.S. Thesis*, Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX.

Holsapple, C.W., and Whinston, A.B. (1996). *Decision Support Systems: A Knowledge-Based Approach*, West Publishing, St. Paul, MN.