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A Decision-Oriented Framework for Evaluating Deployment Strategies for Intelligent Transportation Systems

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of both the stakeholders and the champion of ITS deployment. Decision-tree analysis is an effective approach to minimizing deployment risk as well as to maximizing R&D productivity.

Applications of the Framework

The proposed deployment framework has several important applications. It can be used to help researchers and champions of ITS:

- recognize and organize issues and uncertainties associated with deploying ITS user services;
- evaluate deployment strategies for any particular user service concept or a set of multiple concepts that have been developed, for one location or multiple locations;
- define what constitutes a viable (long-term) user service concept, i.e., high-level design of a forward-looking transportation service, by specifying which issues must be addressed by such a concept;
- design deployable user service concepts and steer the R&D process;
- optimize allocation of resources to study deployment issues;
- provide a "cognitive map" of the issues, uncertainties, projects and risks;
- determine what can be expected from a deployment or RDD effort.

A case study of TravInfo has been performed to test the validity of the proposed framework and to suggest modifications. The findings have been reported in a PATH Research Report entitled "Testing a Proposed Decision-Oriented Framework to Understand ITS Deployment Issues: An Examination of the TravInfo ATIS Project" (UCB-ITS-PRR-98-35).

1 Introduction

The term Intelligent Transportation Systems (ITS) has been used to refer to a collection of concepts and technologies that have the potential of significantly improving current surface transportation systems. Such a concept combined with the companion technology is often referred to as an ITS user service. Approximately thirty categories of such user services have been formally recognized in the the National ITS System Architecture [9], e.g., route guidance, traffic control, incident management, public transportation management, (longitudinal, lateral and intersection) collision avoidance, automated vehicle operation, etc. These user services can be implemented through a large number of *market packages* whose functions and designs are consistent with the System Architecture [10]. To simplify discussion, we focus on the level of user services and address user services exclusively in the rest of the paper.

A user service is usually broadly defined. Therefore, many *user service concepts* or simply *concepts* can be defined and corresponding systems designed. Since some of these user service concepts cannot be developed and implemented suddenly, they are often referred to as end-state concepts; hence, intermediate concepts are required.

Some ITS user service concepts are being deployed while others are being researched and developed. For ease of discussion, we refer to these concepts as *near-term* and *long-term* ITS user service concepts, respectively. To develop a framework robust enough to cover both groups of ITS user services, we focus on the latter group. Occasionally, we will refer to those concepts whose expected deployment time, if actually deployable, is far into the future as "longer-term" ITS user service concepts.

Since ITS R&D is performed for the ultimate possible deployment of the user service concepts in the real world, deployment issues may limit the design options for ITS concepts and technologies and, hence, can be viewed as constraints on ITS R&D. Therefore, researchers and developers of ITS technologies must anticipate the companion deployment issues at the outset of the R&D process. Moreover, recognition and resolution of major deployment issues should actually be an integral part of the R&D process.

This paper focuses on deployment issues generic to most ITS user services. Deployment of any specific ITS user service will likely involve additional issues peculiar to that specific user service.

We propose a framework to help recognize and organize issues that must be addressed for success of ITS deployment. Our objective is primarily to help ITS researchers in developing *deployable* long-term ITS user service concepts and technologies. The findings can also be used to help ITS promoters in deploying near-term user services. For convenience, we will refer to a framework of this nature simply as a *deployment framework*.

The purpose of this paper is to help identify all major ITS deployment issues early in the research, development and deployment process so that they will not catch researchers or implementation agencies by surprise. An attempt has been made to identify as many issue categories and individual issues as possible. This focus on issues/possible problems may appear negative, but the intent is to anticipate problems and overcome them as early as possible.

In the context of ITS deployment, the definition of *deployment* is quite vague. A fundamental question is "who deploys an ITS user service." Given the large number of "players" involved in the deployment of most ITS user services (including the free market and the general public), it is difficult to provide a general answer to this question. Starting with this fundamental question, this paper first focuses on the multitude of decisions that may impact the deployment of ITS user services and then derives a decision-oriented deployment framework.

ITS deployment is a complex interdisciplinary endeavor that can benefit from the knowledge accumulated in many traditional academic areas. One such area is technology transfer. We will briefly discuss its relevance to ITS deployment. Two perspectives will be discussed, namely the perspective of a technology-transfer promoter and that of the intended recipient of the technology. There exists a large amount of literature about technology transfer. To keep our discussion succinct and to avoid the need for extensive discussion about how to extract relevant knowledge from studies conducted purely for private industries or from studies involving public-sector but non-transportation pursuits, both perspectives will be discussed in the context of transferring transportation technologies. These two perspectives actually confirm the importance of a decision focus and a decision-oriented deployment framework.

This paper is organized as follows. Section 2 discusses ITS deployment, its salient features and our approach to developing a framework for recognizing and organizing ITS deployment issues. Section 3 proposes a decision-oriented framework. Section 4 briefly discusses the role of technology transfer in ITS deployment. Concluding remarks are given in Section 5, including possible applications of the proposed framework and urgent research needs.

A case study of TravInfo has been performed to to test the validity of the proposed framework and to suggest modifications. The findings have been reported in a PATH Research Report entitled "Testing a Proposed Decision-Oriented Framework to Understand ITS Deployment Issues: An Examination of the TravInfo ATIS Project" (UCB-ITS-PRR-98-35).

2 Salient Features of ITS Deployment and An Approach to Framework Development

2.1 Who Deploys an ITS User Service?

The term *deployment* has been used extensively in the ITS community. However, its meaning has not been very clear. It is usually clear what user service is being discussed, and also clear that a user service can be said to have been deployed if its functionality has been physically implemented and also widely used. However, it is often not clear just who deploys a user service. This fundamental ambiguity is particularly perplexing when the successful deployment of the user service under discussion involves many "players" and requires acceptance by the free market (including the private service/product providers and the consumers) as well as the general public. Note that answering this question is important because it helps determine *what* actions are needed by *whom* to ensure the success of ITS deployment.

To clarify the point, let us contrast the usage of the term *deployment* in this context with some of the other popular usages of the term, e.g., deploying troops on a battle field or deploying an air bag of a car. In these other contexts, there is a single and organized chain of command, and only spatial spreading is involved. However, deployment of ITS user services in the transportation systems of a democratic society is much more complicated.

2.2 The Need for a Champion and an Organized Effort

In seeking a direct answer to this difficult question, we observe that the deployment of most, if not all, ITS user services requires favorable decisions made by a multitude of decision makers (individuals or organizations) and that these decisions together could culminate in the eventual implementation and wide-spread use of the ITS user services. In addition, it is generally difficult to identify one organization that is able to serve as the "deployer" of an ITS user service in the sense that it alone has the authority over and is capable of taking all the actions needed to ensure the success of deployment.

Therefore, rather than insisting upon the identification or designation of a deployer for an ITS user service (for a given geographical area), we postulate that there need be and can only be a *champion* at best for ITS deployment that motivates or "pushes" the rest of the decision makers to make decisions favorable for the deployment of the ITS user service. Note that, in this paper, a champion refers to an organization. Note that there may be some particular user services for which a deployer in the sense defined above can be found. In such a case, the deployer can be thought of as a special case of a champion. There could be multiple champions. In such a case, we consider them as a group and refer to them as *the champion* for ease of discussion, as if there exists only one champion. Recently, Public Technology Inc. [12] (which is the non-profit technology organization of the National League of Cities, the National Association of Counties, and the International City/County Management Association) also recognized the importance of the existence of a champion or champions for ITS deployment. Section 4.2 of this paper will have a more detailed discussion.

In addition to the need for a champion, a successful deployment of ITS user services depends on a multitude of favorable decisions to be made by relevant players and hence is postulated to require an *organized* effort.

2.3 A Decision-Focus Approach for ITS Deployment

The goal of ITS deployment is to achieve intended *changes* to the current transportation systems or to the traveling public. The changes are postulated to result from human actions, which are in turn assumed to result from human *decisions*. We focus on such decisions in this paper.

Relevant decisions may be made, either consciously or subconsciously, by an individual or an organization. An individual may be a private citizen or a legislator; an organization may be a private organization, public agency or a legislative body. For ease of discussion, we will refer to such an individual or organization as a decision maker.

2.3.1 Controllable, Influenceable and Exogenous Decision Variables

With respect to the champion, relevant decision variables can be grouped into three categories: controllable variables, influenceable variables, and exogenous variables. Controllable variables are those that are within complete control of the champion; influenceable variables are those that cannot be controlled but can be influenced by the champion; exogenous variables are those that cannot even be influenced, let alone being controlled, by the champion. For example, in the State of California, Caltrans is a champion for ITS deployment. From its perspectives, the controllable variables include its budget allocation and policies. Although it does not have jurisdiction over transportation issues of individual counties and cities of the State or over vehicle manufacturers, it can influence the local officials and the manufacturers. Deploying ITS in the State requires funding, which in turns depends on the State economy. Economy is clearly out of the control of Caltrans, and hence it is an exogenous variable. An important factor for the economy is oil price, and the world oil supply would also an exogenous variable. In this terminology, the champion needs to use the controllable decision variables to influence the influenceable decision variables while coping with those exogenous decision variables (and events) so as to maximize the probability of eventual implementation of the ITS user services under consideration. For convenience, we will refer to the decision makers associated with the influenceable and exogenous decision variables as influenceable and exogenous decision makers, respectively.

The impacts of influenceable and exogenous decision variables on ITS deployment vary. In other words, the importance of favorable influenceable and exogenous decisions varies. It is possible that in some cases the individuality of the influenceable decision makers does not matter but the number of such decision makers in support of the champion's desire matters, e.g., the case of a voting process. In addition to these decision variables, the success of ITS deployment may also depend on some exogenous events, e.g., the advances of some fundamental technologies, the price of gasoline, etc. Since exogenous decision variables are beyond the control and influence of the champion, we treat their outcomes simply as exogenous events.

2.3.2 Decision Dynamics

Decisions interact with one another. Some decisions may lead directly to or may contribute to some other decisions made by other decision makers. We will refer to such interaction among relevant decision makers (and decision variables) as *decision dynamics* for ITS deployment. Note that decision dynamics for ITS deployment consist of four major components: (i) the relevant decision makers and decision variables (grouped into controllable, influenceable and exogenous), (ii) the decision-making process of individual decision makers, (iii) the interaction among the influenceable decision makers, e.g., competition, and (iv) the process of the champion's influencing the influenceable decision makers.

2.3.3 Decision Making: Art and Science

Decision making is not always a science; it involves much "art." Also, decisions are not always made with "rational" reasoning. In other words, decision is not always a well-defined deterministic function mapping the input to the decision-making process to a decision made. This introduces much uncertainty in predicting decisions to be made by other people or organizations, especially when the result of interaction among various decision variables is to be predicted. For example, faced with uncertainties, an organizational decision may be made based on the leader's judgement, which may in turn reflect personal belief.

Although ideally ITS user services should be deployed primarily to satisfy people's transportation needs or desires, other types of needs may also propel ITS deployment. For example, a private company may simply desire to sell its products, whether or not the products can actually solve any real transportation problems or satisfy any real transportation needs. This contributed to the so-called "technology push" during the early stages of ITS research, development and deployment (RDD). (Note that technology push can be very good for the society. It is well known that some technologies, e.g., the photocopier, currently enjoying wide-spread every-day use were not perceived as satisfying any customer needs at all when they were first developed.) Some public agencies may simply desire to protect jobs, protect territory, or "build empire." Klein and Sussman [8] observed that (i) the completion of the construction of the National Highway System (the interstate highways) prompted the Federal Highway Administration of U.S. Department of Transportation (US DOT) to look for a new mission and that (ii) ending of the cold war prompted the defense and aerospace industries to look to the surface transportation industry as a potential customer of their technologies. Some academic institutions may simply desire to maintain or grow their educational programs. There is also Congressional and other legislative pressure. All organizations could be biased in their own ways, when compared to the altruistic goal of satisfying people's transportation needs via ITS. This could be part of the reality of ITS deployment and must be recognized in order to maximize the success probability. Such recognition is particularly important when choosing a champion, when endorsing a champion that has emerged for ITS deployment, or when forming a partnership, coalition or consortium for the RDD of long-term ITS user services.

2.4 Other Factors to Consider in ITS Deployment

2.4.1 A Multitude of Transportation Needs and Possible Solutions, Including Non-ITS

The U.S. surface transportation systems have diverse needs. Many ITS user services have been conceived, and some of them developed or even deployed. Although ITS user services have the potential of solving many transportation problems, they by no means form a complete set of possible solutions to satisfy all the myriad transportation needs. Public Technology, Inc. [12] reiterated that ITS is just one of many tools available to meet future transportation goals and objectives.

2.4.2 A Multitude of Stakeholders and Agendas

ITS deployment involves a multitude of stakeholder groups, not to mention individual stakeholders. Each stakeholder will have its own agenda, e.g., organizational charter in the case of a public-agency stakeholder or profit making in the case of private product/service provider; each will evaluate the deployment of ITS based on its own agenda. It is essential that measures be developed for every key evaluation criterion that one or more stakeholders will examine. When the ability of a solution to satisfy a need is the focus, measures of effectiveness (MOEs) are needed. When a solution may introduce possible negative effects on some stakeholders, measures of impact are also necessary. Others have used the term performance/impact measures (PIMs) to capture both the positive and possible negative effects of a user service concept. When participation by some stakeholders (e.g., private product/service providers) is required for the successful deployment of a concept and these stakeholders would participate only when the concept meet some of their needs, measures of appeal or attraction are important. We propose the use of the term "Performance/Impact/Appeal (PIA) measures" to emphasize the need for all three types of measures. PIA measures can be used to describe both quantitative and qualitative concept/system outcomes, as MOEs and PIMs have been.

2.4.3 Cautious Introduction of Changes and Incrementalism

The existence of a multitude of stakeholders suggests complicated decision dynamics, particularly for those long-term ITS user services that need acceptance from the public sector, the private sector, the market, and the general public. We postulate that the interaction of decisions among these entities is a gradual one. For example, before a public agency decides to implement a new policy or new procedure that affects the driving public, it tends to carefully study possible public reaction, e.g., through policy research, public hearings, etc. Before an auto company decides to mass-produce automobiles with a new feature, it tends to conduct thorough consumer research, e.g., focus group after focus group and companion market studies. Before a legislator decides to endorse a high-impacting or controversial legislation, he or she usually carefully solicits the preferences of his/her constituents. All these examples demonstrate that departing from the status quo tends to be under much scrutiny, which implies the necessity of incrementalism, i.e., gradual ITS deployment via introduction of functional increments. These observations point to the need to develop intermediate steps for long-term ITS user services. An Federal Highway Administration (FHWA) report regarding transfer of transportation technologies [13] also pointed out that relevant decision makers will be more responsive to change if the innovation is introduced gradually so that people can adjust to the resulting change.

2.4.4 Cost-Benefit from the Perspective of Each Stakeholder and for Each Step

Cost-Benefit analysis has been a popular subject and term in ITS deployment literature, for a good reason. However, note that, because of the existence of stakeholders' own agendas and the necessity of incrementalism, cost-benefit analysis needs to be performed for each major stakeholder as well as for each intermediate step toward the end state.

2.4.5 Risk Analysis and Mitigation, in Addition to Cost-Benefit

Deployment of ITS involves many unknowns and uncertainties. Examples include technological feasibility and cost, stakeholder value systems, decision dynamics, market, etc. Therefore, *risk analysis and mitigation* is crucial. However, it seems to have received much less attention than required. In private industries, due to the need to operate with a healthy profit margin, assessing and mitigating risks associated with return is routinely performed. Risk analysis and mitigation should be an integral part of all ITS research, development and deployment (RDD) processes. Note that the success of a deterministic deployment path for an ITS user service concept may require the occurrence of a large number of future events. Under the assumption of probabilistic independence of the occurrence of those events, the probability of a successful deployment resulting from the deterministic deployment path is the product of the individual probabilities of those events occurring. In the presence of a large amount of uncertainty, that probability may be very low, especially for any such path designed for longer-term ITS user services. The technique of decision-tree analysis is a useful approach to dealing with uncertainties. (See the Appendix for a brief discussion of decision tree analysis.)

3 A Decision-Oriented Framework for Recognizing and Organizing ITS Deployment Issues

This section proposes a framework to help recognize and organize issues associated with deploying one or more ITS user services. The framework has eight dimensions of issues and concerns generic to ITS deployment. The issues and concerns are posed as questions (following a "bullet"). When and only when an issue needs clarification, some explanation will follow the question.

As mentioned earlier, our goal is to include as many issue categories or individual issues as possible so that they will not catch researchers or implementation agencies by surprise. We take a top-down approach and attempt to exhaust high-level (or abstract) issue categories to the best of our ability. In other words, the goal is that any ITS deployment issue should either be explicitly included in the framework already or fall under one of the issue categories explicitly included in the framework. The proposed framework can be expanded to include more detailed issue categories or specific issues. The framework can also be further developed so as to capture issues that are peculiar to the deployment of specific ITS user services.

Many of the issues to be included in the framework are well known; the "systems" nature of this paper requires their inclusion. However, their discussion will be deliberately kept at a minimum. For example, the need for cost-and-benefit estimates is a well-known issue and will be listed but not discussed at length. On the other hand, risk analysis and mitigation will be discussed in more detail.

The eight dimensions are:

(1) need,

(2) solution,

(3) decision maker/organization,

(4) decision making,

(5) decision influencing,

(6) time,

(7) risk management,

(8) synergy.

This framework can be used to evaluate the strategy for deploying one ITS user service concept as a candidate solution to a particular need, or multiple ITS user service concepts as a set of solutions to a set of needs. For convenience purposes, we focus on the former. The latter will be addressed in the synergy dimension. This framework can be used to evaluate either an ITS user service concept or a detailed ITS user service design. We will treat the former explicitly.

3.1 Need Dimension: A Multitude of Needs and Possible Users

In this subsection, consider the deployment of a given ITS user service.

- *What Is the Transportation Need That the ITS User Service Is Intended to Serve and Who Needs it?*

An ITS user service will likely not be deployed simply for the sake of deployment. There exist many transportation needs, and ITS deployment must be driven by such needs. Klein and Sussman [8] observed the importance of users to successful ITS deployment and also their underrepresentation in the development of U.S. ITS Program, e.g., the National ITS System Architecture Project, the Program Planning activity, and ITS America. They also observed the coincidental occurrence of the completion of Interstate-Highway-System construction and the end of cold war. The former left an opening for a new mission for FHWA while the latter left many defense contractors without federal contracts for advanced technology development. They argued that these are among the reasons for user unrepresentation in the US ITS Program.

- *What Are the Other Needs, Including Those That Cannot Be Satisfied by ITS?*

There are a multitude of transportation needs felt by different people and organizations. One should identify all major needs, rather than falling into the trap of only trying to find needs that ITS can help solve. This is important because the ITS projects will need to compete with other solutions considered for satisfying the same or other needs [12].

Transportation needs should actually be viewed as one particular aspect of overall societal needs. For example, the Advanced Transportation Systems Program Plan [2] developed by the New Technology and Research Program of the Department of Transportation of California stated three general policies and eleven objectives that have been guiding the State's decision making regarding transportation. In addition to improving the State's transportation services and economic competitiveness and providing safety and security for all users of the State's transportation system, the objectives include: promoting tourism and access to California's historic, scenic and recreation area; supporting the development of electronic highway alternatives, e.g., telecommuting, for reducing demands on the transportation system; maintaining transportation systems to preserve investments and serve the public; balancing transportation, energy, economic and environmental goals; respecting community values.

It is the responsibility of the transportation community to search for better ways to serve the general public. In addition to meeting known transportation needs, transportation professionals should actively seek possible innovation opportunities brought about by technological advances made in other disciplines. In theory, an ITS user service concept may be or may have been developed to meet an urgent transportation need or to seize an innovation opportunity. Given many urgent transportation needs and assuming that major innovation opportunities exist only in areas where urgent needs exist, we focus on transportation needs as the primary driver for ITS research, development and deployment. In other words, this paper adopts a needs-driven approach to ITS deployment, rather a combined needs-driven and technology-push approach. However, this assumption can be relaxed, and the framework can be modified accordingly. This could be a worthy subject of future research.

3.2 Solution Dimension: Multiple Solutions for One Need

In this subsection, consider a given transportation need and a given ITS concept. An ITS user service concept conceived for a particular need is not necessarily a solution but, when properly designed and deployed, can constitute a solution for the need. (Such a concept may satisfy, fully or partially, other transportation needs.)

- *What Are Alternative Solutions, ITS or Conventional, for the Need?*

When investigating the deployment of an ITS concept, it is important to examine both other ITS concepts and conventional solutions as possible candidate solutions for the need [12]. Combining the need and solution dimensions together reveals the following important issue.

- *Has an ITS concept been considered as an integral element of all types of solutions (or solution concepts) to transportation problems?*

A white paper published by Public Technology Inc. [12] stated that "The implementation of ITS projects requires the same steps as other more traditional capital projects, namely planning, funding, design and construction, operations, and maintenance." It also observed that the theme of an Interim ITS Handbook being developed by the FHWA (at the time of the white paper's publication) was that "ITS is not a separate and distinct element, but an integral element of all types of solutions to transportation problems, and that ITS planning should be integrated into the comprehensive transportation planning process." However, much of the literature proposed separating the funding sources of ITS projects from those for more traditional solutions. This remains a possibility particularly if cost-and-benefit estimates can clearly demonstrate the desirability of some ITS solutions over their conventional counterparts. The United States General Accounting Office (US GAO) [16] recently reported that a lack of cost-benefit data is a significant obstacle to widespread deployment of ITS.

In order for an ITS user service concept to become a solution, it needs to be properly designed and deployed. The following six dimensions of issues can be used to help guide the development of deployable designs and viable deployment processes.

3.3 Decision-Maker/Organization Dimension: A Multitude of Decision Variables and Events

Tsao and Ran [15] proposed a focus on decision in developing deployment strategies for Automated Highway Systems (AHS). They recognized that many favorable decisions are required for the successful deployment of AHS and partitioned the decision variables into three main categories: independent, dependent and exogenous. (See Section 2.3 for details. With a focus on the champion's perspective, these three categories have been renamed as controllable, influenceable and exogenous decision variables.)

- *Are All Major Relevant Decision Makers and Decision Variables Identified?*

Note that decision makers may include the general public and a variety of players in the free market.

- Is the Champion Proper or Properly Chosen?

As discussed earlier, a multitude of favorable decisions are needed for the successful deployment of an ITS service. We postulated the requirements of a champion and an organized effort. Although they did not use the term "champion," several ITS researchers have discussed the subject of proper composition of an organization promoting ITS. For example, Dahlgren et al. [3] conducted many case studies of local ITS deployment and concluded that a requirement for successful implementation is the presence of "credible, energetic leadership." Zavattero [17] discussed pros and cons of an MPO serving as a champion for the six counties in Northern Illinois. He concluded that an MPO is a good organization in which to reach consensus. However, an MPO is not responsible for operations success or failure. Alternative institutional arrangements can be explored for ITS deployment.

Klein and Sussman [7] compared organizations promoting ITS in Europe, Japan and the U.S. at the national or international level. In the US, ITS America is playing the role of a champion for the deployment of all ITS user services. From the view point of innovation theory and organization theory, Klein and Sussman [8] argued that most ITS user services are incremental innovations, which require close cooperation between researchers and users, and pointed out that the composition of ITS America lacked user participation, particularly that of the local transportation agencies. The local transportation agencies are needed for their implementation expertise.

- *What Are the Controllable (by the Champion) Decision Variables?*

- *What Are the Influenceable Decision Variables?*
- *What Are the Likely Exogenous Decision Variables and Events?*
- *Is the Organization of Champions Clear and Appropriate?*

There may be multiple champions for ITS deployment. There could be champions for particular ITS user services and champions for ITS deployment in particular geographical regions. There could also be multiple champions for the same set of ITS user services for the same geographical regions. For example, ITS America, FHWA and US DOT Joint Program Office all seem to be champions for ITS deployment across the nation. When there exist multiple champions for ITS deployment in the same region, it is beneficial to have a clear organization.

3.4 Decision-Making Dimension

ITS researchers must understand the decision-making processes of individual major stakeholders in order to develop deployable ITS concepts and technologies. Champions must understand them in order to influence the corresponding decision makers. Issues to be discussed in this dimension are intended to help the researchers and the champion probe such decision making processes. The required depth of probing depends on the specific ITS concept or concepts under consideration and, hence, is left unspecified.

- *Are Performance/Impact/Appeal (PIA) Measures and the Value Systems and Specific Interests of Each Decision Maker Clear?*

To the transportation infrastructure providers, important performance measures include benefit measures (e.g., safety, mobility, flexibility, predictability,) and cost measures, etc. Also of concern is the possible need for additional funding. Deployment of ITS technologies may impact such providers' existing organizations. For example, it may require additional staff or staff with different skills. (Section 3.6 has more discussion on this.) In a recent US GAO report [16], three significant obstacles to more widespread deployment of ITS are cited: "a lack of technical expertise and knowledge about ITS among those who will actually deploy the system; a lack of cost-benefit data about ITS; a lack of funding dedicated to ITS, in the light of other priorities for transportation investments."

An ITS service may also have unintended adverse consequences for some stakeholders. Therefore, one needs to study what some stakeholders may not want, not just the user needs and desires. For example, the concept of congestion pricing as a means to reduce traffic demand gives the traffic management authorities a new role of rationing the use of public roads, which the authorities may not want. Possible environmental impact (for transportation infrastructure providers, environmental groups and the general public) and profit potential (for private enterprises) are two examples of important impact/appeal measures for ITS.

- *Are Unintended Adverse Consequences Captured?*

- *Are Uncertainties and Risks Also Captured by the PIA Measures?*

- *Have Fair Evaluatory Scenarios Been Developed?*

The desirability of a solution may depend on the context in which it is applied. A solution coupled with multiple benchmark scenarios produce the corresponding sets of performance/impact/appeal (PIA) measures. These sets of PIA measures in turn can help determine the probabilities of stakeholder participation and deployment success, e.g., through weighing these sets of PIA measures according to the relative importance of the scenarios (from the perspectives of individual major stakeholders). The contexts and detail levels of evaluatory scenarios may depend on the deployment stage.

- *Are Possible Competitive, Partnership and Coalition Relationships Among Some Influenceable Decision Makers Considered as Part of the Individual Decision Making Processes?*

An ultimate question regarding the decision-making dimension is:

- *Are Major Stakeholders' Decision-Making Processes Clear?*

Another is:

- *Has A Cost-Benefit-RISK Analysis Been Conducted for Each Possible Major Intermediate Deployment Step From the Perspective of Each Major Stakeholder?*

The presence of many uncertainties in the deployment of many ITS user services points to the necessity to, in evaluating each of the intermediate steps associated with deploying any particular user service (if such intermediate steps are necessary), explicitly consider the *risk* faced by each stakeholder Note that *risk analysis* is integral to any venture by the private sector. Quite often, despite presence of uncertainties and the resulting risks, important decisions are made. However, it always helps to understand the uncertainties and the companion risks. This helps the ITS deployment champion understand the stakeholders' decision-making processes and hence develop deployment strategies accordingly. Note that the uncertainty and risk aspects may actually help the champion determine what can be reasonably expected of an ITS deployment effort. We invite research into these largely ignored issues. The risks involved in the champion's "pushing" for the widespread implementation of an ITS technology will be discussed later in the Risk Dimension.

- *Is Personal Character/Institutional Culture Considered?*

As pointed out earlier, the decision making of an institution often has much room for the leader or leaders to make decisions based partially on personal judgement, beliefs or even styles, e.g., risk-taking vs. risk aversion, degree of supportiveness of innovation and research, etc. This introduces more uncertainties. The same can be said about individual citizens, e.g., consumers and taxpayers, as decision makers.

Developing partnerships is necessary for ITS deployment. Partnerships have both an agency-to-agency aspect and a person-to-person aspect. Schnur and Georgevich [14], after pointing out that the analysis of the institutional issues involved in agency-to-agency partnerships is "standard fare for students of political science or public policy," addressed the diplomacy or personal dimension in forming a partnership. They stated that "The person-to-person aspect of partnerships is more complicated, and often requires skills in psychoanalysis and diplomacy" and that "even when partnerships have come together, personnel changes may result in the need to revisit past agreements or even prove fatal to the partnership."

- *Are There Any Hidden Agendas for the Champion or the Stakeholders?*

3.5 Decision-Influencing Dimension: The Champion Influencing Other Stakeholders

While many implementors and their roles have been defined in the ITS System Architecture Implementation Strategy [10, 2], the issue of how to motivate the implementors to fulfill the roles remains largely unaddressed. Hall also observed (in Appendix B of Horan et al. [6]) that "The NSA [National ITS System Architecture] is largely silent on authority and decision-making." This entire dimension addresses this very issue, particularly how the champion can influence the stakeholders to make favorable decisions leading to successful deployment of ITS user services.

- *Are Target Supporters for Deployment Identified?*
- *What Are the Methods of Influencing?*

Influence can be achieved through many different means, e.g., good system design and deployment strategies, providing incentives (e.g., funding), exertion of power (in the form of funding or legislative pressure), educating local agency staff, and educating the public. The absolute and relative effectiveness of the above methods has not been established yet.

- Are Partnership and Collaborative Decision Making with the Stakeholders Attempted?

The sheer large number of decision makers involved in ITS deployment may introduce many uncertainties, which make the champion's task more difficult. Collaborative decision making and partnership with stakeholders may help.

3.6 Time Dimension: Deployment Steps and Post-Deployment Stages

This subsection addresses the time dimension along which deployment issues can be recognized and organized. We discuss issues related to the possible need for intermediate ITS concepts and technologies leading to the full deployment of an ITS concept and technologies during the deployment phase as well as issues regarding post-deployment phases, e.g., operations, maintenance, etc.

Some of the user services cannot be implemented suddenly, and, hence, intermediate states need to be defined. Consider the concept of congestion pricing. Some variations call for implementation to reduce the traffic through a point, e.g., the San Francisco-Oakland Bay Bridge; some other variations are intended to reduce traffic going into an area; yet some other variations seek to reduce the "dwell time" of traffic in an area. ("Dwell time" refers to the amount of time that a vehicle spends in an area.) These three variations may require different operating concepts and technologies. Also, the first two may be viewed as intermediate ITS concepts for deploying the third concept.

- *Are Intermediate Steps Needed?*
- *If So, What Are the Possible End States and Possible Intermediate States of the Solution?*
- *If So, Is Each Intermediate Step Worthwhile for Each of the Key Stakeholders to Participate in Deployment?*
- *How to Integrate the Intermediate and End-State Concepts/Technologies into the Existing Transportation System?*

Given a particular ITS user service and the companion technology, it helps to recognize major attributes of the technology relative to the existing process into which the new technology will be integrated. Characteristics of technology integration can be used in evaluating and developing deployment strategies. Recognizing the importance of integration of new technologies into existing transportation systems, Blumentritt and Krammes [1] identified several major characteristics of technology integration and offered some experience in integrating some particular technologies into the existing transportation systems.

- *Are All Major Implementation Issues Considered, e.g., Who Pays for It, Which Organization Owns It, How to Pay for It, Staff Training, Winning Legislative and Citizens' Support?*
- *Are Post-Implementation Phases Considered, e.g., Who Operates It, Who Evaluates It, Who Maintains It, Who Improves It?*

3.7 Risk Management Dimension: Uncertainty and Decision Tree Analysis

This dimension addresses risk management for deployment of ITS user services as a whole from the perspective of the champion. Risks faced by the individual decision makers (i.e., stakeholders) and the required risk management were addressed in Subsection 3.4 (the decision-making dimension).

Given uncertainties, the champion needs to manage the overall risk associated with the deployment of the ITS user services. The goal should be to try to maximize the probability of actual implementation of the user services and to maximize the net benefit of the whole deployment process.

- *Are Major Technical and Non-Technical Uncertainties Identified?*
- *Particularly, Are Market Uncertainties Addressed?*
- *Does One Single End State Suffice?*

If the deployability of any single end-state concept of a user service is uncertain, then multiple end-state concepts should be considered if the user service is to be deployed at all.

- *If Not, Has a Deployment Decision Tree Been Developed?*
- *What Is the Deployment Strategy?*

A deterministic strategy addresses the following issues: transition of intermediate and end states; technological feasibility, cost and human interface for the states; technological upgradability; integrability with other technological grades; roles of the champion and the stakeholders. Note that defining roles for stakeholders is not sufficient, and developing ways to motivate them to fulfill the role is critical. A stochastic strategy consists of decision trees, in which branching of deployment steps occurs at major "uncertainty nodes."

Tsao and Ran [15] recognized the limitations of deterministic deployment strategies for AHS and proposed the development of *contingency plans* to deal with the uncertainties. Hanson and Tsao [5] identified many uncertainties for AHS deployment. Lathrop and Michael [11] proposed the use of *decision trees* for developing AHS deployment strategies. (See the Appendix.) Their approaches can be applied to other ITS user services.

Further questions include the following.

- *Is the Deployment Plan Sensitive to Exogenous Decision Variables or Events?*
- *Are the Contingency Plans or Decision Trees Sufficient to Deal with Such Exogenous Variables and Events?*
- *What Is the Probability of Deployment Success and What Can be Expected of the Deployment Effort?*

3.8 Synergy Dimension: Synchronization for Multiple Needs/Solutions and for Multiple Locations

- *Is Technological Synergy Capitalized On?*

When only one ITS concept is considered for deployment, a particular technology may be considered optimal, with respect to the success criteria defined for the deployment of only that particular concept. However, when multiple user services are deployed, a cross-cutting technology, which may not be optimal for any of the individual concepts, may actually be the best overall choice.

- *Is Synergy across Efforts in Deploying Different ITS Services Capitalized On?*

Much synergy may be achievable by properly sequencing and timing deployment of different ITS services.

- *Is Synergy across Efforts in Deploying ITS services at Different Locations Capitalized On?*

Much synergy may be achievable by synchronizing deployment of ITS user services among neighboring geographical locations.

The cost, benefit and risk associated with ITS deployment hinge upon synergy. For example, the well-known concept of interoperability can be viewed as a form of cross-location synergy. Also, the well-known practice of partnering among neighboring municipalities for deploying ITS technologies like coordinated signaling to achieve the "network effect" (benefit that increases faster than linearly in the size of the network equipped with the technologies) [3] is another form of cross-location synergy. The National ITS System Architecture can also be viewed as a means to achieve synergy among various efforts in deploying different ITS technologies or in deploying similar ITS technologies at different locations. These attest to the advantages of possible synergy among different ITS implementation efforts.

4 Technology Transfer

ITS deployment can benefit from the knowledge accumulated in many traditional academic areas. One such area is technology transfer. This section discusses its relevance to ITS deployment. Note that technology transfer is an important aspect of ITS deployment, but ITS deployment cannot be subsumed under technology transfer as a special case.

Technology transfer has many different definitions, depending on the context and the audience. Therefore, many corresponding branches of literature have accumulated. In this paper, we follow Schmitt et al. [13] and use technology transfer to refer to "all the activities leading to the appropriate adoption of a new product or procedure by any group of users. 'New' is used in a special sense: it means any improvement over existing technologies or processes, not necessarily a chronologically recent invention."

A fundamental discriminator of technology transfer processes is the "direction" of transfer. Two such directions have been discussed in the technology transfer literature, namely "vertical transfer" and "horizontal transfer" [4]. In vertical transfer, a general principle is used to produce a new product or process within a given scientific or technical discipline, and, generally, within an organizational entity or from the public sector to the private sector of a society (e.g., from a national laboratory or a university research program to for-profit companies). However, in horizontal transfer, one technology is adapted to a different area of application, generally across institutional lines. Given the nature of ITS deployment, we are concerned with "horizontal transfer," instead of "vertical transfer." Therefore, we will focus on such horizontal technology transfer in the rest of this section. There is a large literature on such technology transfer. We cite only what we consider to be the most relevant and general discussions.

This section consists of two components. In the first component, we draw material from the technology transfer literature that is particularly helpful for ITS deployment champions. Such material includes the nature of (horizontal) technology transfer, issues faced by agencies promoting or facilitating technology transfer, and lessons learned. The material verifies and augments the discussion in the previous sections.

In the second component, we shift our focus from the perspective of the champions of ITS deployment to the perspective of the implementation agencies. The champions tend to be the federal government and, in some cases, the state governments, while the implementation agencies tend to be regional and local governments. We draw material from studies conducted by Public Technology Inc. (PTI), which is the non-profit technology organization of the National League of Cities, the National Association of Counties, and the International City/County Management Association. PTI, The American Association of State Highway and Transportation Officials (AASHTO) and the National Association of City Transportation Officials (NACTO) recently published a white paper entitled "Technology: A Bridge to the States" addressing the technology-transfer process associated with ITS deployment. In addition to verifying and augmenting the discussion in the previous sections, the second component is also useful for local implementation agencies.

4.1 Technology Transfer: A Transportation Perspective

The federal and state governments have attempted and succeeded in transferring many technologies to regional and local governments. In this subsection, we draw material from a study sponsored by the Federal Highway Administration of the U.S. DOT on transferring transportation-related information and technologies to local governments [13].

Schmitt et al. [13] regarded technology transfer as a means to bring about "change" and defined technology transfer as all the activities leading to the appropriate adoption of a new product or procedure by any group of users, where the qualifier "new" refers to improvement over existing technologies or processes, not necessarily a recent invention. They addressed "the nature of change" and provided general guidelines for technology transfer, e.g., the nature of technologies that tend to get successfully transferred, reasons why people resist change, general observations about decision makers, reasons why there are problems with technology transfer, and how to facilitate technology transfer. Although they acknowledged that technology transfer is not simply information dissemination but actually results in actual innovation, the focus of their study was actually the dissemination of information or know-how. As a consequence, the techniques they proposed centered around communication of know-how to the local implementation agencies, rather than about the eventual adoption of technologies. However, their discussion about the "nature of change" provides insights into the intricacy of technology transfer. We note some of their key observations.

Regarding what kind of technologies tend to get successfully transferred, they concluded the following. The captions they used for capturing the main ideas are enclosed between brackets at the end of the corresponding descriptions.

- Innovations (technologies) must be seen as producing a significant improvement over current procedures and techniques. The benefits must be perceived as so great as to be well worth the inevitable problems and costs associated with any change. [Advantageous]

- The innovation, or at least the way it is presented, should be easy to understand. [Simple]
- The new method must be easy to introduce, as well as easy to abandon if it does not seem to be working out. [Easy to try]
- It must be easy to measure the benefits, whether in money, time efficiency or some other measures. [Easy to measure]
- If there is a large immediate increase in costs, it will be difficult to get the technology adopted. [Inexpensive]
- The more a new idea is compatible with past procedures, techniques and values of an organization, the more likely the organization is to adopt it. [Compatible]

In short, innovations tend to get put into practice because they are advantageous, simple, easy to try, easy to measure, inexpensive and compatible.

They made the following observations about the attitudes of decision makers toward change and stated that decision makers will be more responsive to change if

- the information presented coincides with their current values, beliefs and attitudes;
- they perceive that the change will benefit them more than it will cost them;
- the innovation requires marginal rather than major changes in their views and lives;
- they have a demonstrated need for the innovation; and
- the innovation is introduced gradually so that people can adjust to the resulting change.

They highlighted six hardest learned lessons about technology transfer:

- People and organizations are naturally resistant to change.
- Personal contact - the human element - is the most important factor in innovation diffusion and adoption.
- Personal contact - through one-to-one technical assistance and special transfer agents - is expensive in the short run but immeasurably cost-effective in the long run.

- Effective communication of new ideas and techniques is best done through multiple channels: people, news letters, case study reports, professional association networks, and publications.
- The experience and endorsement of peers is a very important element in the widespread adoption of innovation and technology.
- Acceptance of new technology takes time, a lot of work, and risk.

Their discussion is consistent our view. Our decision-focus approach and the proposed decision-oriented framework are also consistent with their emphasis on the decision-making processes involved in technology transfer.

In a brief discussion of problems associated with technology transfer, they [13] stated:

- "Researchers prefer to bend problems to suit their methods.
- Users of research prefer to bend methods to suit problems.
- User always think that the researcher doesn't understand the problem; researchers always think that the user doesn't understand the method. USERS ARE USUALLY RIGHT!"

The primary objective of this paper is to help ITS researchers "understand the problem."

Note that their study predated ITS deployment and that ITS deployment necessitates even more emphasis on the related decision-making processes because of its complexity, potential impact, and the involvement of many public-sector and private-sector decision-making individuals and organizations.

4.2 Local Governments' Perspective on Technology Transfer for ITS Deployment

Public Technology Inc. recently published a white paper on technology transfer regarding ITS deployment entitled "Technology: A Bridge to the States - Opportunities for Intergovernmental Cooperation on Intelligent Transportation Systems" [12]. We draw some key points made in the white paper that are particularly relevant to the subject of this paper.

The PTI white paper pointed out that the theme of the Interim ITS Handbook being developed at the time by the FHWA was that ITS is not a separate and distinct element, but an integral element of all types of solutions to transportation problems, and that ITS planning should be integrated into the comprehensive transportation planning process. It also pointed out that ITS should be used as tools to implement the transportation policies and goals of the region.

The white paper stated that ITS may sometimes need to be considered as a competing alternative to other transportation strategies and, in a planning environment with constrained resources, ITS needs to be considered as just one of many tools available to meet future transportation goals and objectives.

Eight urban areas were selected for study in developing this white paper. They are New York, Boston, Philadelphia, Chicago, Los Angeles, Houston, Seattle and Minneapolis-St. Paul. Focus group discussions and interviews were constructed to ascertain the officials' assessment of factors that contributed to successful implementation of the Intelligent Transportation Infrastructure (ITI; a set of important near-term components of ITS) in their areas and those factors that inhibited implementation of ITI.

The first three factors leading to successful implementation of ITI that were identified in the white paper are:

1. The existence of a high-level agreement on a plan or a vision for a region for transportation and ITS.
2. The existence of a champion or champions for ITS.
3. Transportation congestion and safety problems sufficient to attract political attention.

Factor 2 has been the most important hypothesis of this paper and has driven the development of the decision-oriented framework. The white paper stated that "There was agreement that the existence of a champion or champions was critical to successful ITS programs and that the lack of a strong champion was inhibiting the implementation of the ITI in areas struggling with the ITS program."

Factor 1 is not likely to be achieved without Factor 2. Factor 3 and PTI's position regarding the role of ITS with respect to (i) overall transportation problems and (ii) other transportation solutions are consistent with our view on the very first two dimensions of the decision-oriented framework: Need and Solution.

Note that these are factors related to the success or failure of ITI deployment. Since (i) the scope of ITS is much larger than ITI and (ii) ITS involves not just mostly the public-sector decision-making entities but also many private-sector decision-making entities, the market place and the general public, a decision focus and a decision-oriented framework for identifying and organizing ITS deployment issues become even more relevant.

5 Conclusion

Starting with the fundamental question of "who deploys ITS user services" and based on a focus on the multitude of decisions impacting the deployment of ITS user services, we have "derived" a framework for recognizing and organizing issues associated with ITS deployment. Given the existence of many transportation needs and many possible solutions, selecting, developing and implementing proper ITS user services for solving properly selected transportation needs involves a tremendous amount of decision making and a multitude of decision makers.

Under the assumption that no single organization has the full authority over and the full capability of taking all the actions required for the successful deployment of an ITS user service, we postulated the necessity of a champion for ITS deployment. We also grouped decision variables relevant to ITS deployment success, from the perspective of the champion, into controllable, influenceable and exogenous variables.

Although numerous roles have been defined for the stakeholders in the literature, very little study has been about how to influence (e.g., motivate) the stakeholders to fulfill their assigned roles.

Since 80% of the projected $209 Billion ITS investment by year 2011 [2] is expected to come from the private sector in the form of products and services, success of ITS deployment hinges upon acceptance by the free market. Consequently, market research should be an integral part of ITS research, development and deployment.

Cautious introduction of changes by the stakeholders implies gradual introduction of new functionality, which necessitates intermediate steps for long-term user service concepts. Much attention is needed in designing such intermediate steps and in evaluating each of them from the perspective of each of the key stakeholders.

In the presence of a multitude of ITS deployment uncertainties, the current efforts on ITS cost-benefit analysis should be augmented to include risk analysis, from the perspectives of both the stakeholders and the champion of ITS deployment. Decision-tree analysis provide an effective approach to minimizing deployment risk as well as to maximizing R&D productivity.

The proposed deployment framework has several important applications. It can be used to help researchers and champions of ITS:

- recognize and organize issues and uncertainties associated with deploying ITS user services;
- evaluate deployment strategies for any particular user service concept or a set of multiple concepts that have been developed, for one location or multiple locations;
- define what constitutes a viable (long-term) user service concept, i.e., high-level design of a forward-looking transportation service, by specifying which issues must be addressed by such a concept;
- design deployable user service concepts and steer the R&D process;
- optimize allocation of resources to study deployment issues;
- provide a "cognitive map" of the issues, uncertainties, projects and risks;
- determine what can be expected from a deployment or RDD effort.

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APPENDIX: The Simplest Nontrivial Decision Tree: An Example

Decision-tree analysis consists of four stages:

- formulation: formulate the problem as a decision tree,
- quantitative assessment: quantify event uncertainties as probabilities and the degrees of desirability of possible overall consequences (of decision options) as utility values,
- calculation of expected utility: calculate backward the expected utility associated with each of the decision options,
- decision-making: select the option with the highest expected utility.

These four stages will be illustrated in this Appendix with the simplest nontrivial decision tree and a fictitious example.

Consider a self-employed consultant who, for the foreseeable future, has more work than what he can accomplish in a 40-hour work week. It is clear to him that the current level of consulting work does not warrant his hiring another person. However, he can bid for another project. If he eventually wins that project, the additional work will justify economically his hiring an employee. But, the price he has to pay is that he has to work even harder for an extended period of time in order to prepare a proposal that has a winning chance. The decision he needs to make is whether to work even harder and bid for the project.

This decision problem can be represented as the decision tree depicted in Figure A-1, which illustrates the first stage of decision-tree analysis - formulation. There is only one decision to be made in this problem. In Figure A-1, the square represents the the decision node. The two different options associated with his decision are represented as the two arrows stemming out from the decision node toward the right-hand side. Each of these two arrows points to a circle. A circle represents an event node. At each of these nodes, a random event occurs. Possible outcomes are represented by arrows stemming from an event node toward the right-hand side. Each outcome leads to an overall consequence. If an event will occur with certainty, then there is only one arrow, and the circle representing the event node may be replaced by a single point.

To make his decision, the consultant needs to assess quantitatively (i) the *utility* $u(C_i)$, $i = 1, 2, 3$, for each of the three overall consequences, C_i, $i = 1, 2, 3$, and (ii) the probability p of winning the project if he bids for it. If he does not bid for the project, the certain outcome is that he does not get the project, and the consequence C_1 is to endure the current high workload for the foreseeable future. This leads to the utility of $u(C_1)$. If he does bid for project but eventually loses, the consequence C_2 is that he ends up working even harder for an extended period of time for nothing. The utility $u(C_2)$ is definitely lower than $u(C_1)$. The final possibility is that he decides to bid for the project and eventually enjoys the outcome of winning the project. The consequence C_3 is that he works reasonable hours (after the preparation period) and grows his firm in the meantime. Therefore, utility $u(C_3)$ is higher than $u(C_1)$. This illustrates the second stage of decision tree analysis - quantitative assessment, and the results of the first two stages are summarized in Figure A-2.

He now performs the third stage of decision-tree analysis - calculation of expected utility (for each of the possible overall consequences). The expected utility is $u(C_1)$, if he decides not to bid for the project. Otherwise, the utility would be $pu(C_3) + (1 - p)u(C_2)$, obtained by weighing the utility values of the two consequences by the probabilities of the corresponding bidding outcomes. This illustrates the third stage, and the results so far are summarized in Figure A-3.

According to the highest-expected-utility criterion, he should choose to bid for the project if and only if $pu(C_3) + (1 - p)u(C_2) > u(C_1)$. This is the last stage - decision-making, and the complete decision tree analysis is summarized in Figure A-4.

For a detailed discussion about decision tree analysis and decision theory, the reader is referred to

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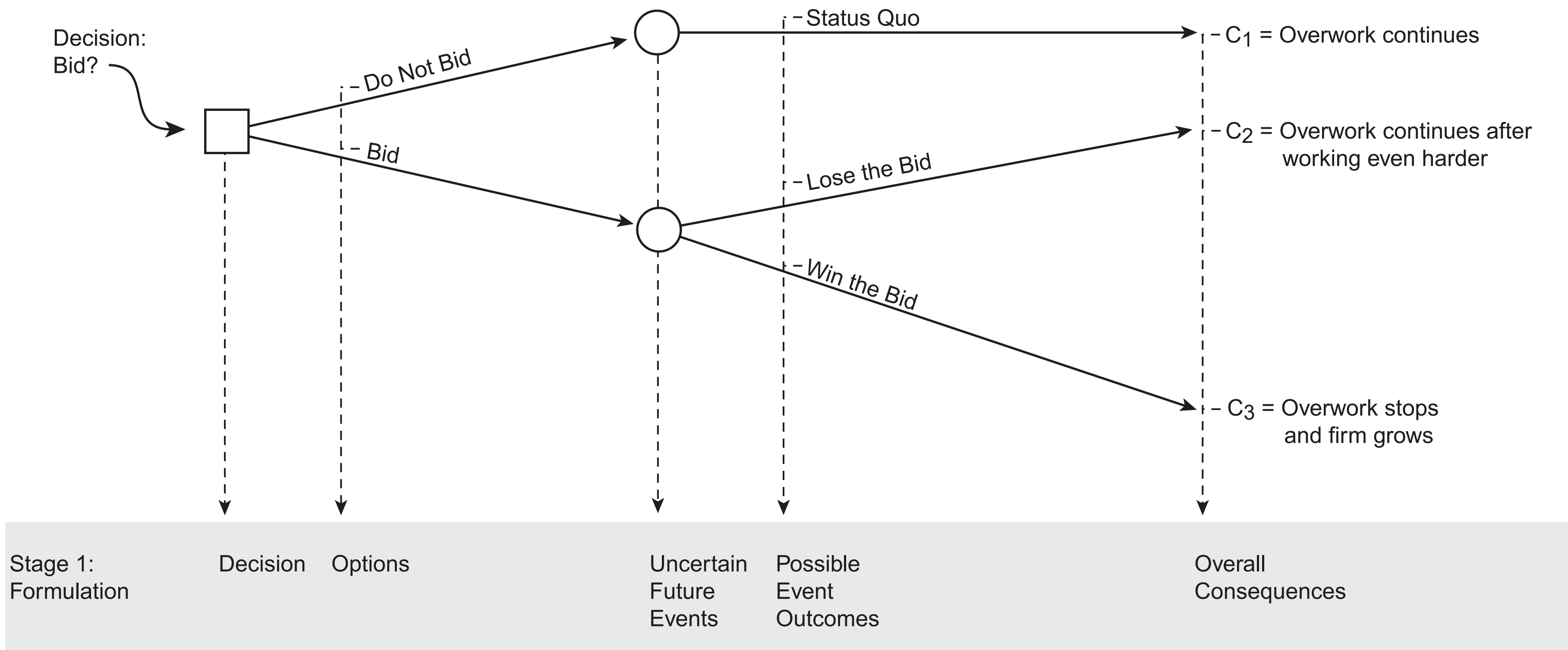

Figure A-1. Decision-Tree Method: Stage 1 - Formulation

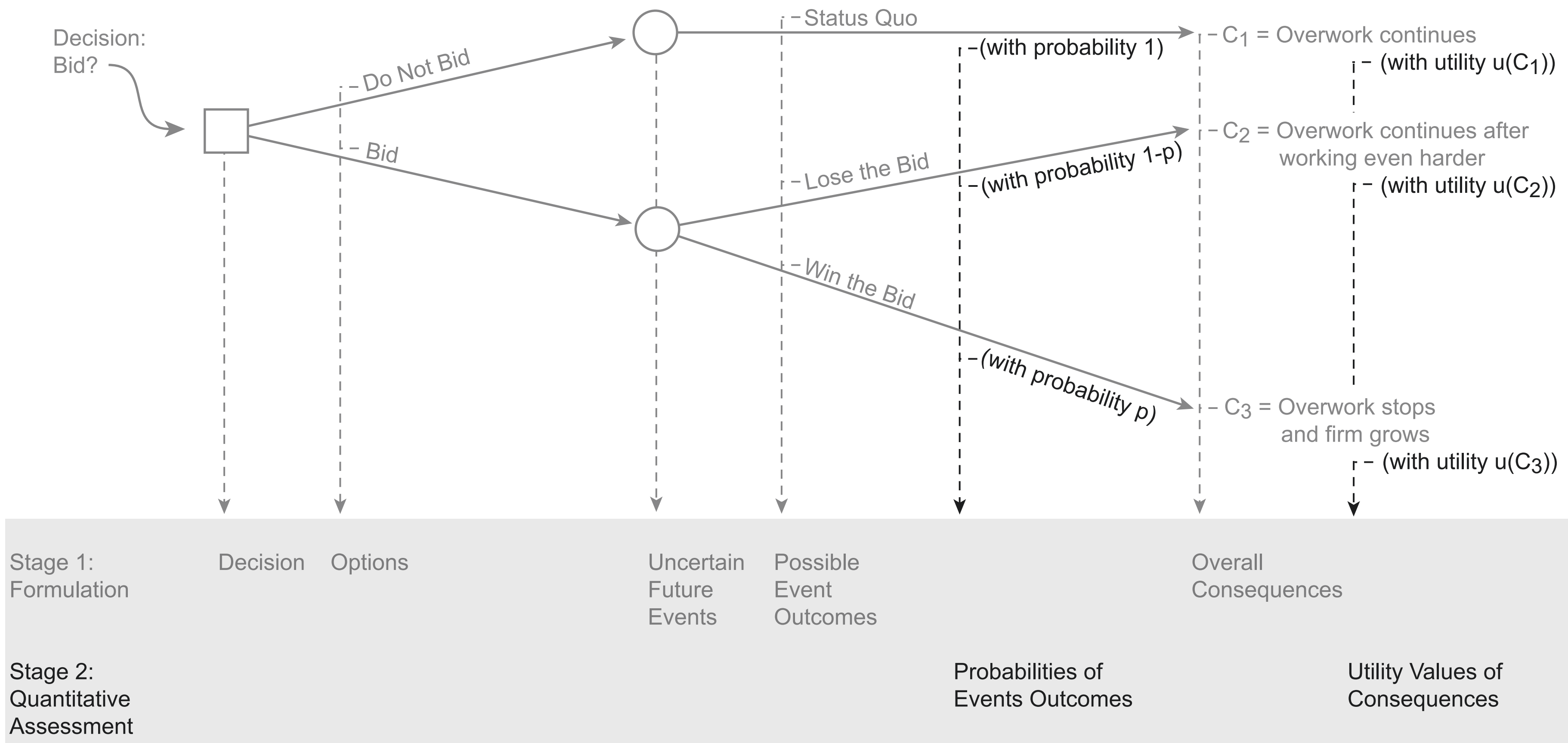

Figure A-2. Decision-Tree Method: Stage 2 - Quantitative Assessment

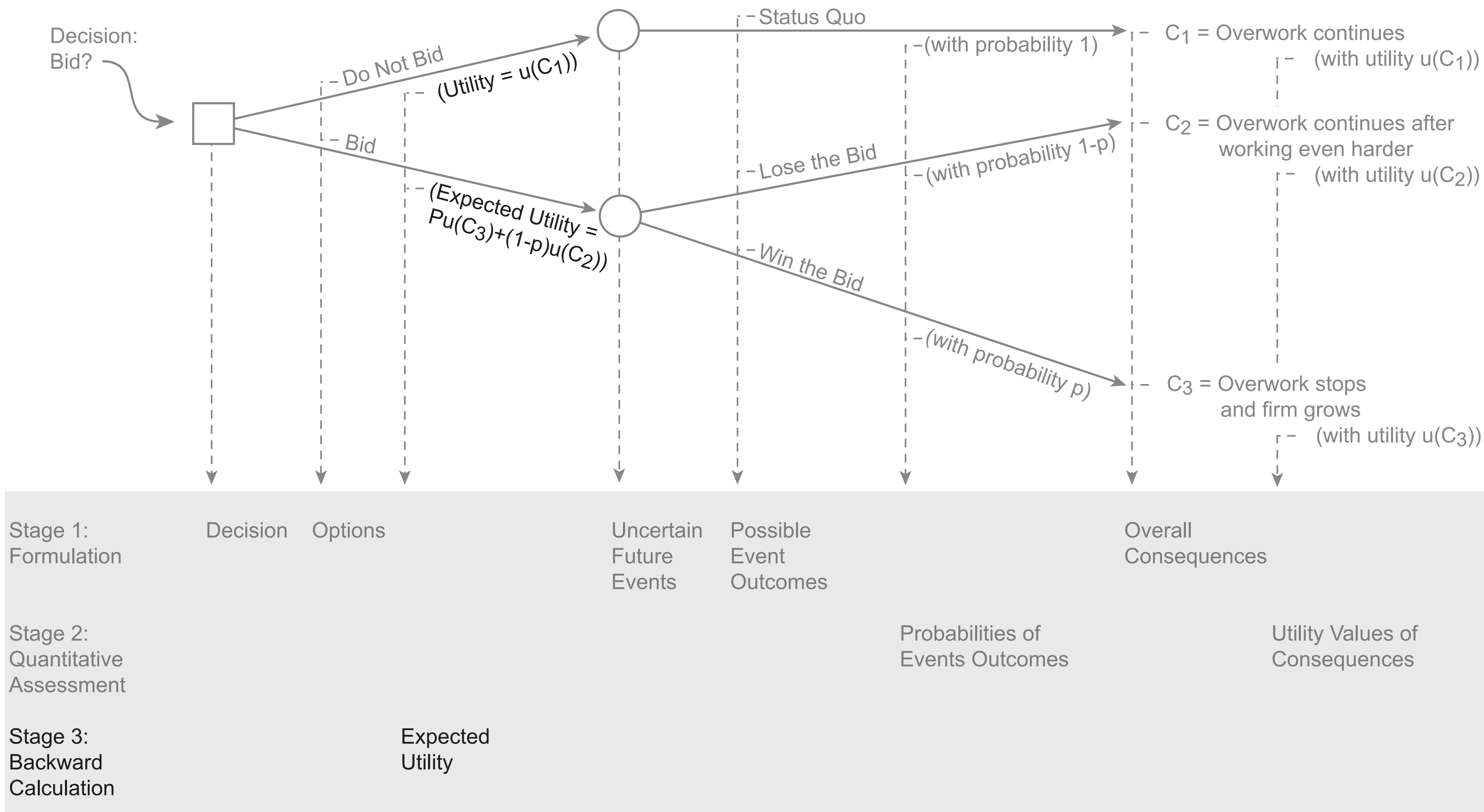

Figure A-3. Decision-Tree Method: Stage 3 - Backward Calculation of Expected Utility

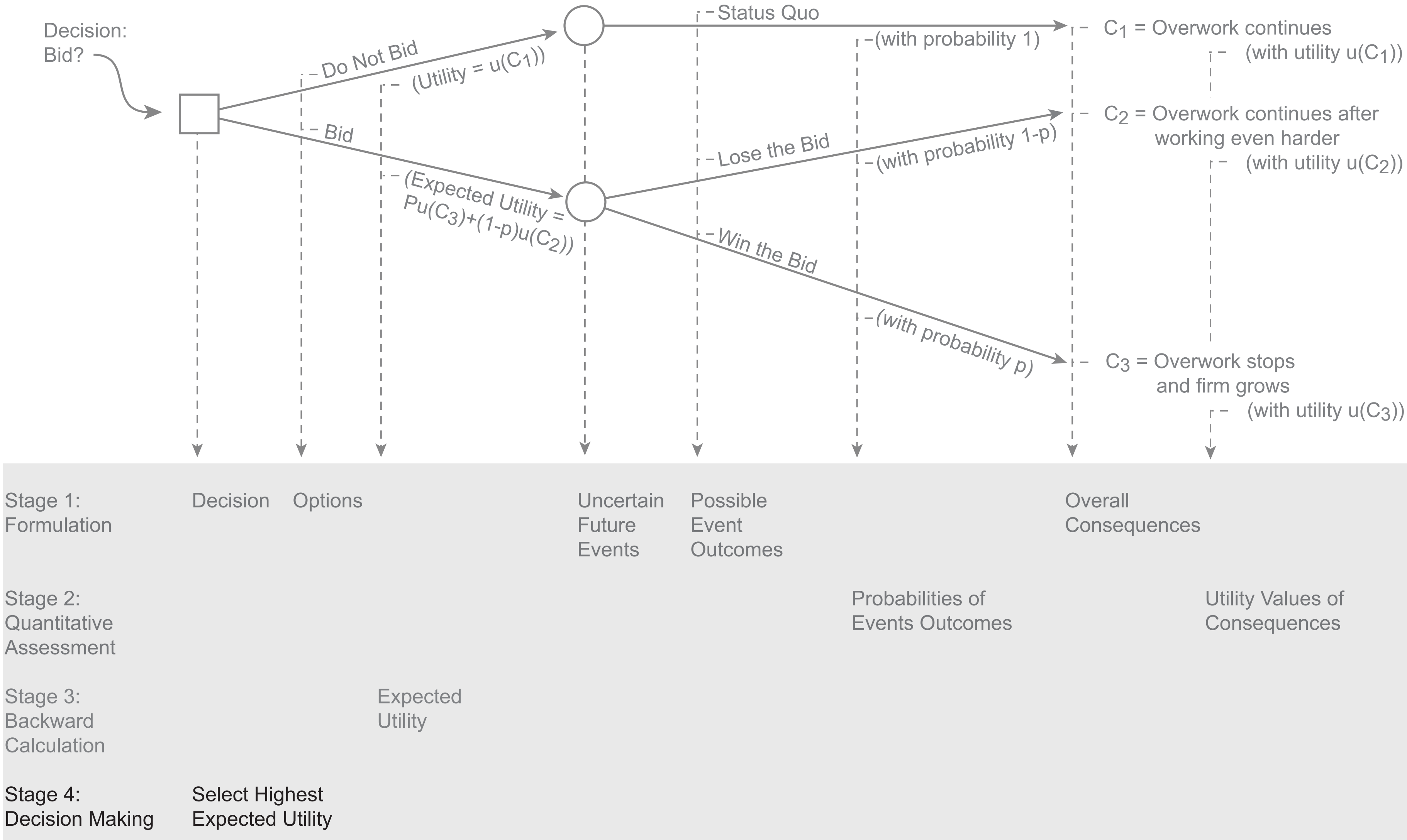

Figure A-4. Decision-Tree Method: Stage 4 - Decision-Making