MULTI-CRITERIA DECISION MODELING FOR BEST VALUE SELECTIONS IN TARGET VALUE DESIGN INTEGRATED PROJECT DELIVERY

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Architecture

by
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February 2017

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ABSTRACT

Multi-Criteria Decision Modeling for Best Value Selections in
Target Value Design Integrated Project Delivery

Brent Patrick Griffis

Integrated Project Delivery (IPD) combined with Target Value Design (TVD) is a better way to deliver value for the client than traditional guaranteed maximum price (GMP) methods. With traditional GMP delivery methods, the interests of the parties are often at odds. The goal of IPD is to align all party interests in order to achieve a win-win scenario. Due to the aligning nature of IPD and the fact that each party's success is dependent on achieving the project objectives as a whole; a non-biased, transparent, decision-making process is necessary in order to deliver the project objectives within the constraints of the TVD. Thus delivering the expected value for the client and ensuring that all parties achieve project success. The need for this transparent decision-making process is compounded by the fact that a "target" based system rapidly declines to a less than optimal state if there is no unbiased decision-making process in place. If we treat the entire lifespan of a project as the complex system that it is, we can begin to take advantage of the hierarchical nature of complex systems. The goal of this paper is to show that by modeling the life span of a project through a multi-criteria decision making model, built on a hierarchical framework will allow you to find a non-inferior solution to your TVD. I'm proposing to use Hierarchical Holographic Modeling (HHM) as the framework for an Analytical Hierarchical Process (AHP) multi-criteria decision-making model complete with post-optimality analysis as the preferred project management method.

Keywords: Multi-Criteria Decision Making, Analytical Hierarchical Process, Hierarchical Holographic Modeling, Target Value Design, Integrated Project Delivery, Architectural Design and Construction, Project Management

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CHAPTER 1 - INTRODUCTION:

The biggest risk facing design and construction teams today is that the completed design will not meet the performance expectations specified by the project owner and therefore will not be adequate based on the demands of the end users. When you consider the increasing levels of complexity and performance being required by project owners today and their demands for tighter cost controls, shorter schedules, and higher quality you can begin to understand the burden placed on Program Managers. The burden to not only select the design team and the builder but to establish clear performance criteria, "objectives" based on the owner's needs and manage the project to it's successful completion in meeting those objectives. Leading up to this successful completion are a series of complicated interconnected decisions that need to be made. For program managers, navigating the inherent uncertainty associated with bringing multiple projects all the way from initial feasibility studies to fruition can be quite time consuming and extremely challenging. So how can we ensure that the initial concept (the initial value) the owner envisioned years ago is what they actually receive when the doors open and the lights go on? How can we make sure that the decisions we make actually guide us in achieving the initial concepts and value determined by the owner's needs? In order to understand the answers to these questions and others, we need to start with getting a better understanding of decision making itself and how we "the human cognitive system," (the decision maker) tend to solve problems on a basic level and how we perceive decision-making. By better understanding what limitations are associated with our current decision making paradigm we will be able to conduct meaningful research and present new solutions to decision making problems. As stated earlier, in order to deliver the value a client is asking for, a series of complex decisions must be made. Therefore, one could say that the A/E/C industry has potential to benefit from an evolution in decision-making that is capable of dealing with increased levels of complexity. Given that the right framework for this evolution to be developed in, is established, easily accessible, and produces superior results when compared to the current paradigm.

In the opinion of this author, Integrated Project Delivery and Target Value Design are the delivery methods capable of accommodating the framework for which this decision making process can be developed. This combined delivery method is being championed as the next big step in the delivery of capital projects for both private and public owners. Having said that, some have noted that one area of concern with this delivery method has to do with the decision making process. In order for the author to propose that this contemporary delivery method is a superior alternative, this concern over decision-making must be addressed. If a solution to this concern can be created, then it will truly be the future of project delivery. It is again the opinion of this author, that by presenting an evolutionary change in decision-making it will not only solve the issues with this delivery method; but can be adapted to a wide variety of applications in the A/E/C industry, as well as other related industries. In order to begin to develop an alternative to the current decision-making paradigm, we must first develop an understanding of the status quo in regards to decision-making and identify the pros and cons associated with it. Once we do this, we will then be able to understand how we can go forward with an evolved form of decision-making; one that is capable of dealing with the complexity of modern project delivery. This understanding will set the building blocks for informing how this paper will proceed in regards to identifying the need for and creating a multi-criteria decision making model capable of dealing with these issues.

1.1 Complexity and the Human Cognitive System:

It is generally agreed that decision-making is a goal-directed activity that involves a wide range of cognitive operations and that the specific process and strategies employed by individual decision makers can vary widely. In light of this variety in completing goal-directed activities, it might be influential to look at employing known successful methods for solving goal-directed problems. Mathematical modeling and optimization methods are well known strategies for solving goal-directed problems. However, mankind's ability to think freely, and utilize intuition and experience during problem solving can be of great advantage during complex decision-making when not all of the variables are quantifiable or known. Therefore, mathematical models that are designed to assist, not replace, human decision makers in solving complex problems involving multiple criteria can be of great assistance in a goal or "target" oriented problem situation. Having said this, the concept of using mathematical models to assist the human decision maker is the cornerstone of my graduate research being presented here in this paper; but before we can fully consider if the human decision makers actually do struggle with solving complex problems on their own, we must first define what a "complex problem" is. The relative level of complexity of a problem can be defined as: "The primary function of the number of inter and intra relationships that exist among the internal and external components of the problem, considered simultaneously with the varying levels of strength between these relationships and the degree of uncertainty that surrounds the definition of these components." (Pohl 7) Or to put it another way, typically, complex problems involve many strong relationships among internal components as well as important dependencies on external factors. This inter-connectedness of a complex problem poses particular difficulties to the human cognitive system, because it forces the decision maker from the normal sequential problem-solving paradigm into a parallel reasoning process. (See Figure 1) Parallel reasoning implies that the reasoning body is able to consider/organize multiple related or unrelated concepts simultaneously while being capable of reasoning/analyzing them simultaneously as well. If we accept that this lack of a parallel reasoning process is a flaw of the human cognitive system, we quickly realize that we must begin to look for

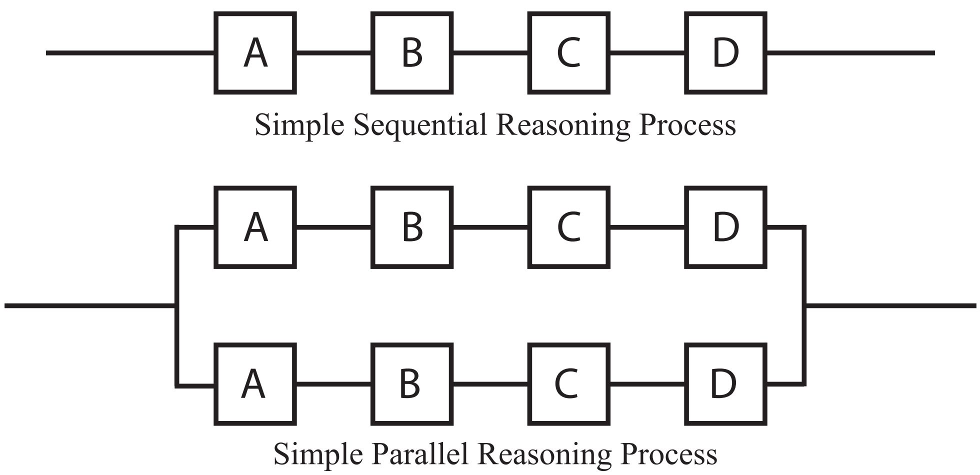


Figure 1. Reasoning Processes

ways to shift our decision-making strategies to a more parallel reasoning process; thus allowing us to efficiently solve more and more complex problems. Another aspect of complex problems that problem solvers struggle with is our inability to fully define the problem while attempting to identify the interrelationships of the problem situation. The problem situation is likely to include factors that are unknown at the time when a solution is desired. This means that parts of the problem are not understood and in particular, that the relationships among the unknown and known parts of the system cannot be explained.

As is so often the case in project management, when developing the project control plan, not all of the variables can be defined or quantified, nor would one want to be bogged down with the task of anticipating every single variable. In regards to decision making in project management it appears there is potential here to look for an improved decision-making process that is better capable of dealing with this uncertainty.

Now that we have begun to define what a complex problem is and identified some of the inherent difficulties in dealing with and/or solving complex problems within the current problem solving paradigm we should take a closer look at what means and methods have been successful in the past for solving complex problems. Historically, humans have used their special evolutionary trait of rational thought and logical reasoning to solve all levels of problems.

"This rationalistic approach to problem solving proceeds in well defined and largely sequential steps: define the problem, establish general rules that describe the relationships that exist within the problem, apply the rules to develop a solution, test the validity of the solution, and repeat all steps until an acceptable solution has been made. This simple view of problem solving suggests a model of sequential decision-making that has retained a dominant position to the present day." (Pohl 46-47)

There is a close correlation between the rationalistic approach and what is commonly referred to as the scientific method. Though there is nothing wrong with this type of sequential problem solving technique for more basic problem situations though, as noted earlier, with regards to solving complex problems, the human cognitive system needs to begin to shift from this lower level sequential problem solving technique to a more parallel reasoning process.

Additionally, decision makers find it exceedingly difficult to consider more than three or four issues at any one time. In an attempt to deal with the concurrency requirement several strategies have been commonly employed to reduce the complexity of the reasoning process to a manageable level. Some of these strategies will be discussed below.

1.2 Decision Making and the Human Cognitive System:

Real world problems are often very complex involving many related variables, neither the relationships among the variables nor the variables themselves are typically well understood enough to provide the basis for clear and comprehensive definitions. In other words, problem situations are often too complex to be amenable to an entirely logical and predefined solution. Therefore, as previously stated, problem situations need to be considered through the lens of a parallel reasoning process. The initial step taken to shift from a sequential decision-making process to a more parallel/analytical process taken by the human cognitive system was to decompose the whole into component parts; this was completed as follows: First, decompose the problem into a series of sub-problems. Next, study each sub-problem in isolation and further decompose if necessary. Third, combine the solutions of the sub-problems into a solution of the whole.

Underlying this problem solving strategy is the implicit assumption that an understanding of the parts leads to an understanding of the whole. Under certain conditions this assumption may be valid. However, in many complex problem situations the parts are tightly coupled so that the behavior of the whole depends on the interactions among the parts. Decomposition is a natural extension of the scientific method approach to problem solving and has become an essential component to rationalistic problem solving methodologies. Nevertheless, decomposition has serious limitations. First, the behavior of the whole usually depends more on the interactions of its parts and less on the intrinsic behavior of each part. Second, the whole is typically a part of a greater whole and to understand the former we have to also understand how it interacts with the greater whole. These flaws with decomposition can be over come by paying strict attention to the interactions of the parts, and the understanding of how the whole of the parts interacts with the greater whole.

Rationalism and decomposition are certainly useful decision-making tools in lower level complex problem situations. However, care must be taken in their application. At the outset it must be recognized that the reflective sense and intuition of the decision maker are at least equally important tools. Second, decomposition must be practiced with restraint so that the complexities of the interactions among the parts are not overshadowed by the much simpler behavior of each of the individual parts.

It is in the opinion of this author, that by introducing hierarchical modeling techniques; you can take advantage of some of the more successful aspects of decomposition and rationalism problem solving strategies even when not all of the "parts" are known or fully quantifiable. When the interactions of the parts are fully studied and integrated into the hierarchical model, it allows us to better model the complexities of reality and begin to explore possible non-inferior problem solutions when previously, all solutions seemed possible. As we have investigated the decomposition problem solving strategy, it is worth noting the following. As the decision maker continues to decompose the problem further and begins to analyze the interactions of the parts and their affect on the whole, the complexity of the problem begins to escalate. The major defining character of a complex problem is the number of, and the strengths of, the inter and intra relationships that exist among the internal and external components of the problem. As you further decompose the problem, you introduce more inter and intra relationships, further adding to the complexity of the problem. Having recognized this, it appears that the complexity of a decision-making activity does not appear to be due to a high level of difficulty in any one area but due to the multiple relationships that exist among the many issues that impact the desired outcome. (See Figure 2)

Since a decision in one area will tend to influence several other areas there is a need to consider many factors at the same time (parallel reasoning). This places a severe burden on the human cognitive system which we identified earlier is incapable of dealing with a

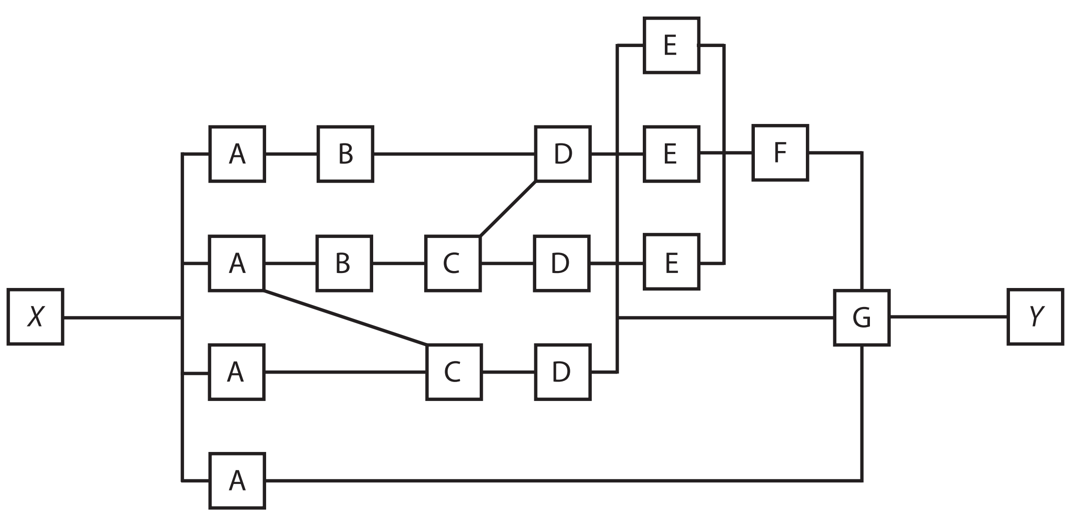


Figure 2. Example of a Complex System

large number of conflicting issues at a single time nor is it capable of considering problem situations in a parallel reasoning process, which we know is critical to solving complex problems.

"Although the neurological mechanisms that support conscious thought processes are massively parallel, the operation of these reasoning capabilities is largely sequential… Accordingly, decision makers tend to apply simplification strategies for reducing the complexity of the problem solving activity." (Pohl 50)

As we further understand the rational (sequential decision making) portion of the human cognitive system, we continue to discover various limitations in the way we try and solve complex problems. Besides the fact that humans typically apply a sequential decision-making process combined with decomposition techniques to solve complex problems, the rational portion of the brain that is responsible for this current problem-solving paradigm is also highly vulnerable to emotional influences. This vulnerability to emotion can be further problematic. All of these compounding flaws though, should not suggest that it would be best to strive to remove the human element altogether from decision making systems. On the contrary, particularly in complex problem situations where there tends to be a significant element of uncertainty, human intuition and emotions are not only desirable but often necessary ingredients for a successful outcome.

"Nevertheless, the intuitive aspect of decision making is most important. Even if only a very small percentage of these intuitive associations were to lead to a useful solution, they would still be considered one of the most highly valued decision-making resources." (Pohl 61)

"…decision-makers frequently make value judgments for which they cannot rationally account. Yet, these intuitive judgments often result in conclusions that lead to superior solutions. It would appear that such intuitive capabilities are based on a conceptual understanding of the situation, which allows the problem solver to make knowledge associations at a highly abstract level." (Pohl 51)

With the knowledge we just gained, it seems possible to begin to understand how we can build a more optimal decision-making process revolving around the human element. *By striving to build a multi-criteria decision making system that utilizes an unbiased parallel reasoning process, that allows for controlled and brief intuitive judgments to be made in the face of uncertainty by the human element.* We can begin to create a new paradigm in complex problem solving; one in which there is a harmony between man and the "computer."

By looking first at the cognitive decision making process we are able to begin to understand where there might be areas for improvement in how we try to solve complex problems. As the end result of our work in managing this complexity is delivering the value our clients initially envisioned based on demands of the end users. With an understanding that all of this complexity is adding up to one thing, decisions to be made. Having said that, we need to consider all the decisions to be made by the project stakeholders and team members to determine what set of, or types of decisions would be most impacted or well served by an evolution in decision-making. It is in the opinion of this author, that decision-making during the project team selection and the design process would benefit the most since, these decisions have the biggest impact on the formation of the project overall. Especially when you consider that "Design is the process of originating systems and predicting their fulfillment of given objectives." (Sless 1978)

As it is the selected team that will carry out the design process and the result of the design process is a series of decisions made towards fulfilling these given objects. How can we ensure that there isn't another series of decisions that would lead to a superior fulfillment of these objectives given the constraints of the project? In order to explore the possibility of achieving an optimal or non-inferior fulfillment of the given objectives to a complex problem, we should consider employing help from a formal mathematical modeling process as there are many well documented cases of mathematical modeling being used to determine non-inferior solutions. The next section of this paper looks into the possibility of using optimization methods to help find an answer to the previously mentioned question.

1.3 Design Optimization:

"To go further we need to formalize a model of design as decision making which allows us to explicitly represent the interaction between the design decisions and design performance." (Gero 231)

Let's assume from the beginning that the preeminent intent of design is that design is goal seeking; however ill-defined those goals might be, design necessitates decisions be made in regards to the best way of achieving those goals. As the design process is carried out, it results in a designed solution, i.e. decision made, based on achieving one or more performance characteristics (goals) and will be judged based on it's ability to meet those performance characteristics.

"Many different performances may characterize one solution and many different solutions may have the same performance. The exploration of the relationships between design decisions and solution performances is fundamental to design - a process of predicting the performance consequences of design decisions and postulating the decisions which will lead to desired performance resultants." (Gero 230)

When you consider further, that design is not only goal seeking, but is by definition multi-criteria in nature it leads one to believe that design is a complex problem situation. One with multiple competing criteria and decisions to be made based on achieving specific performance criteria (goals).

Multi-criteria analysis represents a general philosophy of design and planning. There are two distinct subsets of "Multi-Criteria Decision Making;" they are "Multi-Criteria Choice Methods," and "Multi-Criteria Programming." I will briefly introduce these two subsets and describe their strengths and weaknesses. As this paper progresses, I will revisit these two subsets and explain them in further detail as they are applied to an academic exercise modeling a real world experience.

Multi-Criteria Choice Methods

Multi-Criteria Choice Methods (MCCM) "are directed at problems in which there is a finite set of predefined alternatives or choices." (Gero 165) "Multi-Attribute Utility Theory" has been determined to be the most robust MCCM method for selecting a single alternative out of a feasible set. Multi-Attribute Utility Theory is a well-known tool for choice problems as it seeks to estimate the decision maker's value function which is defined over the multiple criteria of the problem statement. Once the merit of the value function is known, the identification of the solution should be fairly straightforward and simple. MCCM techniques are a good alternative to solving decision-making problems due to the fact that they are less computationally heavy when compared with more formal programming models. MCCM techniques like "Analytical Hierarchical Process" require the decision maker to initially make smaller value judgments pitting criteria vs. criteria in order to avoid having to make larger more controversial singular judgments later on. These types of smaller value judgments will inform the model and once the analysis is complete it allows the decision maker to comfortably select an alternative based on the output generated from comparing the criteria against each other. The downside to using MCCM stems from the fact that MCCMs place an initial burden on the decision maker to make multiple smaller value judgments which can become quite difficult or time consuming depending on the size and complexity of the problem situation. Secondly, MCCM can require the decision makers to state their preferences before they know what the final choices are. This problem can be dealt with if you consider that as you develop the model further and compare the criteria against one another, that you are actually helping to shape the final choices. So that way at the end all of your preferences are prebaked into the choices. I will apply an MCCM technique called "Analytical Hierarchical Process" further below that will clearly demonstrate how this type of method works.

Multi-Criteria Programming

"Multi-Criteria Programming" (MCP) is a set of mathematical programming techniques directed at situations in which the alternatives are not know in advance. Rather, choices are represented by decision variables – controllable aspects of a system…" (Gero 166)

Multi-Criteria Programming is concerned with finding the optimal (non-inferior) solution to a problem given certain constraints and performance requirements. It is important to state that the formal definition of optimal is not to be considered. As finding a truly optimal solution for a complex multi-criteria problem is potentially unfeasible; we should instead be concerned with the concept of "non-inferiority." "A feasible solution to a multi-criteria programming problem is noninferior if there exists no other feasible solution that will yield an improvement in one criterion without causing a degradation in at least one other criterion." (Gero 167) Since in theory, there are many feasible solutions to a particular problem statement, we want to know which out of all the feasible solutions maximizes the value function while satisfying all constraints.

The main benefit of using MCP methods, is that it provides the decision maker with the non-inferior set of choices to be made without requiring the initial value judgments of some of the MCCM methods. Having said that, as the number of criteria increases so does the level of complexity of the problem. This increase in complexity is a direct result due to the increase in the number of criteria and their relationships to one another and the project as a whole. This increase in complexity directly correlates to larger, more exhaustive amount of computer time and therefore greater computational cost in order to solve the problem. This increase in computational cost represents the main drawback of utilizing this method.

This basic understanding of the pros and cons associated with these two subsets of Multi-Criteria Decision Making helped inform my research and development of a Multi-Criteria Decision Making Model that I applied to an academic exercise modeling a real world experience. I will explain in detail below how these two subsets are utilized in my hybrid model and show the results generated by my model.

The author has suggested so far that the design process should be considered as a complex problem situation. Therefore, since all A/E/C projects require a design process to bring them to fruition, we can say that the A/E/C industry needs to come up with a more holistic way to not only manage the design process, but the entire life span of the project. Although it is the design process that is a direct response to the performance demands specified by the owner, there are other aspects of an A/E/C project that can also impact the initial value identified during the design process. By taking a more holistic approach to the way we analyze and manage projects as a whole, it will allow our decision making to be faster and better targeted towards adding real value through out all stages of the project. Thus a more holistic approach to analyzing the life span of a project allows for clearer: identification, quantification, evaluation, and trading-off of risks, benefits and costs associated with the project. The fore mentioned benefits of a holistic approach should constitute an integral and explicit component of the overall managerial decision making process and should not be a separate cosmetic afterthought; because: "The maximum risk exposure occurs at the point of maximum investment - when the project is completed and either does not function or is no longer needed." (Jobling 84) (See Figure 3)

If we strive to develop a holistic approach to project management, we should be very clear as to why the A/E/C industry would want to do this. In the opinion of the author, owners hire project managers to help them determine the value they need, to solve the problems they must, to bring their project to life. Project managers in general are responsible for protecting value and controlling budget, schedule and risk. The traditional methods for delivering projects are marginally adequate at best in regards to serving the needs of project managers in preforming their tasks. While delivery methods like Integrated Project Delivery and Target Value Design have the potential to deliver real value for the client. These contemporary delivery methods need a more sophisticated project management approach to help ensure that they actually deliver the value they are championed to.

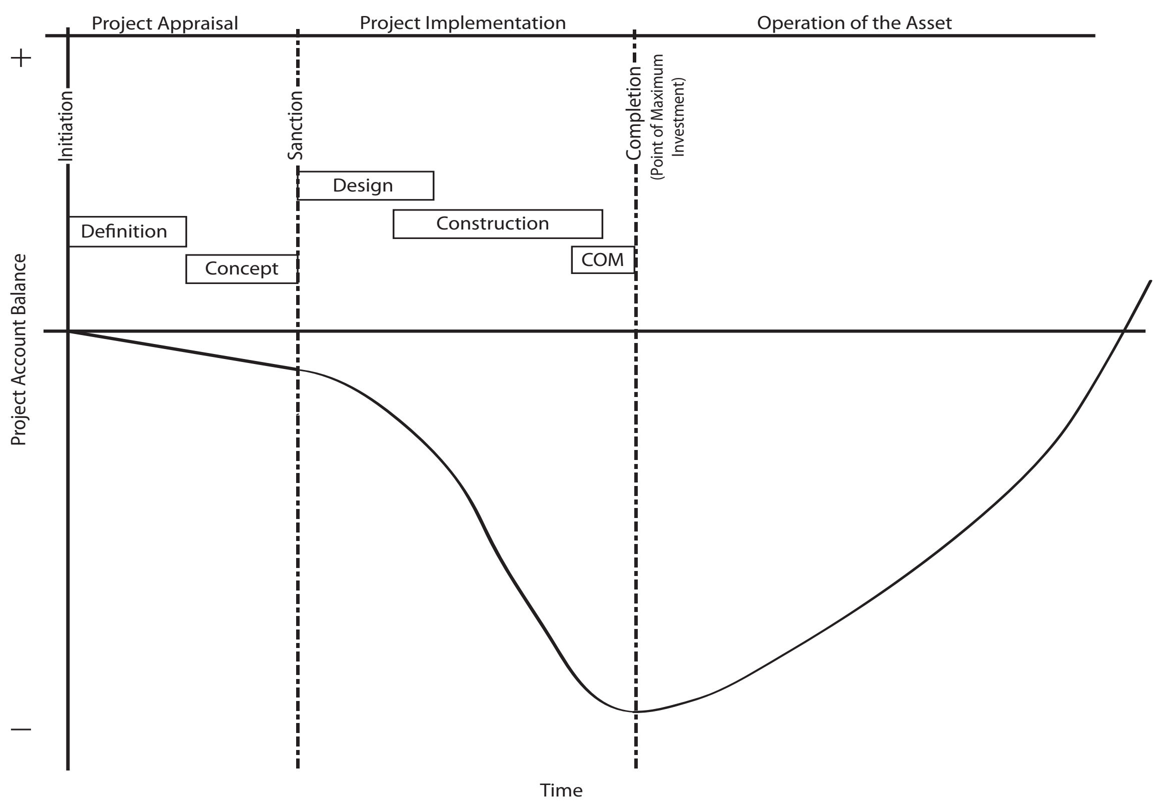


Figure 3. Financial Project Risk Over Time (3 Design Alternatives)

CHAPTER 2 - RESEARCH REVIEW:

2.1 Value Driven Decision Making:

The author would like to shift our discussion for the moment from decision making and complexity to the concept of value, particularly the Best Value Selection (BVS) process. What does "Best Value" actually mean? "Best- of the most excellent, advantageous, effective, or desirable type of quality." (New Oxford American Dictionary) "Value - the regard that something is held to deserve: the importance, worth, or usefulness of something. The material or monetary worth of something." (New Oxford American Dictionary) How the term "Best Value" is applied can vary depending on how the entity using the term defines "value." In the A/E/C industry, does Best Value refer to the perceived level of service versus the price to provide those services? Is the term Best Value referring to the best design solution for a stated budget, as is common in some Design-Build procurements? Or is the term Best Value completely relative to the users and the situation; thus having the potential to mean something else completely? Now that we have considered the literal meanings of these words, it is important to understand how we can accurately translate them to the A/E/C industry while paying especially close attention to the way we use the term value.

Typically, BVS within the A/E/C industry has been considered as follows. "A Best Value Selection is a selection process for construction services where total construction cost, as well as other non-cost factors, are considered in the evaluation, selection, and final award of construction contracts." (AGC 7) It has been mainly used, due to the fact that "... today's project owner's main challenge is to figure out how to buy value, not just low price..." (AGC 6) It has been especially popular in the public sector as many public owners have grown tired of the litigation usually resulting from the low bid environment, but still need a clear and honest way to select the project team based not just on the traditional objective criteria of cost but based on the critical subjective criteria as well. Since it is not only cost that makes up the project overall, but a combination of cost, schedule, value and constructability concerns, it becomes clear that making decisions based solely on cost would be ill-advised. The burden on the public sector owner is to maintain a fair and open process of selection. Which becomes heavier when they make selections involving subjective evaluations as opposed to purely cost.

“The best way to maintain the trust of the public is to have a process that, though it may include some subjectivity, is still one that is difficult to influence. The absence of a formal process to incorporate non-price criteria into the final evaluation and selection increases the chances of subjecting your selection committee to scrutiny resulting from charges that the process was not as “fair” as it should have been.” (AGC 6)

Therefore, in regards to the Best Value Selection process; *How can we ensure fairness with our scoring framework, so that we can include the critical non-price criteria into the final evaluation of the proposed design and construction teams, thus truly providing a “Best Value Selection” method?*

2.2 Systems:

In order to begin to try and answer this question, I began researching related disciplines to see if any of them had any means or methods for dealing with analyzing subjective criteria in a fair and formal way. This research led me to systems engineering, where I found many parallels to the A/E/C industry. “Systems engineering may be viewed as a philosophy which looks at the broader picture. It is a holistic approach to problem solving that relates interacting components to one another.” (Haimes 53) A holistic approach to problem solving that relates interacting components, people, decisions, etc. together is exactly what I feel in general is lacking in the A/E/C industry with respects to team selection and the design management process. The goal of my research presented in this paper is to create a project management tool that takes into consideration the strong points of, and the difficulties the human cognitive system is faced with when trying to solve complex problems. A project management tool that is based on the idea that a design and construction project is nothing more than a “complex system” that is hierarchical in nature. To develop a multi-criteria decision making system that is fully integrated across the design and construction team members; owner included and is capable of treating the design and construction project as a complex system. A project management tool that integrates these concepts with the idea that you are attempting to manage the critical flows of information between the project team members and trying to understand in a structured way the impact this information will have on the decision making process and thus, the project overall.

"Both practitioners and academics have difficulties accepting and treating projects as complex systems, and tend to reduce the management of projects to the application of tools such as PERT, WBS, earned value, etc... Consequently, managers facing complex projects need access to a decision-making aid model based on relevant performance evaluation. In this situation modeling plays an important role in project management in supporting "complex" decisions. Modeling is often presented as a simplification of reality and this simplification is a powerful advantage. This enables us to analyze and come to simplified conclusions about the real world which would be impossible to reach if we had to deal with all the complexity of the real world." (Gourc, Lauras, Marques 1058)

If we can implement a project management tool of this nature then the project overall should gain efficiencies in it's decision making and information sharing. It is important to understand that it is the flow of information and the decision making process that you are attempting to manage in a highly structured way. As opposed to managing the people in this structured way it allows the project team (people) to remain the creative problem solvers that you hired to work together in the first place. Since engineered systems are almost always designed, constructed, and operated under the unavoidable conditions of risk and uncertainty and are often expected to achieve multiple and conflicting objectives, modeling is the best way to understand the potential outcomes of the project based on changes to the inputs or constraints of the project. By treating a design and construction project as a complex hierarchical system and modeling the connections between the major performance requirements and the decisions needed to be made to deliver the value of those requirements, you can begin to optimize the system overall.

"Hierarchical control, when applied to risk management systems, has a harmonizing effect on the subsystems and contributes to the holistic approach within which the overall system is viewed… When dealing with a low dimensional multi-objective optimization problem and identifying the impact of the subsystems' reliability on the overall system's performance, a preferred Pareto Optimal solution of a large scale overall system can be reached by introducing coordination among subsystems." (Haimes 94)

The above quote is an example of how we can learn from and apply techniques from systems engineering. As essentially a design and construction project should be viewed as a logical series of decisions to be made based on the interactions of subsystems of information organized hierarchically within the overall context/framework of the project specifics.

My research in systems engineering led me to discover two modeling techniques; HHM and AHP. I will incorporate them together as the backbone of my proposed multi-criteria decision making system. The first technique is known to systems engineers as Hierarchical Holographic Modeling (HHM); it is a modeling framework technique. (See Figure 4) "Since its introduction in 1981, HHM has provided a general framework for modeling complicated, multi-objective problems of large scale and scope." (Haimes 117) The role of modeling problems is so that you can represent the intrinsic and indispensable properties that characterize the system, i.e. modeling captures the essence of the system. If we consider a design and construction project to be a complex system, then HHM for that matter is a natural fit as the framework for modeling these types of problems. As it does not require much more additional work necessary to create the framework of the model than the data/work that you would normally gather when determining the scoring criteria for a "Best Value Selection" process.

On the other hand, Analytical Hierarchical Process (AHP) is much more than a technique for establishing a framework for your modeling system. AHP captures priorities from "paired comparison judgments" (pairwise comparisons) (See Table 1) that are arranged in a matrix (See Table 2), and has unique advantages when important elements of the decision

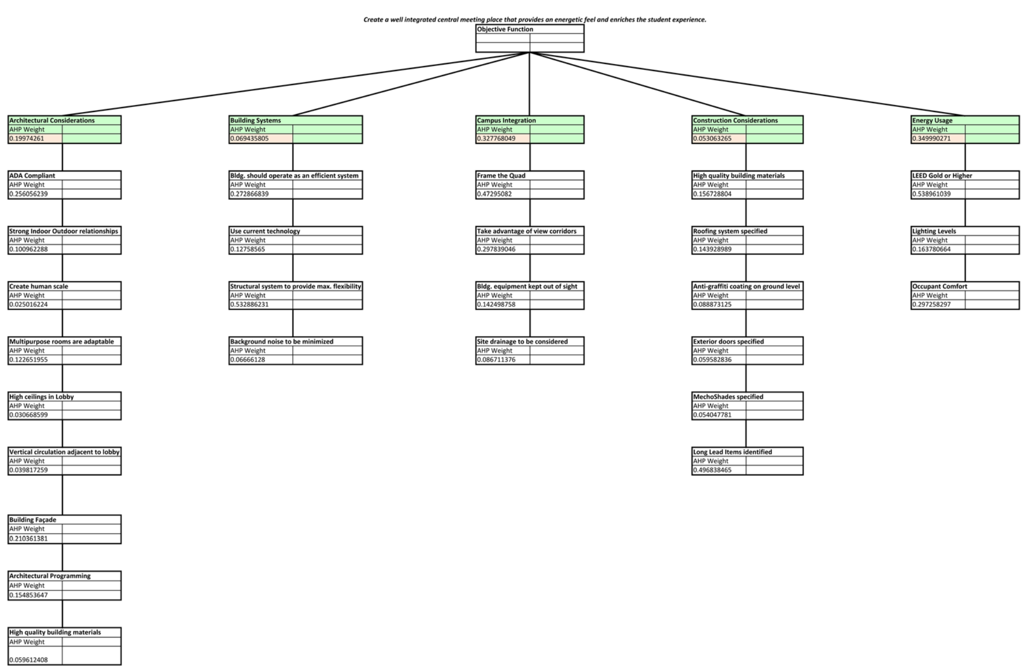


Figure 4. Hierarchical Holographic Modeling Framework

are difficult to quantify or compare. The results of the AHP is a weighted value or priority that is assigned to a criteria that is part of a multi-criteria decision making model. Using HHM as the framework component of my multi-criteria decision making model allows me to use AHP as the number crunching portion of the model. The "number crunching" will result in weights that are assigned to the individual criteria and sub-criteria that make up the HHM thus allowing me to have a fully weighted, structured hierarchical model that we will be able to use to analyze and determine the Best Value Selection of a competitive RFP process. This model can then be used to manage the design process through Target Value Design. Since AHP is well know for it's ability to quantify and compare subjective and objective criteria, it will be a great tool for modeling the evaluation criteria of a Best Value Selection and can be transitioned over to managing the design and construction process. AHP also has a reliability feature built into the modeling process that constantly validates the decision making process allowing the modeler to verify if the process is fair and accurate. This feature is especially important for public works projects due to the intense scrutiny that can take place after the selection has been made. AHP allows for human judgments to work with objective criteria as well as the subjective criteria and converts all of these evaluations into numerical values that can be introduced into mathematical models.

As previously mentioned, a graphical representation of the HHM framework combined with the AHP weights, is shown in Figure 4 and will be described in further detail in the paragraphs to follow. The author would like to mention that in actuality, the completed HHM graphic is a visual way of presenting a mathematical model in a more "user friendly" manner. Having said that, for the modeler, the actual model is an extremely powerful tool that can be used with any number of optimization or mathematical analysis techniques to study and satisfy the requirements of the project.

2.2.1 Hierarchical Holographic Modeling (HHM):

As previously mentioned, HHM is a framework for hierarchical modeling. More specifically, HHM is capable of considering "large-scale and complex systems that have more than one hierarchical overlapping structure." (Haimes 95) By considering the various hierarchical structures of a system together, we can expect to get a better understanding of the corresponding sources of risk, uncertainty and overall system performance.

"The fundamental attribute of large-scale systems is their inescapably multifarious nature: hierarchical non-commensurable objectives, multiple decision makers, multiple transcending aspects… that most large-scale systems respond to a variety of needs which are basicly non-commensurable and which may under some circumstances become openly conflicting." (Haimes 97)

Haimes has also pointed out that "Our inability to treat the most basic attributes of large-scale systems from some relevant vantage point with some degree of commonality constitutes a remaining weakness in our theoretic modeling base." (Haimes 97) In response to this "remaining weakness," Haimes, the developer of HHM explored the various modeling techniques and discovered that "…even present integrated models cannot adequately cover all systems aspects per se, the concept of hierarchical holographic modeling constitutes a comprehensive theoretical framework for systems modeling and risk identification… a systems single model is divided into several decompositions in response to the various

Table 1. Example Analytical Hierarchical Process (Pairwise Comparison)

Pairwise Comparisons				
Architectural Considerations	5	Building Systems	1	Architectural Considerations are what we are trying to optimize and should be weighted more than Building Systems. Some of the Building Systems issues can be solved through architectural considerations.
Architectural Considerations	1	Campus Integration	2	As stated by the owner, Campus Integration is one of the most critical criteria that must be satisfied. But since Architectural Considerations are also important, the difference between the values given to the two criteria should not be that great.
Architectural Considerations	3	Construction Considerations	1	Architectural Considerations are of a higher importance than their construction counterpart. Generally speaking, this is due to the fact, that decisions made during design have a larger impact to construction than visa versa.
Architectural Considerations	1	Energy Usage	2	Although Architectural Considerations and Energy Usage are tightly linked, and Architectural Considerations greatly dictate Energy Usage, for this project we will give priority to Energy Usage so that as we make design decisions going forward, we make them with energy in mind. This is especially important due to the LEED Gold minimum rating that is required for this project.
Building Systems	1	Campus Integration	5	Based on the owner's preferences, Campus Integration clearly is more important to consider than Building Systems. This is especially true when considering that all equipment should be housed out of sight.
Building Systems	2	Construction Considerations	1	Building Systems while close with respect to owner's preferences to Construction Considerations should be weighted more due to their interconnectedness to the Energy Usage category, which will likely be the most critical criteria.
Building Systems	1	Energy Usage	5	Energy Usage dictates many of the systems used with in the building.
Campus Integration	5	Construction Considerations	1	Campus Integration is part of the objective function due to the importance that the owner has placed on it.
Campus Integration	1	Energy Usage	1	Based on the owner's preferences and RFP content, Campus Integration and Energy Usage are the two most important criteria, and thus should be valued evenly.
Construction Considerations	1	Energy Usage	7	Energy Usage far out weighs Construction Considerations during the design process.

Table 2. Example Analytical Hierarchical Process (Matrix)

		Architectural Considerations	Building Systems	Campus Integration	Construction Considerations	Energy Usage	Priority	Rank
1	Architectural Considerations	1	5	0.5	3	0.5	0.19974261	3
2	Building Systems	0.2	1	0.2	2	0.2	0.069435805	4
3	Campus Integration	2	5	1	5	1	0.327768049	2
4	Construction Considerations	0.333333333	0.5	0.2	1	0.142857143	0.053063265	5
5	Energy Usage	2	5	1	7	1	0.349990271	1
						Sum of Priorities:	1	
						Inconsistency:	0.029497343	

aspects of the system, and these decompositions are coordinated to yield an improved solution." (Haimes 97)

Since the basic philosophy of HHM is to build a family of models which address the different aspects of the system all within a single framework, it is possible to see how by utilizing HHM, it provides the analyst with a holistic, unified approach to modeling the system as a whole. From the viewpoint of the human cognitive system discussed earlier, the fact that HHM relies on utilizing decomposition techniques to organize the model framework makes adopting the use of HHM simple for the analyst who through evolution should be quite prone and skilled at utilizing decomposition as part of their problem solving technique.

As discussed in section 2.2 we realized that we should being to consider design and construction projects as complex systems. When you consider the various objectives, decisions, relationships, resources, multiple decision makers, etc. that A/E/C projects have, then it becomes clear that we should consider using modeling techniques to find a non-inferior solution to our design and construction projects. It would then be best to utilize HHM as the framework for our systems model since it is capable of dealing with the various hierarchical structures of the system together and will give us a better understanding of the systems performance overall. Furthermore, HHM is capable of unifying different modeling techniques together. For example you can combine the various components of the system together in the HHM that utilize different modeling techniques like MCP and MCCM to determine their values. This reason alone makes using HHM as a modeling framework a valid effort.

2.2.2 Analytical Hierarchical Process (AHP):

Analytical Hierarchical Process is a well researched and proven Multi-Criteria Choice Method (MCCM) which is a branch of Multi-Criteria Decision Making. As there is much literature on this subject (AHP), I will only describe to a basic level how the process works. The goal of this section is to provide the reader with a general understanding of AHP so they will be more familiar with the topic prior to it's application in the example described in section 3.2.

To understand the world, we assume that we can: describe it, define relationships between it's parts and make judgments to relate it's parts. To understand a problem situation we make the same assumptions listed above as well as we typically have a goal or purpose in mind when we are defining the relationships and making judgments. This is important to consider due to the fact that in order to create an AHP model, we must be able to do the same thing in regards to the "world" we want to reason about. As mentioned previously, one of the major strong points of AHP, is that it is capable of modeling not only objective criteria, but subjective criteria as well. In the A/E/C industry, the "world" (team selection and design management) we want to reason about is made up of objective and subjective criteria. During the team selection and design management process, there are many easily identifiable objective criteria to consider, but there are also a large amount of subjective criteria to consider as well. Some of the subjective criteria are more important than any of the objective criteria are in the eyes of the owner. Therefore, it seems as if AHP is a perfect fit for the A/E/C industry.

For the purpose of this paper, the author is suggesting that AHP be used in combination with HHM. I mention this for the reason that the initial step in building an AHP model is that you must first identify and establish the criteria or "system components" that will influence the decision you are trying to make with respect to achieving your objective function. For my example, the HHM takes care of completing this initial leg of the work and is a natural fit for setting up an AHP analysis. Once the HHM framework is set up, the criteria of the system will have been identified and organized in a hierarchical way and you will then be ready to begin the formal AHP analysis.

As previously mentioned, AHP is exceptional in regards to analyzing objective and subjective criteria together. The reason that this is possible has to do with the fact that the AHP model is built upon pairwise comparisons. In order to complete these pairwise comparisons you need to establish a clear scoring system. Table 3 is an example of the scoring values I used for the example worked on in Section 3.2 As you can see in Table 3, only odd numbers are used for the ranking system. This reserves the even numbers to be available for intermediate values (to reflect compromise) should the analyst or decision maker have a need to give a score that is between numbers. Also, various studies have shown that using odd numbers provides for better results.

Now that we have identified our scoring values, we are ready to proceed with the next step of the AHP process, pairwise comparisons. "Pairwise comparisons are a judgment; a relative measure of preference between a pair of elements with respect to a common property

Table 3. Pairwise Scoring Values

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and judgment moderately favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very Strong Importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2,4,6, and 8 can be used to express intermediate values. Intensities of 1.1,1.2,1.3, etc. can be used for elements that are very close in importance.		

they share." (Haimes 178) As noted earlier, the human cognitive system is capable of utilizing intuition to solve problems or make judgments at a highly abstract level (pairwise comparisons). In fact, based on the research presented in this paper, in Section 1.2, the author came to the conclusion that in order to create a shift in our current problem-solving paradigm we need to utilize a parallel reasoning process that incorporates controlled value judgments in the face of uncertainty. AHP offers this opportunity.

The MCDM portion of the AHP molding method is the parallel reasoning process, while the pairwise comparisons are the controlled value judgments made by the human cognitive system. Once the pairwise comparisons have been made, see Table 1, the results need to be built into a matrix format so the data can be used in the mathematical modeling portion of the AHP process. Table 2 shows a fully completed pairwise matrix. The mathematical operations to determine the values of the matrix cells will not be covered here, but "Risk Modeling Assessment, and Management" by Yacov Y. Haimes and "The Analytical Hierarchical Process" by Thomas L. Saaty are great resources for further understanding of how to develop the matrix and the AHP process in general. The "Priority" value is a "Normalized Principle Right Eigenvector" that is to be applied as a "weight" to the criteria it is associated with. These weights show the relative importance of each criteria and/or sub-criteria in contributing to achieving the objective function.

Another strong argument for the use of AHP is the fact that included with the comparison matrix is a built-in, consistency function. In Table 2, the "Inconsistency" value demonstrates how consistent the decision maker was in completing the pairwise comparisons and thus deriving the "priorities." According to Thomas Saaty the creator of the AHP method, he states that an inconsistency value of less than 10% (.10) is required to ensure accuracy within your model. If the inconsistency value is greater than 10%, then it is necessary to re-perform the pairwise comparisons for that matrix. Once each section of the hierarchical model and all its related criteria and sub-criteria have been pairwise compared and the results built into individual matrices then your baseline model is set; as all the levels of the individual criteria are now weighted in regards to supporting the objective function. Now that the baseline model is complete, you can begin to evaluate the "alternatives/concepts" in regards to their potential in achieving the objective function.

To begin evaluating the alternatives against the baseline model, we will need to perform similar pairwise comparisons as we did to establish the baseline model, only this time instead of determining the weights of the criteria through pairwise comparisons, we will be evaluating the alternatives against each other with respect to their ability to satisfy the each individual sub-criteria and criteria. We will start at the lowest level of the model and then work our way up through all of the sub-criteria to the criteria. In order to do this, you will need to treat each concept as a system and separate out the components of the system that match up to the various sub-criteria/criteria of the baseline model. Again the example in section 3.2 will provide for a good demonstration of this.

The author describes the bottom up process of the AHP evaluation of the alternatives through the HHM as "pushing" the concepts through the model; see Figure 5. With the final concepts pushed through the model, and the matrices developed, the decision maker needs to determine the final selection of one of the concepts based on how they compare with the baseline model. Table 4 shows the final matrix which will yield the chosen concept at the conclusion of it's calculation. Table 4 is essentially the multi-criteria decision making model data in it's raw form. This is the data that the decision maker developed in order to make a selection (decision) of a concept. The results of this matrix, gives the decision maker

Table 4. Synthesized AHP Data

		Synthesizing Final Priorities			
Criterion	Priority vs. Goal	Concept	A	B	C
Architectural Considerations	0.19974261	Concept 1	0.137287664	0.19974261	0.027422196
		Concept 2	0.623224728	0.19974261	0.124484534
		Concept 3	0.239487608	0.19974261	0.04783588
			1		0.19974261
Building Systems	0.069435805	Concept 1	0.231082375	0.069435805	0.016045391
		Concept 2	0.665070243	0.069435805	0.046179688
		Concept 3	0.103847382	0.069435805	0.007210727
			1		0.069435805
Campus Integration	0.327768049	Concept 1	0.457671958	0.327768049	0.150010245
		Concept 2	0.416005291	0.327768049	0.136353243
		Concept 3	0.126322751	0.327768049	0.041404562
			1		0.327768049
Construction Considerations	0.053063265	Concept 1	0.231613959	0.053063265	0.012290193
		Concept 2	0.696531334	0.053063265	0.036960227
		Concept 3	0.071854707	0.053063265	0.003812845
			1		0.053063265
Energy Usage	0.349990271	Concept 1	0.174853801	0.349990271	0.061197129
		Concept 2	0.632748538	0.349990271	0.221455832
		Concept 3	0.192397661	0.349990271	0.067337309
			1		0.349990271

**Key: Column A shows the priority of this Concept with respect to this Criterion. Column B shows the priority of this Criterion with respect to the Goal. Column C shows the product of the two, which is the global priority of this Concept with respect to the Goal.
For each criterion, the sum of Column C must equal the Priority vs. Goal value.

a few options on how to interpret the data to make a selection. Either the decision maker can sum up the "earned value" in column 'C' (See table 4) for the individual alternatives over each criteria and select the alternate whose sum has the highest value. Or they can take this data and perform some sort of sensitivity or "Post-optimality" analysis to further enhance the selection process.

"While optimization identifies the optimal value of the objective function and the set of decisions to be taken to obtain that optimal value, the designer may desire more information about the stability of the design decision or information about other policies." (Gero 267) Post-optimality analysis is a critical part of the model presented in this paper, as it allows the "designer" to test the stability of the "design solution" and further determine the BVS based on how the design solution performs under theoretical uncertainty. As their is potential for a high "value" achieving design solution that is not well planed for to perform poorly under less than ideal project conditions and therefore potentially loose a portion of its value; making it now an inferior solution when compared to the others.

As previously mentioned, this research paper is not pursuing an optimal design solution to a multi-criteria problem, as optimal can often be unachievable or too expensive to determine. Instead we are looking for a non-inferior solution. Having said that, the concept of post-optimality analysis is still applicable; and in the opinion of this author and along with many others, post-optimality analysis is a critical step to ensure robustness of your decision making model.

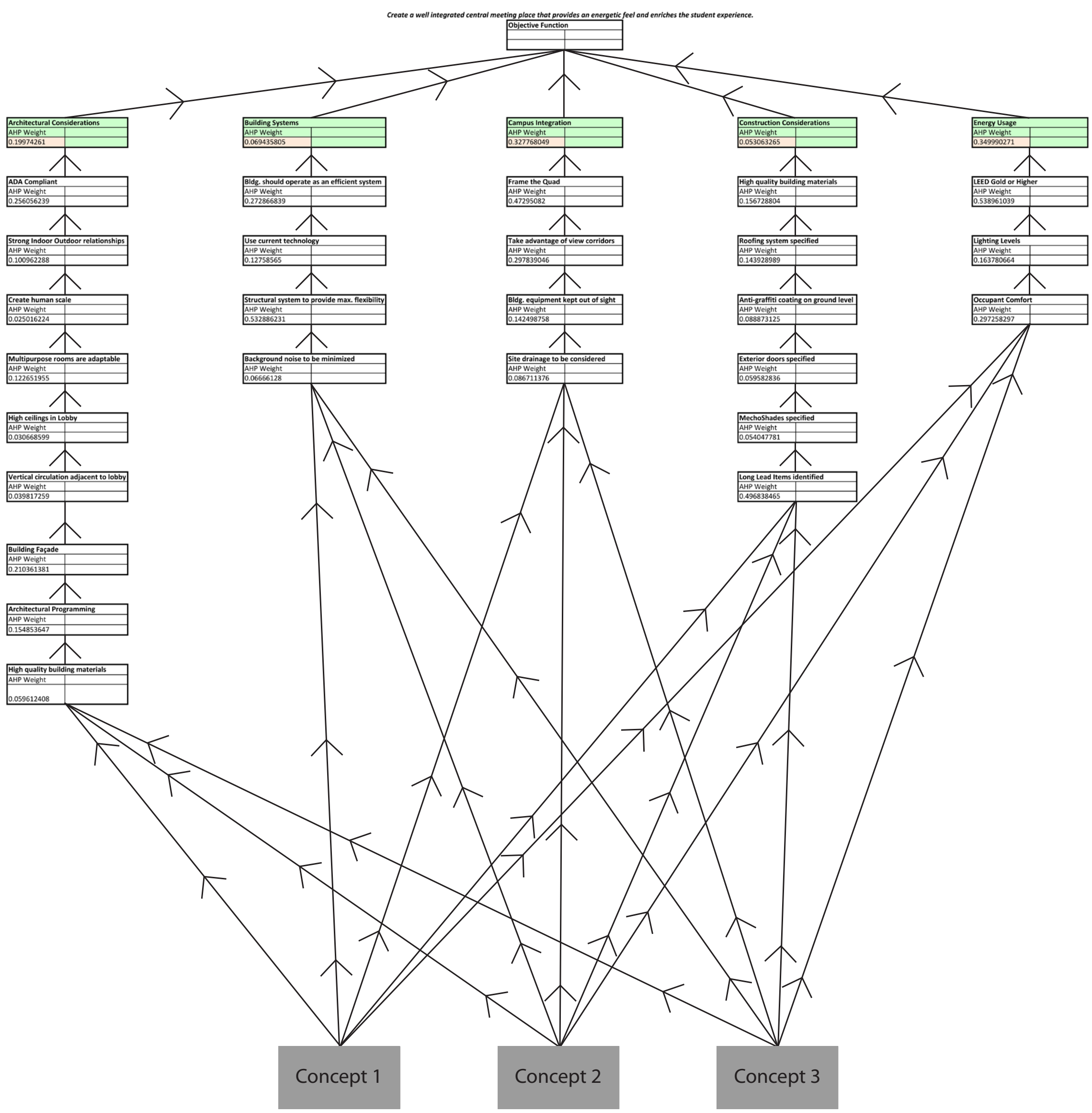


Figure 5. Bottom Up Push of the AHP Evaluations for the Concepts (Alternatives) through the HHM

CHAPTER 3 - APPLICATION:

Through out this paper so far, we have reviewed and analyzed: what complexity is and it's impact on the human thought process, how we humans and our cognitive system typically make decisions when dealing with a complex problem situation, and what relevant decision making methods have been developed in the past to assist with complex decision making. We explored the idea that the lifespan of an A/E/C project should be treated as a complex system and if we do so, it will provide project managers with a new set of tools to manage projects that had not previously been considered. We looked at the term "value" in the A/E/C industry and it's dependence on project team selection (BVS) and design management in order to maximize it's significance upon project fruition. Lastly, we looked at Systems Engineering, which "focuses on how to design and manage complex engineering projects over their life cycles" and we were able to shed some light on a few of the aforementioned "new tools" now available to project managers. In this section, we will take what we have learned and apply it to an academic exercise of a real world experience; and in doing so I will attempt to answer the questions previously mentioned along with the following ones:

How do we measure the value of a design? How do we go about managing decision making during the design process and team selection?

What would cause me to pay not only a premium for one company over another, but also feel confident that I could explain to someone why I did?

How can we ensure fairness with our scoring framework, so that we can include the critical non-price criteria into the final evaluation of the proposed design and construction teams, thus truly giving us a "Best Value Selection" method?

Is it possible to identify (to a certain extent), evaluate and incorporate risk and uncertainty into the decision making process?

How do we manage the decision making process during a Best Value Selection scenario that pays particular attention to how the term value is quantified and used?

3.1 Background Information:

An RFP for complete Design Build services was issued by a Community College District in California. The RFP demonstrated the needs the client had in regards to solving their demand for a new "Student Center and Quad" on their existing campus. Besides the functional needs the RFP described the value the client was looking for in both the selected team and the final constructed project. This was a real world exercise with the identities of the actual players concealed for this paper. This real world exercise soon became the subject matter for a course in Construction Management taught by Professor Greg Starzyk for his Integrated Project Delivery design studio quarter long project simulation at California Polytechnic State University San Luis Obispo during the Winter Quarter of 2012. The upper level students were organized into teams that included: architecture, engineering and construction management students. Prof. Starzyk was supported by a team of professors representing these disciplines. The students spent the entire quarter actively working in their teams and competing against each another to win the theoretical Design Build contract. They produced fully detailed designs, estimates, schedules, phasing plans, etc. and delivered them in written and presentation format through out the duration of the course.

For my research project, I acted as the owners representative and shortlisted the 10 teams down to 3 based on their submittals. I then evaluated their final submissions with my proposed multi-criteria decision making model and selected a winning team. My selection was independent of the actual classroom exercise outcome.

3.1.1 The Problem Context:

My graduate research which is partially demonstrated in this paper led me to the understanding that the A/E/C industry was in need of an improved method for not only selecting teams during a Best Value Selection process, but for decision making in general; particularly in regards to how we manage the design process. This need and possible suggestions for meeting this need have been discussed through out this paper. The desire to solve these needs simultaneously is achievable if we model the entire lifespan of a project from initial concept to project completion as the complex system that it is. As alluded to in previous sections, I've developed and suggest using a multi-criteria decision making model utilizing HHM as the framework for an AHP model combined with post-optimality analysis in order to solve these needs.

In order to build the HHM, you need to first get a complete understanding of the owner's desires in regards to function and value for the project. By initially analyzing the RFP document issued by the owner you can begin to discover the intent the owner had in mind when they began to consider the need for a capital improvement project and thus develop an understanding of the function and value this improvement is to have. My method for analysis was to read through the RFP and build a list of all the performance and value oriented items described in the document. Once completed, I then paired all of the repeated items together and recorded the number of times each item was mentioned. Then I tried to group all the related items together into categories. Based on the frequency counts and further analysis, I ended up with the 5 categories (Architectural Considerations, Building Systems, Campus Integration, Construction Considerations, and Energy Usage) these became the "modeling criteria" that ultimately all decisions would be made against. This data has been included in Appendix A. The collection and categorization of this data allowed me to get a very good understanding of the major theme or problem that the client was trying to solve by bringing this project forward. This understanding directly contributed to the creation of the objective function for my model... "Create a well-integrated central meeting place that provides an energetic feel and enriches the student experience."

Now that the objective function has been identified, along with the major modeling criteria (see Figure 4) a holographic hierarchical model is beginning to form. Upon further analysis of the RFP and the modeling criteria, sub-criteria (shown descending from the modeling criteria in Figure 4) began to be developed, decomposed further and organized hierarchically to finish developing the initial HHM framework.

It was important for me to pay attention to the amount of decomposition that occurs within the various hierarchical systems that make up the HHM, as I wanted to make sure that the model captured the critical essence of the system and was not becoming unnecessarily complex due to over decomposition. As this was a concern presented in Section 1.2; in regards to utilizing decomposition problem solving techniques. Therefore, I focused the decomposition efforts around portions of the system that I felt would benefit the most from some extra detail and analysis. Specifically, portions that were well described in the RFP and were: design specific, largely competitive and multi-objective in nature. Portions that I knew would be critical to the design management function of the model. An example illustrated in HHM format shown in Figure 6 is a further decomposition of the “Energy Usage” criteria. A major concern of the owner was that they wanted the new building to achieve a certain LEED rating along with other interrelated energy concerns that would be in competition with architectural design concerns such as: i.e. natural daylighting, occupant comfort, preserving certain views, etc. Due to the interrelated nature of the Energy Usage

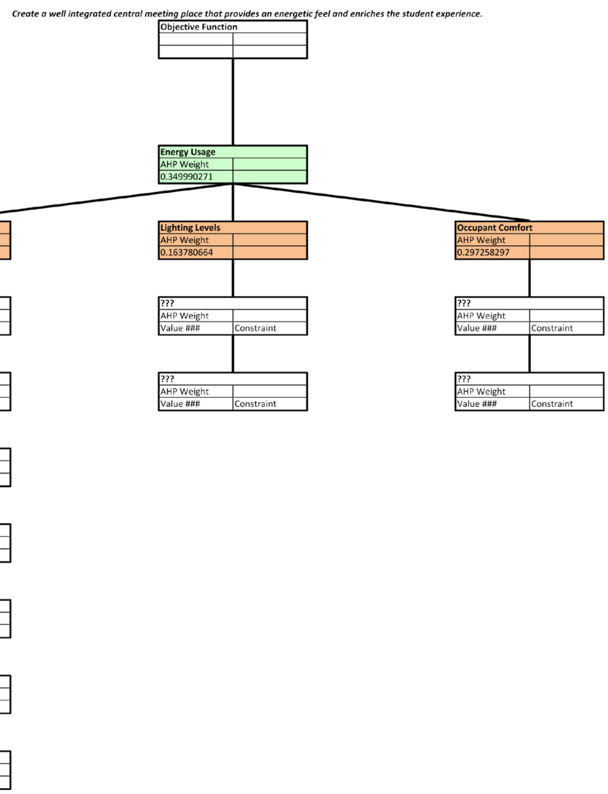


Figure 6. Hierarchical Holographic Modeling: Criteria & Sub-Criteria Decomposition

sub-criteria to the remainder of the model, I felt it necessary to further decompose this modeling criteria to get a better under standing of how this aspect of the project would influence the BVS and management of the design process. Since the student teams would be completing a full LEED analysis, it allowed me to incorporate that data; the actual “LEED Scorecards,” into my model.

Through analyzing the RFP and determining the criteria and sub-criteria of the model, I was able to complete the pairwise comparisons of the criteria against one another and determine their weights. However, if the responding teams did not provide me with actual data to input into the model, then I was unable to proceed with certain portions of the model. Or I would have to eliminate those criteria/sub-criteria all together from the model and recalculate the weights of the related criteria. An example of this occurred in evaluating the shortlisted submissions. As I analyzed the RFP, it was very clear that the owner was concerned about the amount of measurable natural daylight that was available in the various rooms of the building based on the activity of the room. Therefore, I included this criterion into the model. Once the model was built, it turned out that natural daylight was a very interconnected and critical criteria not of just the "Energy Usage" HHM system, but almost every other system as well. Once I began to enter the data from the shortlisted submissions, it became apparent that they did not provide any relevant data for me to input into the model in regards to calculated natural daylight levels. I quickly realized you can not model situations for which you have no data. It became clear that in order for the proposed multi-criteria model to be an effective decision making tool, there needs to be early coordination with the owner to make sure that the RFP asks for all the necessary criteria required to build the model. Also, clear communication with the proposing teams is necessary, so that the deliverables they submit will be compatible with the input requirements of the model.

3.2 Inclusion of the Subjective in the Best Value Selection Process:

One of the main arguments against Best Value Selection has to do with the inclusion of the critical non-price data that is used to help determine the selected team. The fact that you are combining qualitative (subjective) and quantitative (objective) data together in determining your final decision opens the selection committee up to scrutiny as the decision was made based on multiple, not easily comparable sources of data. As opposed to the low-bid approach of making the selection based solely on the objective criteria of cost. Having said this, how can we instill confidence in the selection committee that they can explain to someone else why they decided to pay a premium to select one company over another one? Going back to the questions to be answered in Section 3.0 "how can we justify paying a premium for one company over another? Not only is it necessary for the selection committee to be able to justify their decision to pay a premium, but to be able to demonstrate that they utilized a fair and open process. "How can we ensure fairness with our scoring framework...?" These two questions mentioned in Section 3.0 essentially go hand in hand; as does the solution to the two. As discussed previously, the Pairwise

Table 5. Pairwise Comparison of the Design Alternates with Respect to their Architectural Considerations

Pairwise Comparisons				
Concept 1	1	Concept 2	4	While both concepts utilize similar building materials to that of the surrounding campus, Concept 2 does a much better job of connecting the indoor and outdoor environments. Concpet 2's façade system really helps to capture the surrounding views while maintaing a great functional aspect by being the main facilitator for the design's passive strategies. The concepts have a "tie score" on many of the other sub-criteria of this criteria, but it is these previously mentioned aspects that give the advantage to Concept 2.
Concept 1	1	Concept 3	2	While neither concept created a strong indoor outdoor relationship, Concept 1's mixed geometry and sloped roof is less responsive to the rest of the campus and sticks out in a negative way. Both concepts tied on most of the sub-criteria, but due to the less than ideal configuration of the structure and programed space of the multi purpose room in Concept 1, the author suggests a slight advantage is earned by Concept 3.
Concept 2	3	Concept 3	1	Concept 3's shortcomings are the main factor in this comparison. It's façade system is highly functional, but stands out too much when compared with the existing buildings on campus as well as the proposed future buildings. The building materials are of a lower quality than that of Concept 2. Also, Concept 3's indoor outdoor connection is not quite as strong. The advantage goes to Concept 2.

Comparisons associated with AHP modeling begin to establish a scoring framework that is fair and open. A framework that easily allows for the combination/comparison of both objective and subjective criteria through a parallel reasoning process. A parallel reasoning process which occurs during the matrix analysis portion of AHP. Another strong point of AHP, is that it engages the human cogitative system and utilizes one of it's strongest and most unique abilities; it's ability to make highly abstract value judgments under the face of uncertainty. This can be seen in Table 1 and Table 5, as the ranked pairwise comparisons are accompanied by detailed notes describing the reasoning behind the pairwise comparison values given and serve as a reference for anyone who might want to review the decision making process at a later time. The notes are especially helpful if after completing the AHP Matrix and the inconsistency value is greater than 10%, you can quickly tell how you arrived at the previous comparison and determine any flaws in your reasoning when you reevaluate the pairwise comparisons.

In regards to the inconsistency value determined during the matrix analysis portion of the AHP method, this is probably the strongest argument for utilizing AHP when determining the final selection of a BVS scenario. This value is especially helpful for putting dissenter's doubts at ease in regards to comparing subjective and objective criteria together against one another. As at the end of completing all pairwise comparisons for the selection criteria in question, a matrix is built and the comparisons are measured for consistency in regards

Table 6. AHP Matrix for the Design Alternates with Respect to their Architectural Considerations Pairwise Comparison Results

		Concept 1	Concept 2	Concept 3	Priority	Rank
1	Concept 1	1	0.25	0.5	0.137287664	3
2	Concept 2	4	1	3	0.623224728	1
3	Concept 3	2	0.333333333	1	0.239487608	2
				Sum of Priorities:	1	
				Inconsistency:	0.008186276	

to how each alternative was compared amongst the others. If the inconsistency value is greater than 10%, the model-builder must recreate the pairwise comparisons and rebuild the matrix. In order to better understand these concepts, lets consider the following examples.

In comparing the shortlisted student team submissions, Table 5 shows how they were ranked against one another in regards to their "Architectural Considerations" in a pairwise comparison format. Table 6 is the resulting completed matrix for the Architectural Considerations pairwise comparison. As you can tell from the Inconsistency Value shown in Table 6, it is less than 1% which is well below the required percentage and therefore demonstrates that the model-builder fairly compared the concepts against one another with respect to their Architectural Considerations. As shown in Table 2 in the "Priority" column, the criteria Architectural Considerations contributes .19974251 or roughly 20% of the total value to the completed project based on the pairwise comparison made of the main criteria as described in the RFP; see Appendix A. In Table 6, the "Priority" column shows the total percent of the value earned by the individual concepts with respect to the modeling criteria Architectural Considerations' overall total value. This percent was earned based on the values determined in the pairwise comparisons and then quantified during the matrix analysis. As you can tell, Concept 2 when pairwise compared with the other shortlisted teams' submissions was able to earn close to 62% of the total value that this modeling criteria, Architectural Considerations, was worth. If we consider "Architectural Considerations" as the first of five pairwise comparisons that the shortlisted teams will be evaluated on, (as they are "pushed" through the model) then after the first round Concept 2 has earned 12.4% (62% of 20%) of the total possible "value" identified in the RFP when compared (competing) with the other shortlisted teams' submissions.

Once the pairwise comparison process has been repeated for all selection criteria, the values listed in the "Priority" columns are grouped together in the "Final Matrix;" see Table 7. As shown in this table, the individual modeling criteria "priority" value is shown for each modeling criteria in column B. Then for each shortlisted team (concept) the "priority" value that they earned with respect to the individual modeling criteria that they were pairwise compared with is listed in column A. Finally, columns A and B are multiplied together to equal column C. Then all the values in column C for each shortlisted team are added together to get a "Total Value" score for each team. The completion of this matrix is the realization that the model is fully developed and ready for "Post Optimality" analysis.

Table 7. Synthesized AHP Data "Final Matrix"

			Synthesizing Final Priorities		
Criterion	Priority vs. Goal	Alternative	A	B	C
Architectural Considerations	0.19974261	Concept 1	0.137287664	0.19974261	0.027422196
		Concept 2	0.623224728	0.19974261	0.124484534
		Concept 3	0.239487608	0.19974261	0.04783588
			1		0.19974261
Building Systems	0.069435805	Concept 1	0.231082375	0.069435805	0.016045391
		Concept 2	0.665070243	0.069435805	0.046179688
		Concept 3	0.103847382	0.069435805	0.007210727
			1		0.069435805
Campus Integration	0.327768049	Concept 1	0.457671958	0.327768049	0.150010245
		Concept 2	0.416005291	0.327768049	0.136353243
		Concept 3	0.126322751	0.327768049	0.041404562
			1		0.327768049
Construction Considerations	0.053063265	Concept 1	0.231613959	0.053063265	0.012290193
		Concept 2	0.696531334	0.053063265	0.036960227
		Concept 3	0.071854707	0.053063265	0.003812845
			1		0.053063265
Energy Usage	0.349990271	Concept 1	0.174853801	0.349990271	0.061197129
		Concept 2	0.632748538	0.349990271	0.221455832
		Concept 3	0.192397661	0.349990271	0.067337309
			1		0.349990271

**Key: Column A shows the priority of this Alternative with respect to this Criterion. Column B shows the priority of this Criterion with respect to the Goal. Column C shows the product of the two, which is the global priority of this Alternative with respect to the Goal.
For each criterion, the sum of Column C must equal the Priority vs. Goal value.

3.3 Measurement of Value and Further Analysis:

Detailed analysis is always completed with a goal in mind. The goal of this exercise is to determine a "Best Value Selection" for the design-build competition previously described. "Post Optimality" analysis will be utilized in determining the final BVS and the analysis will be centered around the data produced by the HHM and AHP model presented above. As discussed in previous sections of this paper, the traditional way of evaluating design and construction teams is based on three major project factors: time, money and quality. These three project factors are usually presented as an equilateral triangle to show that they are all equally important in determining the final selection. We discussed, measuring project value based on the "equilateral triangle" concept was flawed and out dated. Having said that, the AHP model determined a critical piece of data that we will use in determining the ultimate Best Value Selection. Specifically, the AHP model determined the overall value (quality) each of the three teams (concepts) earned when compared with one another against the baseline project model. Table 8 shows the overall value each team earned by summing the individual column C values from Table 7 into their complete initial "Value" score. Each team's proposed project budget and schedule will be used in conjunction with the data summarized in Table 8 in determining the final BVS. Based on the data summarized and presented in Table 8, as well as illustrated in Figure 6, the concept earning the highest overall value was Concept 2. As when all three concepts were "pushed" through the baseline model, Concept 2 earned over 56% of the total value available when compared with the other concepts. Figure 7 graphically illustrates how much more dominate Concept 2 was in earning it's "Value" score. When you take into consideration the "Value" scores along with the following project facts we can being to determine how we should structure our post optimality analysis to select the team who truly presents the best value for the owner with respect to their designed solution and project delivery strategy.

The RFP clearly states, that the owner has been awarded $25 Million to spend on this project, and must return the unused portion of the funding back to the state. Therefore,

Table 8. Post Optimality Analysis - Initial Value

Concept #	Total Project Square Footage	Architectural Considerations	Building Systems	Campus Integration	Construction Considerations	Energy Usage	Value	BVS Weight Factor (Value)
1	55,000	0.027422196	0.016045391	0.150010245	0.012290193	0.061197129	0.266965154	3
2	59,087	0.124484534	0.046179688	0.136353243	0.036960227	0.221455832	0.565433523	3
3	53,446	0.04783588	0.007210727	0.041404562	0.003812845	0.067337309	0.167601323	3
Totals:		0.19974261	0.069435805	0.327768049	0.053063265	0.349990271	1	

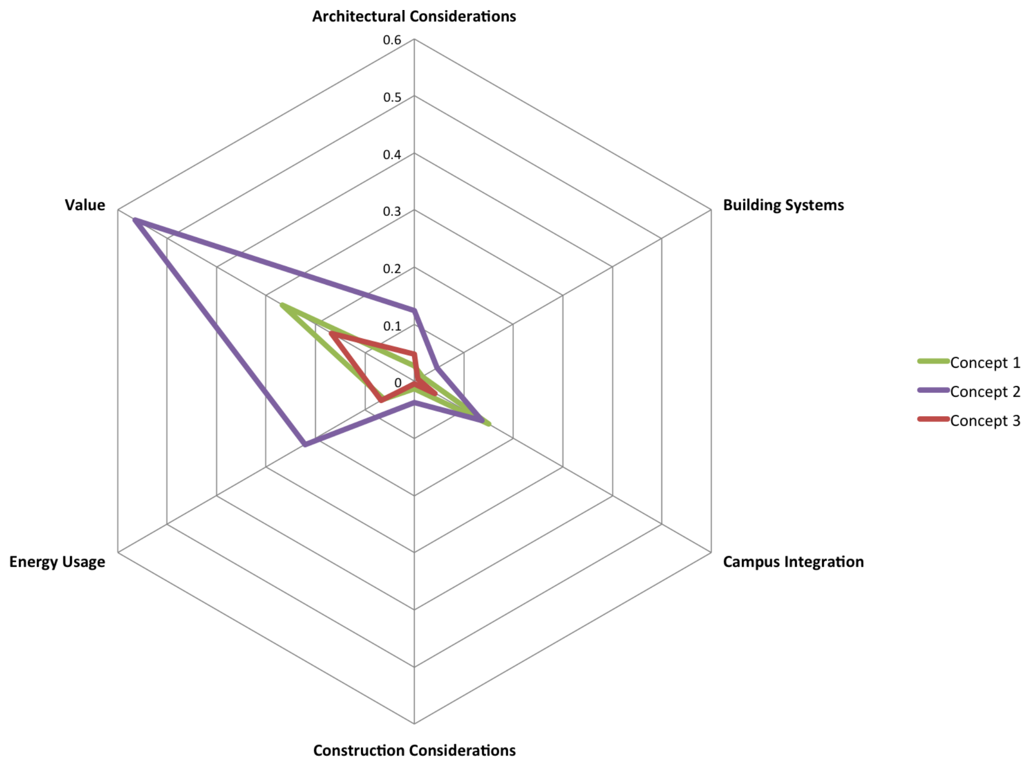


Figure 7. Post Optimality Analysis - Initial Value - Spider Chart

there is no incentive to deliver a project that is well under budget, as the owner would like to maximize the amount of usable building space by utilizing as much of the $25 Million as possible. Also, the RFP states that the owner has a 45 month project schedule duration and opening the doors early is not entirely necessary, as they have no functions or plans associated with their new building until the start of the school year which is at the end of the 45 month project duration. What the owner is most concerned about is that their needs are fully satisfied as described in the RFP, and that the project is designed to be adaptable to the future needs of the campus and student body. Having said this, when taking the owner's budget, schedule and quality (value) needs into consideration, we begin to realize that quality should be considered the main decision driver. With schedule and budget weighted the same as each other, but lower than quality. Now that we have come to this realization, we can finalize our Best Value Selection, post optimality analysis setup.

For this project I determined that BVS should be based on a "dollars spent per unit of design value earned" adjusted for individual project schedule and budget risk. As we want to spend the least amount of money possible per unit of earned value, (determined through the HHM & AHP modeling process) so as we evaluate the maximized value presented in each project submission, we can better determine if the value presented is achievable within the team's proposed schedule and budget and what types of, and/or how much risk is associated with each submission in terms of schedule and budget. Therefore, in regards to "dollars spent per unit of value earned adjusted for individual project schedule and budget risk," the lowest score wins. The author suggests the BVS scoring function (strategy) described above is applicable to and should used on all projects that utilize a Best Value Selection. The only thing that would have to change would be the weights (BVS weight see below) that are applied to cost, schedule and budget so that the post optimality analysis is correctly structured based on the project specifics. This type of risk analysis is critical in determining the BVS because, should a project get delayed, or run into financial increases, scope will need to be adjusted or eliminated to keep the project on budget. This

$$\frac{(Cost)(BVS\ Weight_{Cost})(Risk_{Cost})}{((Value)(BVS\ Weight_{Value}))((Time)(BVS\ Weight_{Time})(Risk_{Time}))}$$

Figure 8. BVS Scoring Function Expressed in an Equation Format

adjustment to scope is an adjustment to project value. So a project with an initial high value score, might over the project duration, lose much of it's value due to scope reductions caused by unforeseen conditions or poor project delivery. Thus making a lower value scored project that was better planned for or less susceptible to budget increases due to unforeseen issues a better selection for the owner in regards to achieving the project the owner initially planned for and the project team initially promised to deliver. Essentially, we are looking to maximize value within the constraints of the project budget and schedule by minimizing dollars spent per unit of value earned. Figure 8 shows in equation format our BVS scoring function of "dollars spent per unit of value earned adjusted for individual project schedule and budget risk." Since we determined that value (quality) was to be weighted higher than schedule and budget, the constant, "BVS Weight" is used to represent these weighted values. Essentially, the BVS Weight is a weight to highlight the level of importance of the criteria based on the owner's preferences as stated in the RFP; therefore it directly impacts the BVS post optimality analysis. The scale ranges from 1-3 with the highest (most important) weighted score given a 3.

Since each team presented a different: strategy, budget and schedule necessary to bring their project to fruition, each team is subjected to individualized risks associated with the aforementioned items. The variable, "Risk Weight" ranges from 0 to 1 and is applied to the budget and schedule aspects of the analysis. The actual values come from probability distributions calculated to simulate "what-if" scenarios that look at the normal, best, worst and anywhere in between case scenarios. With respect to cost, we are looking at the probability the cost will increase as the schedule fluctuates. Therefore, 0 is the best score when we are analyzing cost as we are hoping that there will be little to no impact to the cost as the schedule fluctuates. In regards to schedule, we are looking at how certain we are that the project will end within the specified duration calculated by the proposing teams. Since we are looking at how certain we are in a concept maintaining their anticipated schedule duration, the best score in regards to schedule is 1; which represents 100% certainty.

In developing a Post Optimality Analysis technique to accompany my proposed method of utilizing AHP within a HHM framework for determining a Best Value Selection; I wanted to use methods/practices that would be familiar to the professionals in the A/E/C industry as this is my intended audience. As discussed above, the "Risk Weight" describes a level of certainty that the proposed budget or schedule will be maintained as the project evolves over time. Since a measurement of certainty is desired here it reasons that probability techniques will be used during the analysis. "Program Evaluation & Review Technique" (PERT) was the first widely used pseudo-probabilistic scheduling technique in the A/E/C (and related) industry. PERT incorporates simplification assumptions to allow for ease of use. "However, studies have shown that the results of a PERT analysis are comparable to [more complex] probabilistic techniques despite the simplifying assumptions employed." (Glavinich 193) As PERT is a widely accepted and used technique not only in the A/E/C industry but related industries as well, I propose utilizing aspects of PERT for determining some of the data required for the post optimality analysis.

In regards to the BVS of the shortlisted teams previously described, the owner has never built a building like this before and thus has no historical data of their own to help determine how accurate the budget and schedules are as presented by each team. Therefore, by utilizing the probabilistic techniques described by PERT, it can allow the project analyst to make some comparisons when previously there was no historical data to compare the proposed budgets and schedules with. By having the project analyst share the process that was undertaken to complete the post optimality analysis, it will allow the owner and

Table 9. Post Optimality Analysis - Budget

Concept #	BVS Weight Factor (Value)	Estimate	Cost per sqft.	Hard Cost	Soft Cost & Fees	Risk Weight Cost (Initial)	Risk Weight Cost (Scenario 1,2,3)	BVS Weight Factor (Cost)
1	3	$22,406,000	$407.38	$13,312,000	$9,094,000.00	1	0.9932	1
2	3	$19,841,000	$335.79	$15,102,000	$4,739,000.00	1	0.9792	1
3	3	$23,062,000	$431.50	$14,686,000	$8,376,000.00	1	0.6323	1
	B-mean	**$22,087,833.33**	**$399.47**	**$14,526,333.33**	**$7,889,500.00**			
	Avg. Absolute Deviation	**1,179,722.22**	**34.54**	**649,888.89**	**1,613,833.33**			

the selection committee to ask questions and interpret the data knowing that probability techniques and simple assumptions were utilized during the analysis.

A key PERT probabilistic technique illustrated in Table 9 and Table 10 can be seen in the "B-mean" cells included in this table. These numbers represent the "PERT three point-estimation" or Beta Distribution of the mean which will be utilized during further analysis. The continuous beta distribution's mathematical properties are well suited for the "one-time nature of [design and] construction projects and all of the project-specific variables..." (Glavinich 200) The aforementioned desirable mathematical properties of the beta distribution are as follows: It is a unimodal distribution, it has finite non-negative endpoints, and it is non-symmetrical allowing for the mode to be skewed toward either the largest or smallest anticipated values. The "Average Absolute Deviation" was utilized in lieu of the "Standard Deviation" calculation as the average absolute deviation works better with numbers produced from the beta distribution mean as well as is a better calculation of deviation when the sample size is small; as is the case with our shortlisted teams.

Now that we have determined a usable mean and deviation, the central limit theorem in statistics tells us that "the sum of the means and variances for all types of distributions no matter how asymmetrical, will converge on the normal distribution." (Ang, Tang 168-169) Knowing this, will allow the project analyst to run various "what-if" scenarios and determine how the projects might respond to unforseen project delivery issues by using the means and deviations to calculate probability distribution functions for likely scenarios and using the resulting numbers as the "Risk Weight" variable in the post optimality analysis. By gathering all of this data we are able to introduce uncertainty into our BVS process and help the owner determine the truly best value project team based on their overall design strategy and project delivery methods. Through this analysis, we will be able to determine if it is desirable to select a higher cost lower risk team over one who's design strategy delivered the highest proposed value score, but who's project delivery method puts

Table 10. Post Optimality Analysis - Schedule

Concept #	Stated Schedule Duration (Months)	Cost per Month	Risk Weight Schedule (Initial)	Risk Weight Schedule (Scenario 1)	Risk Weight Schedule (Scenario 2)	Risk Weight Schedule (Scenario 3)	BVS Weight Factor (Schedule)
1	42	$533,476.19	1	0.559	0.6567	0.86	1
2	36	$551,138.89	1	0.015	0.1627	0.476	1
3	43	$536,325.58	1	0.694	0.5704	0.625	1
B-mean	41.167						
Avg. Absolute Deviation	2.61						

the project value at risk due to poor planning. Or just the opposite could be true, based on the owner's risk appetite, the team proposing the highest value score might be worth selecting if after the "what-if" scenarios, when put through likely risk events, they can still maintain their competitive advantage over the next highest value team. No matter how the numbers shake out in the end, by completing an interactive analysis of the individual project teams and their design strategy and project delivery methods, the owner and it's selection committee will be better informed and supported in making their BVS instead of selecting a team based purely on the lowest bid.

3.4 Uncertainty and Best Value Selection:

$$P(a < X \leq b) = \left(\frac{1}{\sigma\sqrt{2\pi}}\right)\int_a^b e^{\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]}\,dx$$

Figure 9. Gaussian Probability Distribution (CDF)

As described above, it is important to factor in uncertainty and risk into the Best Value Selection process. The "B-mean" (μ) and the "Average Absolute Deviation" (σ) values presented in Table 9 and Table 10 will allow us to perform our "what-if" scenarios in regards to budget and schedule risk. The equation in Figure 9 above shows the "Cumulative Distribution Function" (CDF) for the "Gaussian" probability distribution (also know as the "normal distribution") that we will use to solve our risk scenarios. The risk or "what-if" scenarios are events where "X" represents a normal random variable for an event with a distribution N(μ, σ) and a probability of occurrence: (a ≤ X ≤ b); where "a" and "b" are values of the "what-if" scenarios that you would like to test.

Table 11. Best Value Selection Results - Table

Concept #	Best Value Selection (Initial - No Risk)	BVS Risk Scenario 1	BVS Risk Scenario 2	BVS Risk Scenario 3
1	666,100	1,183,489	1,007,416	769,268
2	324,906	21,209,889	1,955,429	668,379
3	1,066,669	971,837	1,182,425	1,079,128

In order to begin to develop the "what-if" scenarios, we must first determine an initial or baseline result so we can get a better understanding of what questions to ask with our scenarios. Table 11 is the results matrix for all of the scenarios associated with this exercise which was determined based on the data presented in Tables 8-10 and using the equation described in Figure 8. I will describe later how we obtained the results for the three "BVS Risk Scenarios." Having said that, the initial result of interest is the controlled/baseline result which is titled "Best Value Selection (Initial - No Risk)." This score was determined using the equation in Figure 8 with the Risk Weights all equaling 1. This initial condition with the Risk Weights all equaling 1 is reflected in Table 9 and Table 10 as well. Upon observing the values listed in Table 11, the reader can tell that under the initial or controlled condition, Concept 2 was the clear winner. Concept 2's winning score can be contributed to it's high "value" score as seen in Table 8 and Figure 7 along with it's aggressive schedule and low budget. Therefore, if the selection team were to end their analysis at this initial modeling stage, Concept 2 would be the clear winner as it appears to be the best choice. Having said that, how certain are we though that Concept 2 really is the best choice? Based on all of the relevant data at that time it certainly appears to be, but how certain are we that the budget and schedule data as presented by Concept 2 can be met; and if the schedule and budget can't be met, what effect would that have on the "value" of the project?

After reviewing the results of the initial "no risk" scenario, combined with further scrutiny of the individual budgets and schedules, some obvious risk or "what-if" scenarios began to emerge. These scenarios will be explained in detail below in regards to how they were: developed, their relevance to the BVS process, along with their impact on the final results. We will initially explore 3 different scenarios that are centered around the schedules presented by the individual teams/concepts. The results of these three scenarios will be the three Risk Weight values listed in Table 10 for each concept. The second set of scenarios will be centered around the proposed budgets and the results of these scenarios will be the Risk Weight values listed in Table 9 for each concept. Once all of the various schedule and budget scenarios are derived, all the data will be present and the final three "BVS Risk Scenario" scores listed in Table 11 will be determined using the equation shown in Figure 8.

3.4.1 Uncertainty in the Schedule:

Each team presented different schedules and as mentioned before each teams' schedule is subject to certain inherent risks associated with each teams' proposed project delivery strategy. Since the owner has no historical data for constructing similar projects, I proposed using the three intended project durations as the data set and then determining the B-mean and Avg. Absolute Deviation for this data set. As discussed previously, in section 3.3, both of these mathematical methods are well suited for data sets which contain small amounts of data points. I then created three scenarios who's results would help determine the Best Value Selection. The intent behind the three scenarios was to try and describe situations that would allow the selection committee to push each team's concept to it's brink of being non-competitive with the next closest team's concept and then determine the likely hood of that event occurring.

$$P(X \leq 42) = \left(\frac{1}{2.61\sqrt{2\pi}}\right)\int_{-\infty}^{42} e^{\left[-\frac{1}{2}\left(\frac{x-41.67}{2.61}\right)^{2}\right]}\,dx$$

Figure 10. Gaussian Probability Distribution (CDF) - Concept 1 Schedule Scenario 1

3.4.1.1 Risk Weight Schedule Scenario 1

For the Risk Weight Schedule Scenario 1, the author wanted to determine ***what the probability was that the project would be completed prior to, or equal to, the proposed schedule duration***. Based on the equation in Figure 9, the equation in Figure 10 was developed for this scenario and the results were determined and are shown in Table 10 (in decimal format) under "Risk Weight Schedule (Scenario 1)." For example, Figure 10 shows the initial equation for Concept 1 as we wanted to determine the probability that the actual schedule duration (X months) would be less than or equal to the anticipated duration (42 months) based on our assumptions described in section 3.4 and 3.4.1 that determined

N(41.67, 2.61) as the distribution for this scenario. As shown in Table 10, the probability that Concept 1 will be completed as described above is roughly 56%. When you compare the results shown in Table 10, it is clear to see that Concept 2's aggressive schedule is very unlikely to be met based on our N(41.67,2.61) distribution where as the schedules proposed for Concepts 1 and 3 appear to be much more attainable by comparison. So a conclusion can be drawn, that if the schedule is not well managed, or if there is a major unforseen impact to the project, there is a large potential that Concept 2's project will not be able to absorb the schedule delay without adding cost to the project or the project team taking a loss. Should the owner decide to select Concept 2 as the overall BVS, the owner will need to have the project team demonstrate that they are capable of delivering the project within their anticipated project duration and have them state their remedies for protecting the overall value of the project should the project be impacted by schedule delays.

Although, Risk Weight Schedule 1 is a somewhat basic question, it is still an important question to ask so we can try to understand what level of risk the proposing teams are exposing the owner to with respect to their initial proposed schedules.

3.4.1.2 Risk Weight Schedule Scenario 2

$$P(40.39 < X \leq 45.61) = \left(\frac{1}{2.61\sqrt{2\pi}}\right) \int_{40.39}^{45.61} e^{\left[-\frac{1}{2}\left(\frac{x-41.67}{2.61}\right)^2\right]} \, dx$$

Figure 11. Gaussian Probability Distribution (CDF) - Concept 3 Schedule Scenario 2

For Risk Weight Schedule Scenario 2, knowing that construction schedules contain float and therefore have the potential to be completed early; while at the same time all projects are subject to unforseen conditions and have the potential to be delivered late. ***The author wanted to determine the probability that each project would be completed within one standard deviation from their proposed duration.*** Utilizing the same N(41.68, 2.61) distribution as used in section 3.4.1.1, with the equation shown in Figure 9, the equation in Figure 11 was developed and the results were determined in decimal format as shown in Table 10. For example, Figure 11 shows the CDF for Concept 3 whose proposed duration is 43 months. Based on using the distribution N(41.68, 2.61) which was determined as described above, the resulting probability of Concept 3 being completed within one standard deviation of it's proposed duration is 57%.

All three concepts propose a project duration of 3 years or more and the average absolute deviation (treated as the standard deviation for this paper) has been calculated to be 2.61 months. As mentioned previously, based on the nature of construction schedules having built in float and facing unforseen conditions, the author is confident that a standard deviation of 2.61 months seems appropriate given the overall project durations.

In finance, the standard deviation on the rate of return of an investment is a measurement of the volatility of the investment. Therefore, the author chose to create Risk Weight Schedule Scenario 2 in a similar regard in order to determine the volatility of the various proposed schedule durations. A high probability that the project will be completed within one standard deviation implies a low level of volatility in the project schedule duration. Whereas a low probability that the project will be completed within one standard deviation implies a high level of volatility in the project schedule duration. Since a low probability implies high volatility, the parameters for determining the BVS Scoring Function, Figure 8, still hold true as the schedule component of the BVS Scoring Function is maximized when the probability is high. Based on their own risk tolerances during the BVS decision making process, it is then up to the owner and their selection committee to compare the probability that each concept will be completed within one standard deviation.

It is interesting to note that when using the Gaussian Distribution (which is symmetrical about the mean) there is a 68.2% chance that the random variable will be within one standard deviation from the mean. When you compare this to the values shown in Table 10, you will see there is quite a difference when instead of being one standard deviation away from the mean the random variable is calculated to exist one standard deviation away from the proposed duration.

3.4.1.3 Risk Weight Schedule Scenario 3

Design and construction projects tend to follow a bell shaped curve in regards to outflows of capital over time. Meaning that during the middle portion of the project schedule the construction activity and capital outflows are at there maximum peaks. Compared to the construction activity and capital required to fund the "tail" portions of the projects where the values are much lower. Having said this, the author intends to complete a break even analysis for Risk Weight Schedule Scenario 3 by simplifying this bell shaped curve concept; by determining what the anticipated average monthly expenditure will be during the life span of each of the individual project concepts. The author believes that using the average monthly expenditure to calculate a break even point is a fairly conservative and accurate way to perform this type of analysis, as it is impossible to determine if the project will run into delays in the beginning, middle, or end portion of the project. By using an average expenditure for the analysis, it allows the author to utilize a more global approach for this scenario calculation.

For Risk Weight Schedule Scenario 3, the author reviewed the results of the "Best Value Selection (Initial-No Risk)" from Table 11 and listed the concepts in order from best to worst in terms of their score with the best being Concept 2, followed by Concept 1 and then Concept 3. Next the author determined the overall total cost differential between each of the concepts when compared to the concept below them in the ordered list. Then the author determined the average monthly expenditure for the higher ranked concept and determined how many months the schedule could be extended (or shortened) to where the cost differential between the two concepts would equal zero; i.e. where they would break even. The author then determined the probability for that event to occur. The following example should help illustrate the steps as described above.

$$P(X \leq 41) = \left(\frac{1}{2.61\sqrt{2\pi}}\right)\int_{-\infty}^{41} e^{\left[-\frac{1}{2}\left(\frac{x-41.67}{2.61}\right)^2\right]}\,dx$$

Figure 12. Gaussian Probability Distribution (CDF) - Concept 2 Schedule Scenario 3

Example: Determine the probability of the Break Even Point between Concept 2 and Concept 1 based on a schedule augmentation and it's associated cost increase.

Step 1 - Determine the Cost Differential:

- Concept 2 Total Budget = $19,841,000 or $551,138.89 /month for 36 months.
- Concept 1 Total Budget = $22,406,000 or $533,476.19 /month for 42 months.

- $22,406,000 - $19,841,000 = **$2,565,000 (Cost Differential for Concepts 2 & 1)**

Step 2 - Determine the Schedule Augmentation so Cost Differential Equals Zero:

- How many months can Concept 2 be extended based on its per month expenditure?
- $2,565,000 = x($551,138.89)
- x = 4.68 months, therefore **x = 5 months [36 (original duration) + 5 = 41 months]**

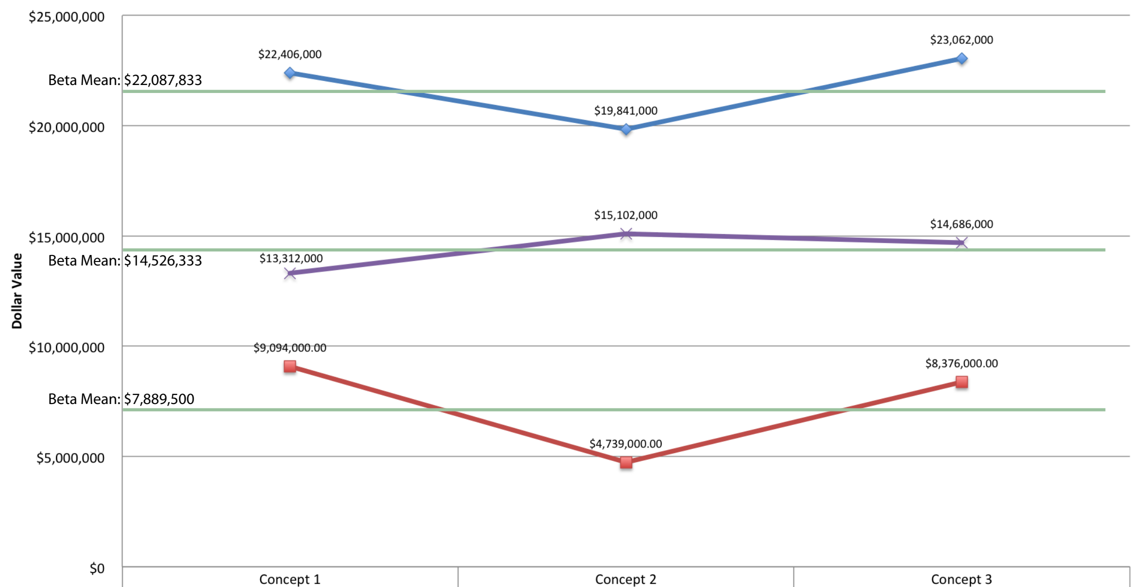
Step 3 - Determine the Probability Concept 2's Schedule duration will be less than or equal to 41 months:

- The result determined by the equation in Figure 12 is that there is a 47.6% chance that the project as described in Concept 2 will be completed within 41 months.

This process was repeated to determine the probability of the Break Even Point between Concept 1 being extended to break even with Concept 3 as well as Concept 3 being shortened to break even with Concept 1. The values determined can be found in Table 10. The author chose to examine the issues presented in Risk Weight Schedule Scenario 3 as the data derived from this analysis would allow the owner to evaluate the risks associated with picking a higher scoring "value" project over the next highest scoring "value" project. The owner is able to fully consider the scenario that would cause the two projects to break even and now base their selection not only on their risk tolerance but on their level of confidence in that scenario coming to fruition or not.

3.4.2 Uncertainty in the Budget:

Similar to the level of uncertainty presented in the schedules proposed by each Concept, the budgets too contain uncertainty within them. This uncertainty can be seen as the direct impact to the project budget shown in some of the Risk Weight Schedule Scenarios when a project is extended or shortened in duration. So not only are the budgets susceptible to uncertainty from the schedules, they are also susceptible to the estimating and project budgeting process which contains an inherent level of uncertainty within it. As can be seen in Table 9, and graphically illustrated in Figure 13, (as part of a Budget Comparison) the project budgets are made up of "Soft" and "Hard" costs. The soft costs, are costs related to the design and preconstruction tasks of the project; while the hard costs are directly related



	Concept 1	Concept 2	Concept 3
Estimate	$22,406,000	$19,841,000	$23,062,000
Hard Cost	$13,312,000	$15,102,000	$14,686,000
Soft Cost & Fees	$9,094,000.00	$4,739,000.00	$8,376,000.00

Figure 13. Post Optimality Analysis - Budget Comparison

to the actual construction of the project. It is interesting to note, how tight the spread is in regards to the hard cost values are around the hard cost mean. When compared to the spread of the soft costs and total estimate values in regards to their means. Right away, the owner can gain some confidence in the fact that since the individual Concepts presented are all roughly of a similar size, scope and materials, the hard costs of the proposed concepts appear to be well know based on the data shown in Figure 12. While on the other hand, it is the soft costs that seem to be quite variable. This presents and interesting set of questions for the owner to consider in evaluating the teams during the selection process in regards to cost savings and cost over runs due to design management and preconstruction issues.

3.4.2.1 Risk Weight Cost Scenarios

$$P(X_H \geq \$14{,}686{,}000) \cup P(X_S \geq \$8{,}376{,}000) =$$

$$P(X_H \geq \$14{,}686{,}000) + P(X_S \geq \$8{,}376{,}000) - [(P(X_H \geq \$14{,}686{,}000))(P(X_S \geq \$8{,}376{,}000))]$$

Figure 14. Expanded Probability Statement for Risk Weight Cost Scenario Concept 3

$P(X_H \geq \$14,686,000) =$

$$1 - \left[\left(\frac{1}{\$649,888.89\sqrt{2\pi}} \right) \int_{-\infty}^{\$14,686,000} e^{\left[-\frac{1}{2} \left(\frac{x - \$14,526,333.33}{\$649,888.89} \right)^2 \right]} dx \right]$$

Figure 15. Gaussian Probability Distribution (CDF) - Risk Weight Cost Scenario Concept 3

$P(X_S \geq \$8,376,000) =$

$$1 - \left[\left(\frac{1}{\$1,613,833.13\sqrt{2\pi}} \right) \int_{-\infty}^{\$8,376,000} e^{\left[-\frac{1}{2} \left(\frac{x - \$7,889,500}{\$1,613,833.13} \right)^2 \right]} dx \right]$$

Figure 16. Gaussian Probability Distribution (CDF) - Risk Weight Cost Scenario Concept 3

As described in section 3.3, when we try to determine the Risk Weight Cost Scenario, we are trying to determine the probability that the project budget will increase. Therefore, the ideal score would be 0; as opposed to 1 which would indicate 100 percent certainty that the budget will increase. As described above, the project budget consists of both hard and soft costs. In light of this, the author suggests that we look at the risks associated with both the hard and soft costs; and when these risks are combined we will try and determine how it will affect the overall budget and ultimately the project as a whole. Therefore, we will determine the probability that the hard costs are exceeded in conjunction (union) with the soft costs being exceeded. Figure 14 shows the probability statement for the Risk Weight Cost Scenario. The portion of the probability statement to the left of the equal sign is what we are trying to determine, while the portion to the right side of the equal sign is the expanded form necessary to solve the probability statement. While Figure 14 represents the probability statement necessary to determine the Risk Weight Cost Scenario for Concept 3, Figure 15 and Figure 16 show the further expanded mathematical equations necessary to solve the probability statement.

For example, Concept 3 proposes a total project budget of \$23,062,000 which is comprised of \$14,686,000 worth of hard costs and \$8,376,000 worth of soft costs. With a distribution of N(\$14,526,333.33,\$649,888.89) for the hard costs and a distribution of

N($7,889,500,$1,613,833.13) for the soft costs, the solution to the equation shown in Figure 14 and the value for the Risk Weight Cost Scenario for Concept 3 is 63.23%. Therefore, based on the hard and soft cost data associated with Concept 3, there is a 63.23% chance that the soft costs and the hard costs estimates will be exceeded based on the statistical data (B-mean & Average Absolute Deviation) determined in Table 9. This process was repeated for Concepts 1 and 2 and the associated values are listed in Table 9 as well.

By analyzing the inherent risk of the project budgeting process for both the hard and soft costs values presented by each project team, it allows the selection committee to get a better understanding of the possibility that the project budget will be exceeded. By understanding the likely hood that this will occur prior to the selection process provides the owner with the opportunity to develop a contingency plan for how to deal with budget over runs and which types of over runs (soft vs. hard) will have the greatest effect on the project.

3.5 The Best Value Selection

Now that all data has been collected and all Risk Scenarios evaluated, the values listed in Tables 8, 9 & 10 are complete and the Best Value Equation shown in Figure 7 is now able to be used to determine the Best Value Scores as shown in Table 11. Figure 17 is a graphical representation of Table 11 and as such Figure 17 is able to display the results of Table 11 to clearly show how the BVS scores from the different concepts compare against one another. As discussed earlier the Best Value Equation is attempting to determine the dollars spent per unit of value earned adjusted for schedule and budget risk per the given scenario; therefore, the lowest score wins. Table 11 is color coded for ease of interpreting the results, with green being the most desirable score and red being the least desirable score. As we can tell based on the results shown in Figure 17, Concept 1 earned the best score under BVS Risk Scenario 2, while Concept 3 earned the best score under BVS Risk Scenario 1. Concept 2 on the other hand earned the best score under the initial Best Value Selection and also earned the best score under BVS Risk Scenario 3. In order to make our final recommendation, further analysis of Figure 17 should be taken into consideration.

When you look at the spread and shape of Concept 3's values ploted in Figure 17, the author sees a fairly consistent shape and tight spread. This would suggest that Concept 3 is fairly

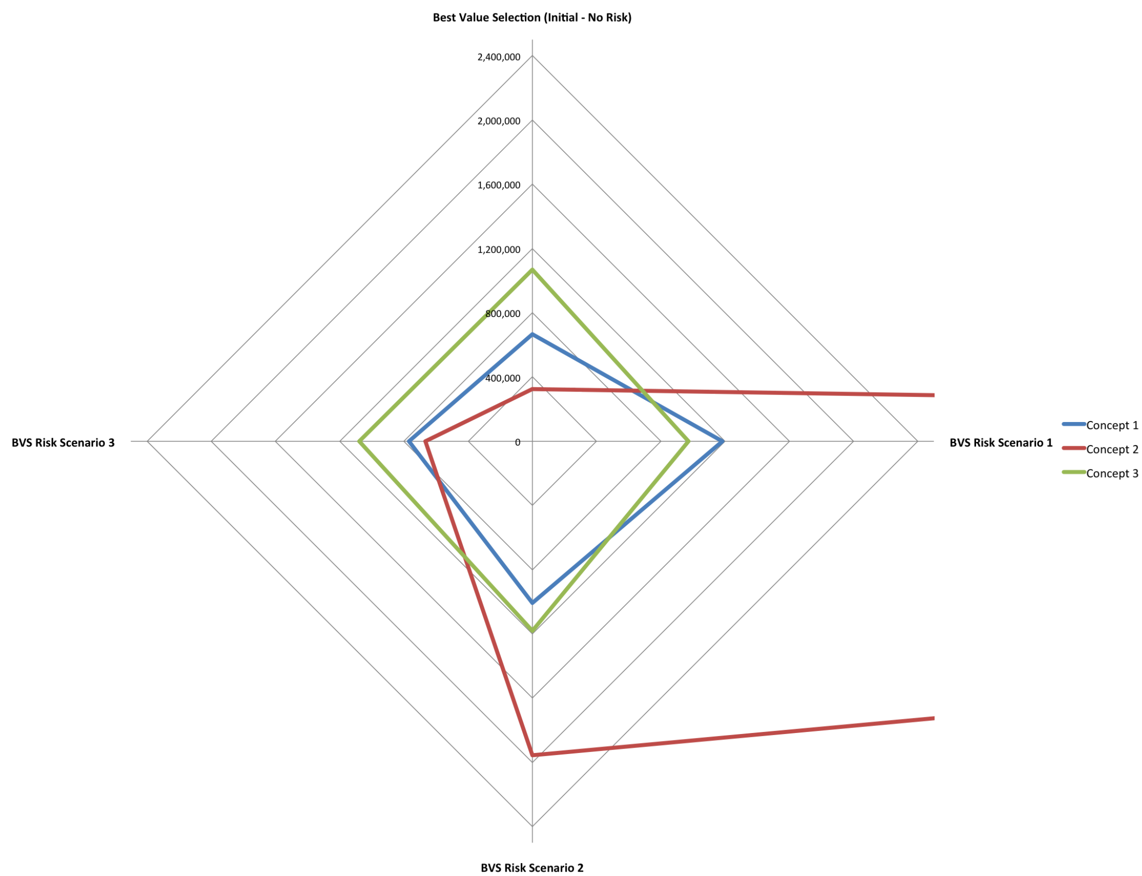


Figure 17. Best Value Selection Results - Graphic

stable when subjected to volatility and therefore is conservatively: estimated, scheduled and planned for. Should the owner select Concept 3, they should feel comfortable with the fact that while Concept 3 might not be the concept that provides the highest value in terms of satisfying the owner's requirements, Concept 3 is the most stable and therefore is capable to overcome typical project volatility with out putting it's overall project value at stake.

Further analysis of Concept 1 shows that it too has a fairly consistent shape and tight spread. Concept 1 is slightly more volatile when compare to Concept 3 but Concept 1 directly responds to the owner's requirements in a more satisfactory way than Concept 3 does. This can be seen by the fact that Concept 1 had a much better value score under the initial no risk scenario. Concept 1 continually came in as a close second best score in the BVS scenarios and also earned the best score when it did not.

As discussed in previous sections, Concept 2 was the most responsive to the owner's project performance demands as Concept 2 had by far the best value score. Having said that, Concept 2 overall is very susceptible to volatility with its aggressive schedule and estimates. During BVS Risk Scenario 3, Concept 3 showed that there is about a 50 - 50 chance that it can be completed under a 5 month schedule slip and still maintain its competitive cost advantage over Concept 1. Based on information gathered during the BVS Risk Scenario analysis, Concept 2 is most susceptible to schedule volatility and soft cost over runs. Knowing the vulnerabilities of Concept 2 can help inform the owner during the selection process to have a better understanding of what risks can potentially derail the best value scoring concept.

The author would recommend to the owner that Concept 2 should be considered for the selection. Although Concept 2 is more susceptible to volatility, the post optimality analysis showed that Concept 2 is still a viable alternative even in the face of uncertainty and should be considered the non-inferior solution. The strongest reason for going forward with the recommendation for selecting Concept 2 has to due with the highly superior "value" score shown in Table 8. Concept 2 addressed the concerns of the owner far better than its competitors did. Based on the risk scenarios we now know where Concept 2 is most vulnerable and the owner can work with the project team to help mitigate the vulnerabilities and protect the value proposed by Concept 2. If the owner had a low risk tolerance or felt that the vulnerabilities of Concept 2 were too great, Concept 1 would be a great alternate to propose.

CHAPTER 4 - CLOSING:

4.1 Conclusion:

With the Best Value Selection process complete and the recommended team and concept identified, our multi-criteria decision making model is now able to be used to monitor the design and construction progress and help the owner evaluate potential impacts to the project as they emerge. By using the model to first determine the impact to the overall value of the project that a particular design or construction change might create will help inform the team if the potential solution should be considered as a viable option. An example could be that the cost of structural steel has escalated and it now appears that the project is tracking over budget. The contractor suggests a cost savings option (equal to or greater than the proposed steel escalation value) of decreasing the total window glazing area by 30%. This design modification is taken into consideration and included in the model to determine the result this impact will have on other individual components of the model as well as the overall project value. Should the impact be too adverse and cause a great sacrifice to the expected performance of the building or the overall project value as we have defined it, then another alternative cost savings solution will need to be considered. By evaluating this alternative in the model prior to the design team performing the change and realizing later that this alternative was inappropriate or created an unintended consequence, it allows the team to work creatively together to come up with alternative solutions prior to spending resources on modifying the design.

As discussed in the beginning of this paper, Integrated Project Delivery (IPD) fosters a unified (collaborative) approach to project delivery and Target Value Design (TVD) allows the IPD team, owner included, to set achievable: performance, monetary or value driven "targets" to help ensure the end users get what they need. By building a multi-criteria decision making model we were able to incorporate all of the complexity introduced by the TVD into a systems based model that allowed us to evaluate various IPD teams' submissions and determine which proposed concept presented a "Best Value Selection" when compared to the TVD based on the requirements of the RFP. Once the BVS team is identified, the non-selected concepts can be removed from the model. The model can now transition from a TVD based team selection tool to a TVD based "design management" tool as described above in the structural steel example. The steel example suggests that one alternative should be presented at a time. In regards to Target Value Design this is not true. The Lean Construction Institute suggests a "Set Based Design Strategy" approach when considering how to remedy a deviation in a TVD project. A set based design strategy suggests that the team generates a series (a "set") of possible solutions and determines through analysis a non-inferior solution. As previously discussed, the complexity associated with multi-criteria decision making can be further impacted by human emotion and bias. Therefore, an unbiased model will allow the non-inferior solution to emerge through analysis of all alternatives and the input of relevant data into the model. In the opinion of the author, the use of the model as a design management tool solves the decision making issues currently associated with IPD as described in Section 1.0 as the results of the model will identify the non-inferior solution free of human emotion or bias.

By modeling the life of a project as a complex system and utilizing the proposed model to not only determine the selected team but as a design management tool as well. Will allow the owner to determine the overall project value described in the RFP, help determine the "targets" of the TVD, justify selecting a team based not solely on cost but best value, understand how uncertainty and project risks might affect the overall value of the project and determine a non-inferior solution to mitigate the impact of project deviations while preserving overall project value. The proposed modeling method is well suited for professionals in the A/E/C industry and is capable of incorporating the increased levels of complexity prescribed by modern project delivery into the decision making process and therefore should be considered as a preferred project management method.

4.2 Further Research:

The author has been successful in implementing the proposed modeling technique in a professional setting in regards to the Best Value Selection of project teams. Public project owners have welcomed the use of the modeling technique and feel that the unbiased selection process is particularly important especially in issuing large publicly funded design and construction contracts not based on the lowest responsive bidder. They have also appreciated being able to see the requirements of the RFP organized into the model and the owner's ability to develop the model along side of the RFP to ensure what they are asking for in the RFP is well described and able to be included in the model. Where the author sees further research opportunities in regards to using the model during BVS has to do with how to incorporate multiple models into a single selection. For example, currently the author has utilized the model in a group setting, with each participant completing their own set of AHP comparisons on paper forms prepared by the author. The author then translates their "value judgments" paper forms into individual computer models and completes the post-optimality analysis for each model. This task is less daunting than it sounds, as once the author completes the post-optimality analysis for one model, the post-optimality analysis can be reused for the next model as all that needs to change is the model inputs; i.e. the "value judgments." The author then presents the results of the models back to the participants, a group discussion occurs and then typically the team is selected based on which team was most frequently selected by the group as the top choice; i.e. majority wins. While to date this has been successful, the author is concerned that if a clear majority winner is not present in future projects, then the BVS process will become subjected to higher levels of human emotion and bias. Therefore, the author would encourage further research in evaluating the possibility of incorporating individual AHP comparisons into a master model of some sort, or more generally, research into how best to utilize the proposed modeling techniques in a group setting.

In regards to utilizing the proposed model as a design management tool, the author would like to encourage further research in this field as well. As discussed previously, it is important when developing the RFP to ask for relevant information that can be used to build the model and determine the BVS. This issue should be taken into further consideration when you consider utilizing the model as a design management tool. The need to be able to take design changes and evaluate their impact on the overall value of the project is dependent on having a model that is capable of accepting this precise level of detail. A well experienced project manager should be able to interpret the major systems being described by the RFP and consider possible changes to those systems and what data should be asked for during the RFP in order to build a model that can be easily transitioned from a BVS tool to a design management tool. Also, further research should be considered to explore the effectiveness of using the proposed modeling techniques as a design management tool for Target Value Design projects utilizing Integrated Project Delivery. The intent of the author to propose a single multi-criteria model that could be used for both BVS and design management was to suggest the possibility that by "upstream investment" or "front loading" the project with work by the project manager and project owner, could help control the cost of the project while maximizing the overall value of the project and lightening the back-end work load by the owner and project manager. The author believes this intent to be true, but further research will need to be completed to prove or disprove this point.

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APPENDICES

Appendix - A: Request for Proposal Synthesis

1. Central Meeting place
2. Enriches the Student Experience
3. Integrate well with rest of campus
    a. Physically
    b. Visually
4. Visual Interest and Visitor Interaction
5. Frame the Quad
6. Energetic Feel
7. Indoor Outdoor relationship of spaces due to mild inviting climate of SoCal
    a. Programed spaces and their adjacencies should reflect this
8. Adjacent 5 story building
9. High quality construction materials and construction practices
10. Use current technology to provide forward thinking environment
11. Take advantage of view corridors
12. Take advantage of sun exposure
    a. Natural daylighting
13. Leed Gold or higher
14. The building should operate as an efficiently designed system
15. Building Equipment should be kept out of site
16. Specific Roofing system must be used see pg. 19
17. Create a human scale
18. Anti-graffiti coating should be used on the entire first level of the exterior cladding
19. Exterior doors should be wide style and be constructed of aluminum see pg. 20 for more door details
20. ADA compliant
21. Spaces should be adaptable and flexible to change.
    a. Multipurpose spaces should be easily transformed from on function to another
        i. Using Moveable Furniture
        ii. Be able to accommodate large and small events, as well as multiple functions at one time
    b. Structural grids and building shafts should be sized and located to provide maximum flexibility for the building footprint
22. Occupant comfort
23. Watershed and site drainage need to be considered
24. The Lobby should have high ceilings especially at the ground level
25. Vertical circulation should be adjacent to lobbies
    a. Vertical circulation needs to be properly sized due to demands of building
        i. 3 elevators
        ii. Wait time during peak hours not to exceed 30 seconds
        iii. Design of stairs must meet building code
26. Use "MechoShades" instead of curtains for drapes in the following locations
    a. Cafeteria – 30% transmittance
    b. ASU Large Conference Room/Conference Rooms – 30% transmittance, blackout capability
    c. Multi-Purpose Room – 35% transmittance, blackout capability
27. Flooring material should reflect room usage
28. Restrooms on each floor
29. Background noise needs to meet criteria listed in RFP section 7.7
30. Building codes to be met, page 22 lists all applicable codes
31. Listed lighting levels must be met. See Room Sheets

*The numbered list corresponds to the numbered matrix on page 58. For example line "15" on page 58 corresponds to column "15" on page 58.

RFP Statements

Initial Categories	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Regulatory Concerns																				X			X					X		X		4
Campus Integration	X	X	X	X	X			X	X		X												X									9
Environmental Factors							X	X	X			X	X										X			X					X	8
Visual Interest			X	X	X	X		X	X	X	X				X		X							X								11
User Experience	X	X	X		X	X	X			X		X	X	X	X		X				X	X	X	X	X			X			X	19
Owner Prescribed	X		X				X		X	X		X	X			X	X	X	X	X	X			X	X	X	X	X	X	X	X	21
Initial Total	3	2	4	2	3	2	3	3	4	3	2	3	3	1	2	1	3	1	1	2	2	1	4	3	2	2	1	3	1	2	3	
Modified Total	1	1	2	2	2	1	1	3	3	1	2	1	1		1		1			1			3	1		1		1		1	1	

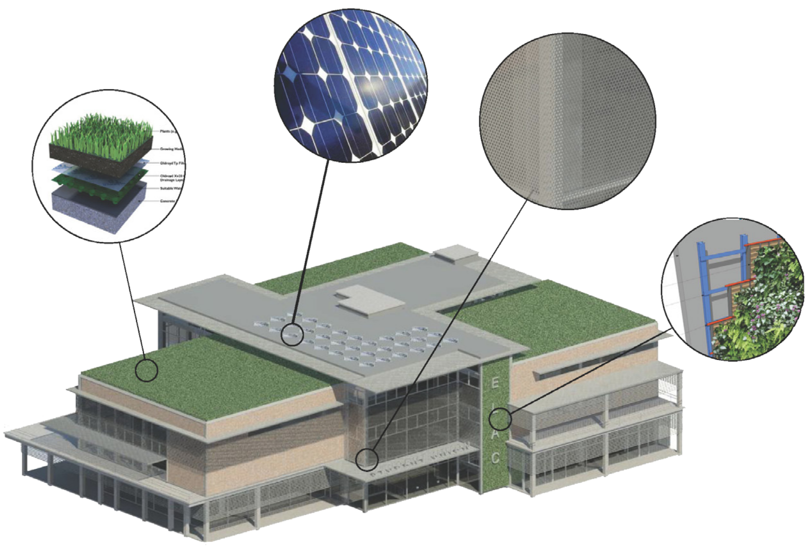
* Due to the fact that the RFP begins the problem statement by saying that all decisions should be made in the "best interests of the campus, faculty, staff, students and other users." The "User Experience" category can be absorbed into the remaining categories as all of the RFP Statements that have an "X" in the box for "User Experience," belong to other categories as well, and since all decisions should be made with the best interests of the end users in mind there is no need for it to be it's own category.

** The "Owner Prescribed" category must be met, as these are specific requirements listed in the RFP by the owner to be included. Due to this fact, many of them can be treated as constraints on the project or absorbed into other categories and thus will eliminate this as a separate category.

*** RFP Statements 1, 2 and 6 will be eliminated and used to form the objective function as they truly define the overall objective of the project as described by the owner and interpreted by the project management team.

Appendix - B: The Shortlisted Concepts

Concept 1



Concept 2

Concept 3