4 ARCHITECTURE EVALUATION CRITERIA AND METHODOLOGY

This section describes the evaluation criteria and methodology used to evaluate the candidate framework architectures. Choosing among alternative technical architectures is not a simple or straightforward task. There is no single measure defining what is a good or a bad architecture, and even those measures that might seem obvious (such as cost and ease of use) must be evaluated against one another and against the particular business problem that the architectures are trying to address. This makes it important to have a well-defined set of criteria against which each of the candidate architectures is evaluated, to assess the relative importance to the organization of each of those criteria, and to have a structured evaluation methodology to decide among the alternatives.

Section 4.1 describes the evaluation criteria used to evaluate the candidate framework architectures. Section 4.2 explains the methodology used to perform the evaluation.

4.1 Evaluation Criteria

The Project EASI/ED framework technical architecture is intended to:

- Mitigate risk associated with untried technologies.
- Provide independence from specific and proprietary hardware-based operating environments.
- Mitigate vendor dependence through compliance with "open" and de facto standards.
- Facilitate integration of information systems with other resources.
- Scale to meet necessary data volume, transaction volume, and performance requirements.
- Deliver technological and price/performance improvements.
- Provide the flexibility to cope with inevitable change.

With the above aims in mind, a set of evaluation criteria was developed (Figure 4-1). Each criterion was weighted in accordance with its relative importance to the success and value of Project EASI/ED. The weighted for the criteria were developed using the AHP methodology, which is described in subsection 4.2. Appendix C details the calculation of the criteria weights, and the weights are listed in subsection 6.2. All the evaluation criteria, and the weights associated with them, were confirmed with ED to ensure that they reflected the objectives and priorities of the Department.

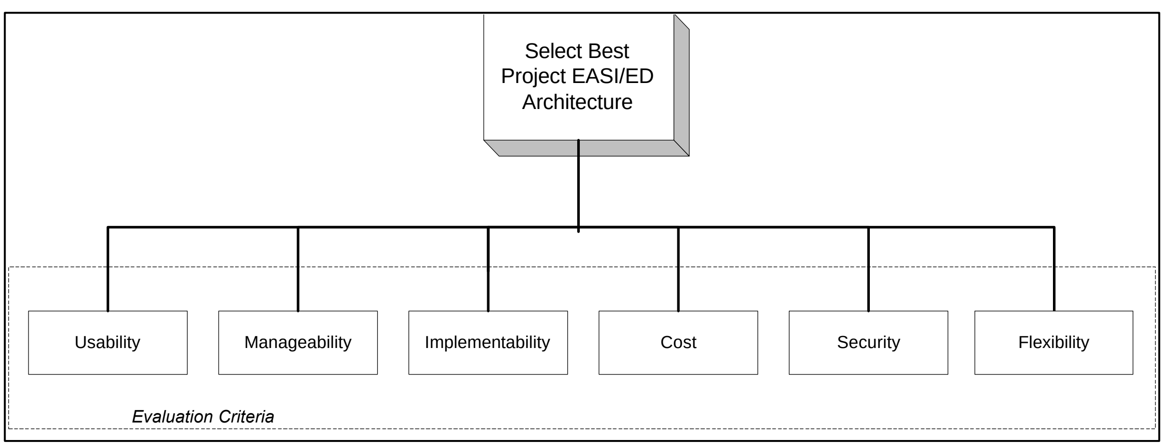

Figure 4-1. Evaluation Criteria to Select Project EASI/ED Architecture

The evaluation criteria are explained in Figures 4-2 to 4-7. Each figure consists of the following:

- **Criterion Description:** A description of the scope of the criterion.
- **Criterion Measure:** The factors that make up the criterion, and against which each candidate architecture is measured. Each measure has an associated definition.
- **Criterion Importance:** The reasons why the criterion is important to the selection of a technical architecture, and the impacts that this criterion can have on the operation of an organization's information systems.

Criterion:	**COST**	
Criterion Description:	The measure of expenses associated with architecture capital investments and operations/maintenance activities.	
Criterion Measures:	CAPITAL INVESTMENTS COSTS	The measure of expected costs to acquire hardware, software, and other components of the architecture.
	OPERATIONS/ MAINTENANCE COSTS	The measure of expected costs associated with operating and maintaining hardware, software, and other components of the architecture.
Criterion Importance:	The Gartner Group, an information technology research consultancy, estimates that US businesses, on average, spend 75 percent of their Information System (IS) budgets maintaining existing systems. Similarly, the Department of Defense estimates that system maintenance expenses typically account for 60 percent to 80 percent of total life cycle costs. Despite these significant investments, many organizations still find it extremely difficult to make effective use of information assets. Realizing that access to and proper utilization of enterprise information is key to long-term success, many organizations are seeking alternative information management solutions. However, many of these solutions are not cheap. In fact, without considering the benefits of improved data access and usability, financial analysis shows that client-server computing does not typically reduce overall costs. For example, the Gartner Group estimated that the cost of ownership is currently $42,000 per desktop over 5 years. Faced with these financial challenges and with the requirement to better leverage information resources, organizations must select flexible, modular architectures, that are: • Capable of providing the price/performance improvements that justify their acquisition. • Inherently supportable and, thus, less expensive to maintain, operate, modify, expand, and use. As a result, we considered technology acquisition costs, as well as estimated operations and maintenance costs when evaluating candidate architectures.	

Figure 4-2. Evaluation Criterion: Cost

Criterion:	**IMPLEMENTABILITY**	
Criterion Description:	The degree to which technologies comprising the architecture are mature, understandable, COTS-based, and supportable by available skilled personnel.	
Criterion Measures:	TECHNICAL MATURITY	The degree to which technologies comprising the architecture have been tried, tested, and standardized throughout the information technology industry.
	TECHNICAL COMPLEXITY	The degree to which the architecture comprise heterogeneous, immature, or non-standardized technical components.
	AVAILABILITY OF REQUIRED TECHNICAL SKILL	The degree to which skills required to design, implement, operate, and maintain technologies comprising the architecture are available within the information technology marketplace.
	COTS/PACKAGED SOFTWARE USE	The degree to which the architecture is implemented via commercially available, vendor-provided, vendor-packaged, and vendor-supported technical components.
Criterion Importance:	To successfully meet mission objectives, organizations need comprehensive, flexible and integrated systems and processes. To create these systems, organizations frequently turn to the rich, but confusing range of COTS solutions available today. COTS-based architectures offer the promise of reduced time to market, increased development productivity, and improved system quality. Furthermore, marketplace competition often leads to commodity-like pricing and alternative sourcing for many technologies. However, choosing commercially available technologies requires analytical caution as: • Many vendors are new. • Many products are relatively unproven. • Many architectural philosophies are immature. • Many solutions are surprisingly complex. • Many open system standards are still evolving. As a result, special care must be given to architect maintainable, open systems, which are inexpensive, flexible and scaleable.	

Figure 4-3. Evaluation Criterion: Implementability

Criterion:	**FLEXIBILITY**	
Criterion Description:	The degree to which architecture components are open to product/vendor heterogeneity are based on widely accepted standards, and are scalable.	
Criterion Measures:	OPENNESS TO PRODUCT/VENDOR HETEROGENEITY	The degree to which architecture components can be interchanged without introducing additional technical complexity and cost.
	TECHNICAL STANDARDIZATION	The degree to which technologies comprising the architecture are based on standards, that are widely accepted and followed by information technology vendors.
	SCALABILITY/ SCALABLE PERFORMANCE	The degree to which the architecture will accommodate a wide variety of system sizes, ranging from small work groups to national networks, and still deliver acceptable performance.
Criterion Importance:	Due to the limitations of single-tiered, monolithic, applications[1], enterprises turned to heterogeneous, distributed systems and two- and three-tier client/server architectures[2]. Presentation, application, and data access logic are typically indistinguishable and inseparable within monolithic applications. However, client/server architectures based on open system standards can allow processing components to be partitioned and distributed among heterogeneous operating environments. This provides necessary independence from computing and network platform suppliers, and leverages available network, desktop, and processing capabilities. Because of this openness to product/vendor heterogeneity and technical standardization, hardware lock-in problems common to monolithic architectures are mitigated, effective strategic use of enterprise information resources is enhanced, and system scalability is improved. For these reasons, we considered technology openness, standardization, and scalability when evaluating candidate architectures.	

Figure 4-4. Evaluation Criterion: Flexibility

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[1]These limitations are largely the result of application dependence on proprietary hardware-based operating environments that often cannot scale to meet necessary data volume, transaction volume, or performance requirements.

[2]This trend was also influenced by the emergence of economical and powerful operating environments, cost-effective and high-speed network products, and open system standards.

Criterion:	**MANAGEABILITY**	
Criterion Description:	The degree to which the technologies comprising the architecture are reliable, available, serviceable, and controllable.	
Criterion Measures:	RELIABILITY/ AVAILABILITY	The degree to which the architecture services perform without failure and are continuously available, as justified by business needs.
	CONTROLABILITY	The measure to which the availability, performance, accessibility, and reliability of the system can be controlled and managed by ED.
Criterion Importance:	The impetus behind distributed architectures is the same one that popularized client/server computing in the first place: the need to put specialized processing on the appropriate machine for each particular task. And the business benefit behind this building block approach? Making key business data readily available to managers who must make rapid, precise, and informed business and policy decisions. However, like mainframe solutions, the client/server paradigm is not without shortcomings and challenges. Not least among these challenges is the added complication of distributed system management and control. As enterprises deploy mission-critical applications across heterogeneous computing platforms, systems can become more complex and the scope of the systems management problem can expand dramatically. By deploying client/server applications, enterprises can raise the total complexity of a system by orders of magnitude. This is particularly true of those systems: • Using significantly dissimilar technologies to support ever widening user populations. • Leveraging public networks, like the Internet, that are not serviced or controlled by the organization. As a result, system management issues, such as serviceability, controllability, maintainability, and their effect on system availability and reliability, were carefully considered in this evaluation.	

Figure 4-5. Evaluation Criterion: Manageability

Criterion:	**USABILITY**	
Criterion Description:	The degree to which the architecture improves system and data usability, while masking system complexities.	
Criterion Measures:	ACCESSIBILITY	The degree to which the architecture is capable of providing appropriate access to information and functions from anywhere within a distributed system.
	TRANSPARENCY	The degree to which the architecture masks the complexity of individual functions of the system from the user, enhances user productivity, and reduces the possibility of user errors.
Criterion Importance:	Organizations generate and use tremendous amounts of data and manage this data from a wide range of locations with disparate technologies. Faced with the challenge of effectively and efficiently using this resource, organizations are turning to technologies that facilitate practical consolidation and analysis of data. These technologies are clearly becoming a significant part of the overall strategic information management solution. When defining enterprise technical architectures, special care should be given to ensure that technologies add business value via their ability to improve decision making, planning, communications, personal efficiency, and organizational control. Architectures should improve system and data usability, while masking system complexities. Research shows the apparent complexity of a system correlated with: • User skill requirements. • Learning time and training requirements. • Error rates and user performance. • User satisfaction and confidence. For these reasons, system accessibility and transparency were considered when evaluating candidate architectures.	

Figure 4-6. Evaluation Criterion: Usability

Criterion:	**SECURITY**	
Criterion Description:	The degree to which the architecture provides adequate authentication, information confidentiality and integrity, access control, security administration, and auditing services, as justified by business needs.	
Criterion Measures:	Authentication	The degree to which the technologies compromising the architecture are capable of identifying valid system users.
	Access Control	The degree to which technologies comprising the architecture can grant, restrict, and revoke system user rights and access permissions.
Criterion Importance:	In the modern age of the heterogeneous distributed network environment, using and managing security required for large-scale mission-critical applications. Today, users find themselves required to repeatedly prove their identity to different elements of the network, including LAN servers, host systems, gateways, applications, etc. From an efficiency standpoint, little could be worse. Similarly, the management of distributed security leaves much to be desired. Maintaining user passwords and user identity (ID) for multiple systems quickly becomes an administrative nightmare, and in many organizations, it is not even possible to determine which users have access to which systems. This makes distributed system auditing becomes nearly impossible. Further complicating distributed security are widely discussed plans to use public networks, which are not managed or controlled by the organization, as infrastructures for mission-critical systems. Security issues raised by these plans must not only be resolved before Internet-based system architectures can be realistically considered, but users must also be convinced that their transactions are protected. For these reasons, we considered security when evaluating candidate architecture.	

Figure 4-7. Evaluation Criterion: Security

4.2 Evaluation Methodology

The Analytic Hierarchy Process (AHP) was used to evaluate the Project EASI/ED candidate framework architectures. AHP is a quantitative decision making methodology that uses pairwise comparisons to:

- Determine relative evaluation criteria importance.
- Determine relative strengths of decision alternatives.

AHP is particularly useful in situations where difficult decisions between complex alternatives must be made. In these situations, decisions cannot be solely based on subjective or intuitive considerations; however, faced with complex alternatives, decision-makers often have difficulty accurately determining criteria importance and evaluation ratings. To solve this dilemma, AHP uses pairwise comparisons to consider all aspects of the complex problem and their relative importance to the decision making process. This allows the decision-maker to rationally choose between otherwise confusing alternatives.

Subsection 4.2.1 gives an overview of the steps within the AHP methodology, and subsection 4.2.2 uses an example to provide a detailed explanation of the methodology.

4.2.1 Methodology Approach

Using pairwise comparisons, AHP reduces criteria weighting and alternative evaluation inaccuracies. This allows decisions to be made with greater precision. The team tailored the AHP methodology to Project EASI/ED, using the following steps for this analysis:

Step 1. Identify criteria for evaluating alternative Project EASI/ED architectures, as well as evaluation scale to be used during pairwise comparisons.
Step 2. Determine the relative importance of architecture evaluation criteria using pairwise comparisons.
Step 3. Tailor relative importance (weights) of evaluation criteria based on ED's managerial and technical experience with the current Title IV systems.
Step 4. Determine the relative strengths of each candidate architecture using pairwise comparisons.
Step 5. Select the most appropriate Project EASI/ED framework architecture based on weighted evaluation of alternatives.

4.2.2 Methodology Details

This subsection describes the AHP in detail using an example that follows the steps listed above. As the following figure illustrates, the recommended Project EASI/ED framework architecture was selected (Step5) only after each candidate architecture was assessed (Step 4) using the identified and weighted evaluation criteria (Steps 1, 2, 3.)

Step 1: Identify Criteria. Criteria used for an evaluation are identified during the first step of the AHP. Evaluation criteria considered for the purposes of this example are Usability, Manageability, and Implementability. These criteria are listed in Figure 4-8.

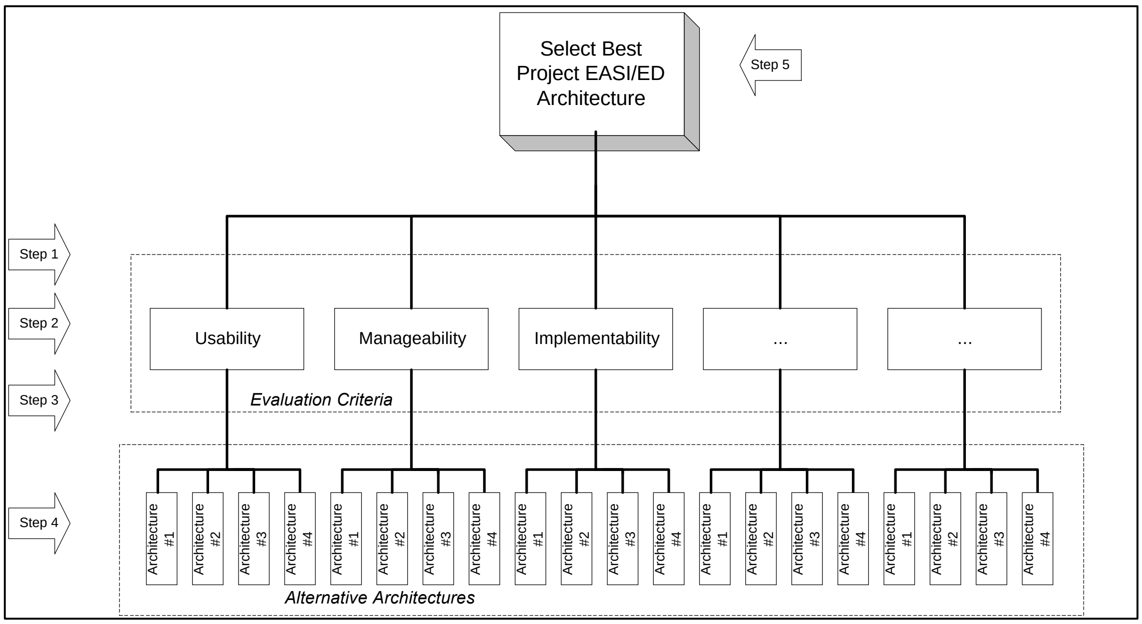

Figure 4-8. Steps in Selecting Project EASI/ED Framework Architecture

After selecting the evaluation criteria, an evaluation scale is defined. This scale is used to determine the relative importance of evaluation criteria and the relative strengths of the candidate architectures. The example evaluation scale is provided in Figure 4-9.

Weight	Preference
1	Equally Preferred/ Equally Important
2	Moderately Preferred/ Moderately More Important
3	Strongly Preferred/ Much More Important
4	Very Strongly Preferred/ Very Much More Important
5	Extremely Preferred/ Extremely More Important

Figure 4-9. Evaluation Scale

Step 2: Weight Criteria. To determine the relative importance of each evaluation criterion, a pairwise comparison of the evaluation criteria is performed. That is, each criteria is compared with every other criteria identified during Step 1. Using the evaluation scale, a level of importance, relative to other criteria, is calculated for each criterion. This step is illustrated in Figures 4-10 through Figure 4-14.

CRITERIA	Usability	Manageability	Implementability
Usability		**3**	**5**
Manageability			**4**
Implementability			

Figure 4-10. Pairwise Comparison of Criteria

Figure 4-10 illustrates the relative importance of the criteria in this example. Usability "Much More Important" (3) than the Manageability criteria and "Extremely More Important" (5) than the Implementability criteria. Manageability is "Very Much More Important" (4) than the Implementability criteria.

To complete the matrix that Figure 4-10 begins, two principles must be understood. First, all criteria are "Equally Important" (1) when compared to themselves. Second, if, for example, one criterion is twice as important as the second, then the second criteria must be considered one-half as important as the first. Following these principals the matrix can be completed as shown in Figure 4-11.

CRITERIA	Usability	Manageability	Implementability
Usability	1	**3**	**5**
Manageability	1/3	1	**4**
Implementability	1/5	1/4	1

Figure 4-11. Pairwise Comparison of Criteria (continued)

Once the matrix is complete, assigned values are converted to decimals (so that they are easier to work with) and column totals are calculated. See Figure 4-12.

CRITERIA	Usability	Manageability	Implementability
Usability	1.0000	3.0000	5.0000
Manageability	0.3333	1.0000	4.0000
Implementability	0.2000	0.2500	1.0000
Total	1.5333	4.2500	10.0000

Figure 4-12. Pairwise Comparison of Criteria

Next, the numbers in the matrix are divided by their respective column totals. See Figure 4-13.

CRITERIA	Usability	Manageability	Implementability
Usability	0.6521	0.7059	0.5000
Manageability	0.2174	0.2353	0.4000
Implementability	0.1304	0.0588	0.1000

Figure 4-13. Divide Criterion with Criteria Total

Finally, to determine the relative importance of each evaluation criteria, row averages are calculated, as illustrated in Figure 4-14.

CRITERIA	Relative Importance
Usability	[0.6193] = (0.6521 + 0.7059 + 0.5000) / 3
Manageability	[0.2842] = (0.2174 + 0.2353 + 0.4000) / 3
Implementability	[0.0964] = (0.1304 + 0.0588 + 0.1000) / 3

Figure 4-14. Row Averages

Based on these example calculations, 62 percent of the architecture evaluation should be based on assessment of Usability. Twenty-eight percent of the evaluation should be based on Manageability, and 10 percent should be based on Implementability. These numbers represent the relative importance of the criteria being considered.

Step 3: Tailor Weights. To ensure that the criteria weights are appropriately defined, they are reviewed and tailored by ED during AHP Step 3. This ensures that ED's managerial and technical experience with the current Title IV systems and their priorities for Project EASI/ED are reflected in the values of relative importance assigned to each criteria. This is important: in subsequent steps these values are used to calculate weighted evaluations for each of the alternative architectures.

For the purposes of this example, assume that ED reviewed the values calculated and Step 2 and tailored these values based on experience and goals. The tailored weights are listed in Figure 4-15 and represent the relative importance of each criterion that will be used in subsequent AHP steps.

CRITERIA	Relative Importance
Usability	53%
Manageability	35%
Implementability	12%

Figure 4-15. Tailored Criteria Weights

As with Step 2, this step requires the use of pairwise comparisons. However, in this step criteria are not compared. Instead, the candidate architectures are compared against each other to determine relative strengths with regard to the criteria defined during AHP Step 1.

As with previous calculations, the evaluation scale defined during Step 1 is used to compare candidate architectures and determine preferences (relative strengths). During this step, each alternative architecture is compared against every other candidate architecture to determine relative strength with regard to each criteria. As an example, the pairwise comparison of the Manageability of each candidate architecture is illustrated in Figure 4-16 through 4-18.

Manageability	Architecture 1	Architecture 2	Architecture 3
Architecture 1		**2**	**5**
Architecture 2			**3**
Architecture 3			

Figure 4-16. Pairwise Comparison of Architectures

Figure 4-16 shows the relative strength of each candidate with regard to the Manageability criteria. This matrix indicates that the Manageability of Architecture 1 is "Moderately Preferred"(2) to that of Architecture 2 and "Extremely Preferred" (5) to the manageability of Architecture 3. The Manageability of Architecture 2 is "Strongly Preferred" (3) to that of Architecture 3.

Once preferences are assigned, the matrix is completed, values are divided by column totals, and row averages are calculated, as described in Step 2. Figure 4-17 lists the relative strength determined based on these calculations.

Manageability	Architecture 1	Architecture 2	Architecture 3	Relative Strength/ Preference
Architecture 1	0.5882	**0.6000**	**0.5555**	**58% (0.5821)**
Architecture 2	0.2941	0.3000	**0.3333**	**31% (0.3091)**
Architecture 3	0.1176	0.1000	0.1111	**11% (0.1096)**

Figure 4-17. Relative Strengths of Each Architecture

These calculations are completed for each criterion. The calculations are not illustrated within this example; however, the matrix in Figure 4-18 documents calculated relative strength resulting from each of the required pairwise comparisons.

Manageability	Usability	Manageability	Implementability
Architecture 1	0.2120	0.5821	0.7010
Architecture 2	0.0320	0.3091	0.2300
Architecture 3	0.6560	0.1096	0.0690

Figure 4-18. Relative Strengths for Each Architecture Across All Criteria

After candidate architectures are compared (Step 4), the recommended architecture for Project EASI/ED is identified. This calculation is made by multiplying the criteria evaluations (calculated in the previous step) by the criteria weights (calculated in Steps 2 and 3), as illustrated in Figures 4-19 through 4-21.

CRITERIA	Criteria Weight	Architecture 1	Weighted Evaluation
Usability	0.5300	0.2120	0.1124
Manageability	0.3500	0.5821	0.2037
Implementability	0.1200	0.7010	0.0841
		Weighted TOTAL =	**0.4002**

Figure 4-19. Weighted Evaluation for Architecture 1

CRITERIA	Criteria Weight	Architecture 2	Weighted Evaluation
Usability	0.5300	0.0320	0.0170
Manageability	0.3500	0.3091	0.1082
Implementability	0.1200	0.2300	0.0276
		Weighted TOTAL =	**0.1528**

Figure 4-20. Weighted Evaluation for Architecture 2

CRITERIA	Criteria Weight	Architecture 3	Weighted Evaluation
Usability	0.5300	0.6560	0.3477
Manageability	0.3500	0.1096	0.0384
Implementability	0.1200	0.0690	0.0083
		Weighted TOTAL =	**0.3944**

Figure 4-21. Weighted Evaluation for Architecture 3

Based on the values provided in this example, Architecture 1 receives the highest ranking and is selected as the best architecture for Project EASI/ED. The total weighted evaluation results are illustrated in Figure 4-22.

ALTERNATIVE	Total Weighted Evaluation
Architecture 1	0.4002
Architecture 2	0.1528
Architecture 3	0.3944

Figure 4-22. Total Weighted Evaluation Score for Candidate Architectures

As this example illustrates, AHP allows decision-makers to evaluate complex alternatives via pairwise comparisons. These comparisons allow the relative importance of criteria, as well as alternative strengths, to be considered during the decision making process. This is important when making difficult decisions. For example, consider the results of the evaluation just described. Architecture 3 was evaluated as a better alternative overall than Architecture 2, despite lower evaluation scores in two of the three criteria being considered. Likewise, Architecture 1 was evaluated as the best, even though Architecture 3 had a significantly better Usability criteria evaluation score. Without the weighted criteria made possible by AHP, the relative importance of criteria as perceived by ED would not be considered and decision results could be different.