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Individual Project Paper

Engineering Resource Selection to Support Electrical Packaging Efforts at a Heavy Trucking OEM

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ABSTRACT

Corporate resource management is a topic of high complexity and is of high interest for corporate management. It requires companies and managers to hire, allocate, move and fire resources as needed to facilitate the corporate direction. When hiring a resource it is important to determine what the roles and responsibilities for that resource might be now and in the future. It is then important to match those requirements against the skills and expectations of that resource.

This paper aims to quantify and analyze the differences between different engineering resource types using a modified HDM (Hieratical Decision Model) method. The model modification uses a data gathering adjustment to reduce the expert survey complexity and reduce the expert inconsistency to zero. The HDM model was developed based on expert feedback and experience. The model was then used to review the hiring criteria, its driving factors and how they relate to several different types of hirable resources.

This study is limited to this specific use case as it removes an entire resource class due to hiring limitations at the company used for this analysis. A future study could be performed to determine the impacts of this omitted resource type. Additionally, this analysis uses expert expectations for resource performance and not measured data. An additional analysis could be completed to use the actual performance data rather than the expected.

INTRODUCTION

This analysis will review the resource hiring selection process at a global vehicle OEM (original equipment manufacturer). This OEM has a significant workforce in the USA and Europe and provides a variety of different vehicle models. One of the roles of management at this company is to hire resources of different types for different tasks. This analysis will focus on the replacement of a resource that was recently lost due to a contract term limitation.

This analysis was done from the perspective of a single group leader trying to select a replacement resource for his/her group. As of January 1st, 2017, the group in question consisted of a manager, 6 full-time (direct) engineers, 1 contractor and 1 internal professional service resource. All of these resources are located in the Pacific Northwest, USA.

On February 10, 2017, a long time contractor with more than 10 years of experience was forced to leave the company due to contractual time limits. Due to the human resource (HR) rules in place, it was not possible to backfill that position with another contractor or convert the existing resource to a different resource type. However, there is a need to have another comparable resource hired to support the work performed by that position. This position is responsible for complex CAD (Computer Aided Design) and schematic diagram assignments and requires a certain level of knowledge and expertise.

This analysis will try to answer the following question: What type of resource should be hired to replace the contractor that was lost? This decision will have direct impact on the next major project that is being worked on at the company. As hours and budgets are formed for this large scale project, the type of resource used directly impacts the overall timing and cost of

the project. This is a quick to market, large scope, budget sensitive project with high visibility.

The project is intended to release in early 2019, so timing is also a factor.

METHODOLOGY

This analysis will use a modified Hieratical Decision Model (HDM) which is an adaptation of the Analytical Hierarchy Process (AHP) for creating a resource selection model for selecting a new engineering resource. An expert panel was used to provide subjective opinions about the selection process and provided values to determine the impacts of each item in the hierarchy.

Methodology Selection

The HDM model method was chosen for its ability to, "…deal with intangible factors, which by definition have no scales of measurement…" [(1)] Selection of a hired resource is neither a numerical function nor one based solely on facts. It is a decision based on opinions and needs. The HDM model was also chosen for its ability to "indicate the preferred object, but [it] can also discriminate among intensities of preference." [(1)] In this case, the strength of the opinion or need is just as important as the definition itself. This makes the HDM process an ideal model for making this decision.

HDM Structure

A basic HDM structure will vary based on its intended use, but it will always follow a basic tiered tree structure. The number of levels within this structure will vary based on the level of complexity of the analysis. The hieratical tree starts with an objective statement or goal (Level 1). The goal/objective is then followed by criteria for evaluation. These criteria are then assigned and connected to the goal through a linked node (web). This process is repeated at each level of the model until an exhaustive list of criterion are assembled. Lastly, the last level of criteria are connected with webs to all of the available options/outcomes. [(1)]

Each criterion is then evaluated based on its importance to higher linked item and the other criterion at the same level. During the evaluation process a comprehensive pairwise comparison strategy is used to compare every relevant item to its linked items. [1] A 100 point system is used for each comparison, where points are assigned based on importance/relevance to the related nodes. [2]

A typical HDM model will look as follows:

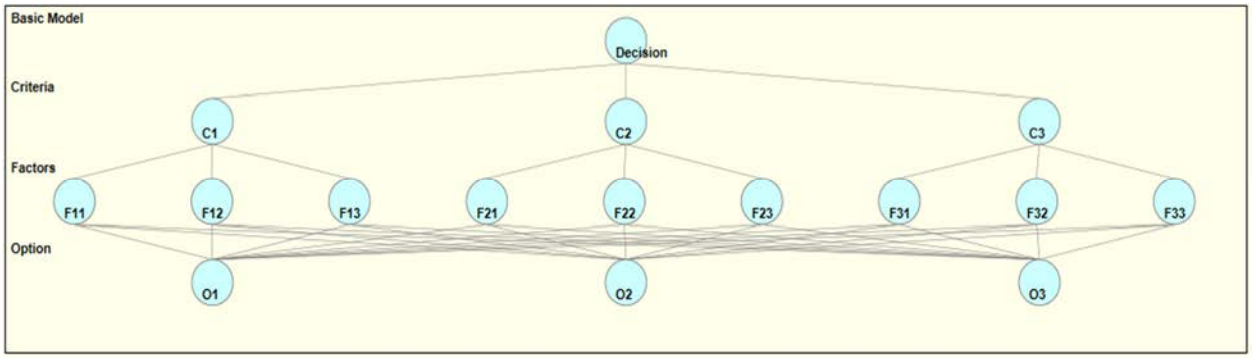

Figure 1: Basic HDM

Items within the tree are defined as follows:

Decision (D) Criteria (C_j) Factor (F_k) Option (O_n)	C_j: The relative importance of each criteria (C_j) to the decision (D) F_{kj}: The relative impact of each factor (F_k) to the criteria (C_j) O_{nk}: The relative performance of each option (O_n) to each factor (F_k)
	C_j: Decision criteria categories — F_k: Influencing factors O_n: Outcome options — S_n: Sum value for each Option (O_n)

Figure 2: Basic HDM Definitions

Each of the alternatives/solutions is then evaluated using the following formula:

$$s_n = \sum_{n=1}^{n} \sum_{k=1}^{k} \sum_{j=1}^{j} o_{nk} * f_{kj} * c_j$$

Figure 3: Basic HDM Formula

Method Adjustment

This analysis will use a slightly modified version of HDM. The model analysis will consist of the standard weighted pair wise comparisons, where the weights are assigned between 1 and 99. However, in an effort to increase the quality of the expert responses, the data collection will use a weighted criteria level comparison.

For example, assume the following model:

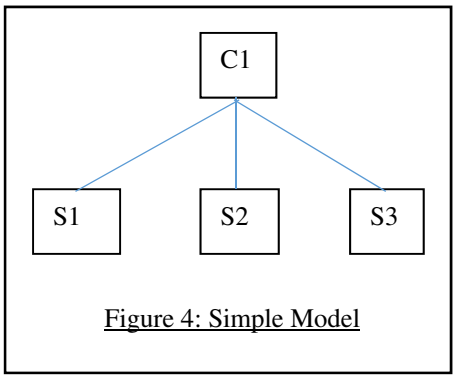

Figure 4: Simple Model

In standard HDM the model would be processed by comparing S1 to S2 in relation to C1, where 100 points would be spread across S1 and S2 so that they are weighted in relative importance to one another. This would then be repeated 2 more times to compare S1 and S3, and then again to compare S2 and S3.

For this analysis, the pair wise comparisons will still be made, but there will be an additional arrhythmic step added to reduce the impact on the experts. Using Figure 4 above, in this analysis, the experts were asked to compare S1, S2 and S3 relative to C1 all at one time. They were asked to spread 100 points across all items at the second level, where no item could be 100 or 0. This will give a relative weighting across all items within the grouping relative to each other. The pair wise comparison will then be performed between each of the items as is done in standard HDM after each item is normalized to 100 using the following formulas:

$$A^* = (Ax100) / (A+B) \qquad B^* = (Bx100) / (A+B)$$

Where A is criteria 1's weighting and B is criteria 2's weighting. A* is the normalized value of A relative to B. B* is the normalized value of B relative to A.

Figure 5: Normalization Formulas

Using the same nomenclature as above, the comparisons will consist of S1* and S2* relative to C1, S1* and S3* relative to C1 and S2* and S3* relative to C1. Using this method will result in a balanced pair wise model, but will minimize the time needed for the experts to provide feedback. The intent of the change is to increase the quality of the answers provided by the experts by asking them to provide pointed and specific comparisons in a short and concise survey. This modification should also minimize/eliminate the expert inconsistency. The inconsistency values will still be calculated to verify this holds true. The data collection will be discussed later in the analysis.

The Experts

An expert panel was used to create the hierarchal model and provide comparative values between the criteria items. The experts were selected out of industry and specifically are managers within the engineering department and/or engineering directors at the company. All of the experts are responsible for hiring new employees, managing project resources, group budgets and managing human capital. Each expert was chosen based on their knowledge of the company, projects and areas of impact. A total of 4 experts were polled for this analysis.

Expert 1 is the Director of engineering over the group in question and is responsible daily operations for all engineering operations. He has a direct interest in the outcome of the selection decision and is currently making all hiring decisions for this specific engineering group.

Experts 2 & 3 are managers in the engineering department which are responsible for their own engineering groups and the management of those teams. They do not have direct experience with the group in question, but they do have experience with the hiring processes and budget limitations of the department. Both managers also have direct knowledge of the project for which the resource is being hired for.

The Expert 4 opinion was provided by the senior design engineer within the impacted engineering group. This engineer has direct experience with the group, the project and the needs of the position. The engineer also has 10+ years of experience with the roles that the new hire will need to perform and was managing the previous resource for the past 3 years.

Model Definition

The model used for this analysis was developed in conjunction with all 4 experts and was based on experiences from each of them. The topics and criteria were agreed to by the forum and scored accordingly. A four-level hierarchy model was developed to analyze the decision of what resource should be selected.

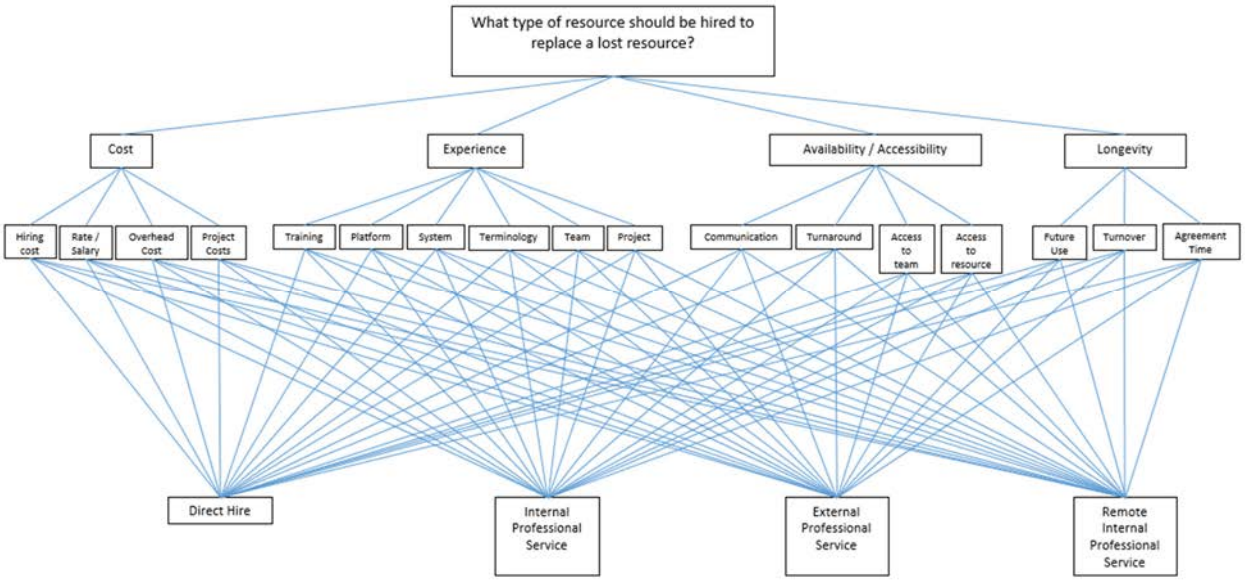

Figure 6: The Decision Hierarchy

The following section gives a breakdown of each level of the model and defines each of the items and what it is intended to determine.

Level 1

This level represents the goal of the study. For this study, the goal is to determine: What type of engineering resource should be hired to replace an experienced contractor?

Level 2

Level 2 consists of the high level impact criteria. There are 4 items at this level: cost, experience, availability/accessibility and longevity.

Level 3

Level 3 consists of influencing factors that are directly linked to the level 2 items. This list of diverse items spans the full scope of the items used when deciding what type of resource to choose.

Level 4

Level 4 consists of the 4 possible engineering resource types. Each of these engineering resources has unique characteristics and will be measured using both expert opinion and quantitative values.

Criteria and Factor Definitions

Cost (L2)

Costs are considered to be the full financial burden related to the onboarding and continued employment of the resource.

Hiring Cost (L3)

This is the cost to originate the position. Direct employees tend to have higher hiring costs while third party employees tend to have very low origination costs as they are absorbed by the hiring body.

Hourly rate/salary (L3)

This is the general cost to have the employee do the work. Different types of employees are paid different rates and therefore have different impacts on overall budgets.

Overhead costs (L3)

Overhead is tracked by the company at a department level and is assigned to anyone directly employed by the company (direct hires and contractors). Overhead is charged against the general departmental engineering budget and tends to have high visibility within the company.

Project budget costs (L3)

These costs are approved on a per project basis and are considered to be flexible budgets. The overall project budgets tend to be reviewed, but the employee contribution to these budgets tend not to get the same scrutiny as the overhead costs.

Experience (L2)

This is the overall experience level of the resource. Different types of resources tend to have different expected levels of experience with company systems, the vehicle models and the project structures.

Training needed (L3)

This is the overall need for training of the resource. The more experienced the resource the less training required and the quicker the investment payback tends to be.

System experience (L3)

This is experience with the company's systems. This includes company specific programs and tools.

Terminology experience (L3)

The company uses a wide variety of acronyms. This is a measure of how comfortable the resource is with the terms used on a daily basis within the company.

Platform experience (L3)

This is experience with the different vehicle types and specifically the types of vehicle they will be responsible for supporting.

Team experience (L3)

This is experience with the team members and other members within the company and engineering departments.

Project experience (L3)

This is experience with how projects are processed and performed at the company. The company has a very specific project structure that must be followed and any deviation from that process can result in significant delays.

Availability/Accessibility (L2)

This is how available the resource is to review and communicate designs. This is also a measure of how quickly design iterations can be made.

Resource access to team (L3)

This is how easily the resource can contact the team members for questions, reviews and/or assignments.

Team access to resource (L3)

This is how easily the team members can contact the resource for questions, reviews and/or assignments.

Turnaround time (L3)

This is how important the design iteration timing is. In projects with short timelines, quicker turnaround times are desirable.

Communication (L3)

This is the resources ability to communicate clearly and concisely about what they are working on.

Longevity (L2)

This is a measure of how long the resource will be available to the team. The longer the term of employment, typically the higher the acceptable time and training investment.

Length of working agreement (L3)

Different resource types have different time terms of employment. This is a measure of how long it is expected that a resource will be in the position in question.

Turnover (L3)

This is a measure of how important it is to retain the resource over time. Direct resources tend to be more stable, while professional service resources tend to be more fluid.

Desire to use in future (L3)

This is a measure of how desirable it is to keep the resource for additional projects in the future.

Types of Resources

The company manages several different resource types, each with their own set of costs, requirements and limitations. The 5 most common are direct hire, contractor, internal professional service, external professional service (third party) and remote internal professional service. Based on the limitations of this case, only 4 of the options will be reviewed (contractor will be removed). A summary of the resource types is as follows:

Direct Hire (Direct)

Direct hires are full-time, salaried employees of the company. These employees have full benefits, no work term limits and are charged against the general engineering overhead budget. These employees are trained and supported fully by the company and are located on site. For the purposes of this analysis, a direct hire would be a resource with at least 3 years of

related experience in the vehicular OEM industry. A minimal level of training would be expected, but experience with the company's systems is expected.

Contractor

Contractors are full-time, hourly employees of the company. These employees have no benefits, an 18 month work term limit and are charged against the general engineering overhead budget. These employees are trained and supported fully by the company and are located on site.

Internal Professional Service (IPS)

Internal professional service employees are employed by a third party employer on behalf of the company. These employees are hourly, have no term limits and are charged against the engineering project budgets. These employees are trained and supported fully by the company and are located on site. For the purposes of this analysis, an internal professional service would be a resource with at least 5 years of related experience in the vehicular OEM industry. A minimal level of training would be expected, but advanced CAD experience is expected.

External Professional Service (EPS)

External professional service employees are employed by a third party employer on behalf of themselves. These employees are hourly, have no term limits and are charged against the engineering project budgets. These employees are trained and supported by the third party employer and are located off-site. These resources tend to be higher quality, pre-trained and have previous company experience. For the purposes of this analysis, this resource would have significant experience in the vehicular OEM industry. No training would be required by the

company and advanced experience with company specific systems and CAD systems is expected.

Remote Internal Professional Service (RIPS)

Remote internal professional service employees are employed by subsidiary of the company. These employees are hourly, have no term limits and are charged against the engineering project budgets. These employees are trained and supported fully by the company, but are located off-site, in this case Mexico. For the purposes of this analysis, the resource would have 1-2 years of related experience in the vehicular OEM industry. A minimal level of training would be expected, but experience with company specific systems is expected.

DATA AND DATA SOURCE(S)

Data Collection Process

Data for this analysis was collected from 2 types of sources, experts and quantitative information from HR sources. Data for the webs between levels 1 & 2 and 2 & 3 are all qualitative and were gathered based on expert feedback. Data for webs between levels 3 & 4 were gathered from HR sources for quantitative data and from expert feedback for qualitative data. The model was built and qualitative data was gathered using the following process:

1. Talked to the experts and got their agreement to participate in the study.
2. Created and developed the model based on conversations with the experts.
3. Created and distributed a survey to collect expert feedback on opinion based topics. Surveys had 2 sections: 1 to cover levels 2 & 3 and 1 to cover qualitative items at level 4.
4. Once compiled, the results of the survey were presented to the expert panel for validation.
5. The data for levels 1 through 3 were then entered into the HDM model based on the completed survey feedback.
6. The results for level 4 items were averaged and normalized. These values were then entered as fixed values to achieve a consistent comparison.

The Data

The data was broken into four distinct sub-sets:

1. Opinion based weightings (levels 1-3) (See Appendix B)
2. Fixed values based on HR averages (level 4)
3. Opinion based values for resource performance (level 4)
4. Assumed values based on this analysis (level 4) (see 'Types of Resources' section)

The level 4 values for the 4 resource types are shown below. Fixed items are indicated by an (F) following the description, while opinion based items are followed by (O) and assumed values (A). All opinion based items are an average of the scorings provided by the experts. Scales were used for opinion based items to allow for later calculations.

Costs

Cost				
	Hiring Cost (O)	Hourly Cost (F)	Overhead Cost (F)	Project Cost (F)
Direct	High (5)	$75	Yes (5)	No (1)
IPS	Medium (3)	$57	No (1)	Yes (5)
EPS	Low (1)	$52	No (1)	Yes (5)
RIPS	Medium (3)	$27	No (1)	Yes (5)

Table 1: Cost values for level 4 items

In this data set, the hourly cost is unique in that the higher the value the less desirable the outcome is. Therefore, these values were entered as inverses of their true values. For example, when comparing Direct ($75) to IPS ($57) their adjusted weights come out to 57 and 43 respectively. However, when these values are entered into the analysis tool the values are reversed. This gives preference to the lower cost option as it is more desirable to have a low cost than a high cost.

Experience

Experience						
	Training (A)	Systems Exp. (A)	Terminology (A)	Platform Exp. (A)	Team Exp. (A)	Project Exp. (A)
Direct	Medium (3)	High (5)	High (5)	Medium (3)	High (5)	High (5)
IPS	Medium (3)	Medium (3)	Low (1)	Low (1)	Low (1)	Low (1)
EPS	Low (5)	High (5)	Medium (3)	High (5)	Medium (3)	High (5)
RIPS	Medium (3)	High (5)	Medium (3)	Medium (3)	Low (1)	Medium (3)

Table 2: Experience values for level 4 items

Availability / Accessibility

Availability / Accessibility				
	Resource Acc. (O)	Team Acc. (O)	Turnaround (O)	Communication (O)
Direct	4.75	4.75	5.00	4.75
IPS	4.25	4.25	4.50	4.50
EPS	3.00	3.00	3.75	3.00
RIPS	3.00	3.00	3.75	2.75

Table 3: Availability / Accessibility values for level 4 items

Longevity

Longevity			
	Length of time (O)	Turnover (F)	Future Use (O)
Direct	9.50	Low (5)	5.00
IPS	4.13	High (1)	4.00
EPS	4.63	Low (5)	3.50
RIPS	4.50	Medium (3)	3.50

Table 4: Longevity values for level 4 items

ANALYSIS AND KEY FINDINGS

In this section, the results of the model and the data will be analyzed. The following table shows the results of the model based on the expert data:

Best Resource	Direct Hire	Internal Professional Service	External Professional Service	Remote Internal Professional Service	Inconsistency
Expert 1	0.3	0.17	0.27	0.26	0
Expert 2	0.31	0.19	0.27	0.23	0
Expert 3	0.32	0.19	0.26	0.23	0
Expert 4	0.3	0.18	0.27	0.25	0
Mean	**0.31**	**0.18**	**0.27**	**0.24**	
Minimum	**0.3**	**0.17**	**0.26**	**0.23**	
Maximum	**0.32**	**0.19**	**0.27**	**0.26**	
Std. Deviation	**0.01**	**0.01**	**0**	**0.01**	
Disagreement					**0.009**

Table 5: Model Results

The Result

Based on these results it is recommended that the company hire a direct employee to replace the lost contractor. The direct employee had the highest score with a score of 31. An external professional service is the second most desirable type of resource for this position with a score of 27. Ranked third is the remote internal professional service with a score of 24. The lowest scoring resource is the internal professional service with a score of 18.

These scores are significant, as based on the expert feedback, it is 15% more desirable to hire a direct employee than it is to hire any other type of resource. To hire a direct employee is 15% more desirable than hiring an external professional service, 29% more desirable than hiring a remote internal professional service and 72% more desirable than hiring an internal professional service resource.

What the experts think is most important

Since this analysis is primarily based on expert opinion, the weightings of the criteria and factor groups is significant, especially since there is a wide span between the ratings. It should be noted that full table data can be found in Appendix B.

Criteria level

The final criteria ratings are as follows:

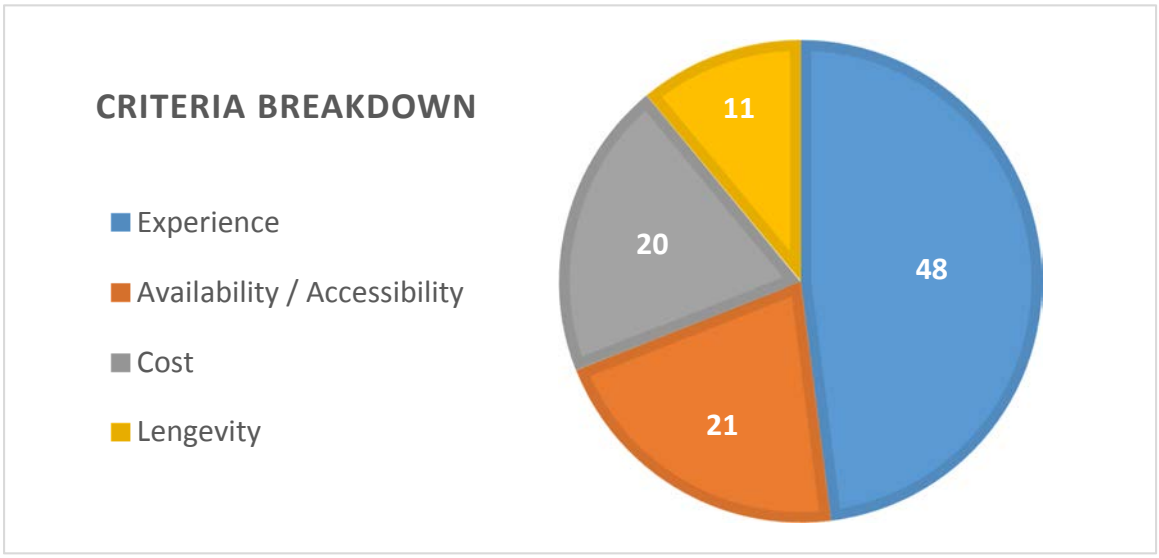

Figure 7: Criteria Breakdown

With an average score of 48, experience was deemed to be more than twice as important as cost and accessibility/availability. Experience was also rated almost five times more important than longevity of the resource. This means that the experts value what the resource knows and their skills over everything else by a significant margin. Based on the scores listed in Table 2, it is not surprising that the direct resource and the external professional service resource got the top final scores. Both resources scored high in the experience category and with the significant weighting of the single criteria, it is reasonable that these two resource types would be at the top of the list.

In contrast, per Table 4, the direct resource gets a significantly higher scores for longevity than the other three types of resources. However, since the criteria weighting for longevity is only 11, it has a minimal impact on the overall decision.

Cost Factors

The Cost criteria item consists of four factors: Hiring Cost, Hourly Rate / Salary, Overhead Cost and Project Cost.

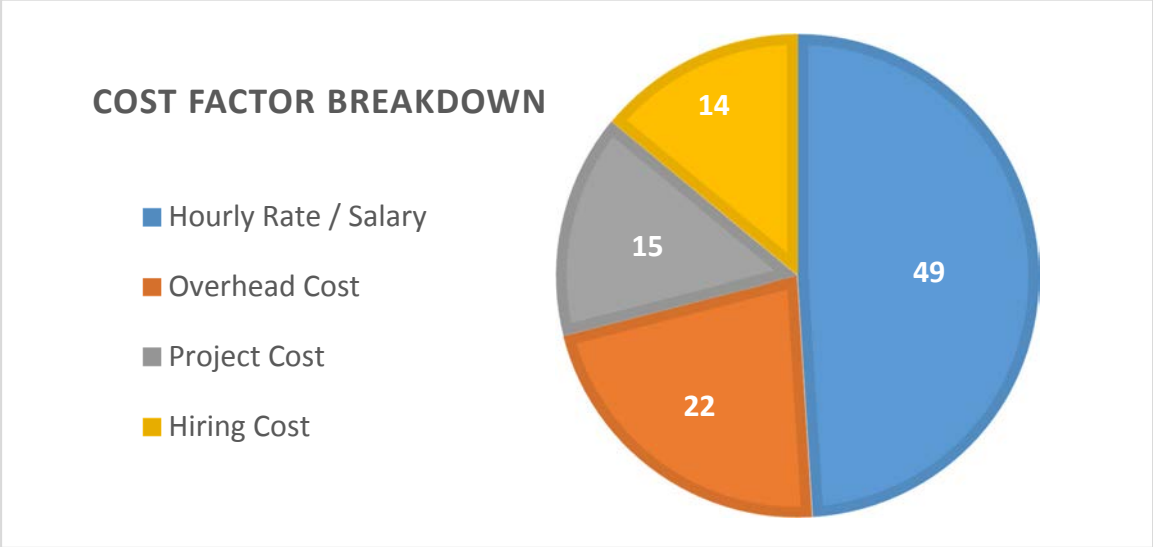

Figure 8: Cost Factor Breakdown

It can be observed in Figure 8 that hourly rate and salary was determined to have the largest impact within cost with a score of 49. The experts placed a value on hourly rate and salary that is double that of overhead costs with a score of 22. Hourly rate and salary was also rated more than three times higher than project and hiring costs, 15 and 14 respectively.

It should be noted that Expert 3 had relatively different opinion about costs from the other three experts. Expert 3 put more weight on the hiring costs and less on the project costs. This is likely due to their perspective on how projects are processed through their group and how resources are used within their portion of the engineering organization.

Experience Factors

The Experience criteria item consists of six factors: Training Needs, System Experience, Terminology Experience, Platform Experience, Team Experience and Project Experience.

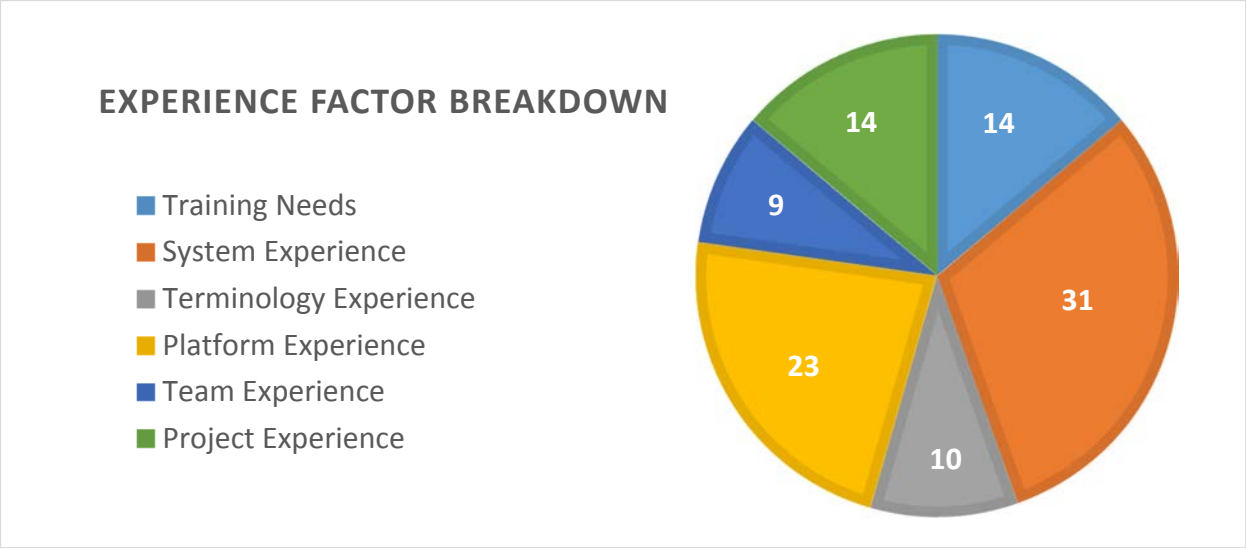

Figure 9: Experience Factor Breakdown

It can be observed in Figure 9 that system experience was determined to have the largest impact within experience with a score of 31. Platform experience was rated second with a score of 23. This means that platform experience is 35% less important than systems experience. Training needs and project experience both have a score of 14, which means that systems experience is deemed more than twice as important. Terminology and team experience were given the lowest scores, 10 and 9 respectively, meaning they are three times less important than systems experience.

These results emphasize the desire to have a resource that can “hit the ground running” on the product at hand. It is accepted that training will be needed and that other types of experience are needed, but the priority should be on systems knowledge and familiarity with the vehicle in question.

It should be noted that Expert 3 placed a significantly higher rating on training needed than the other three experts. However, Expert 3 also assumed a lower systems level impact. Since these two factors are related, aka the resource can be trained to learn new systems or improve their skills in them, the data from Expert 3 still seems to make sense and is still considered to be aligned with the other experts.

Availability / Accessibility Factors

The Availability / Accessibility criteria item consists of four factors: the Resource's Access to the Team, the Team's Access to the Resource, Turnaround Time and Communication.

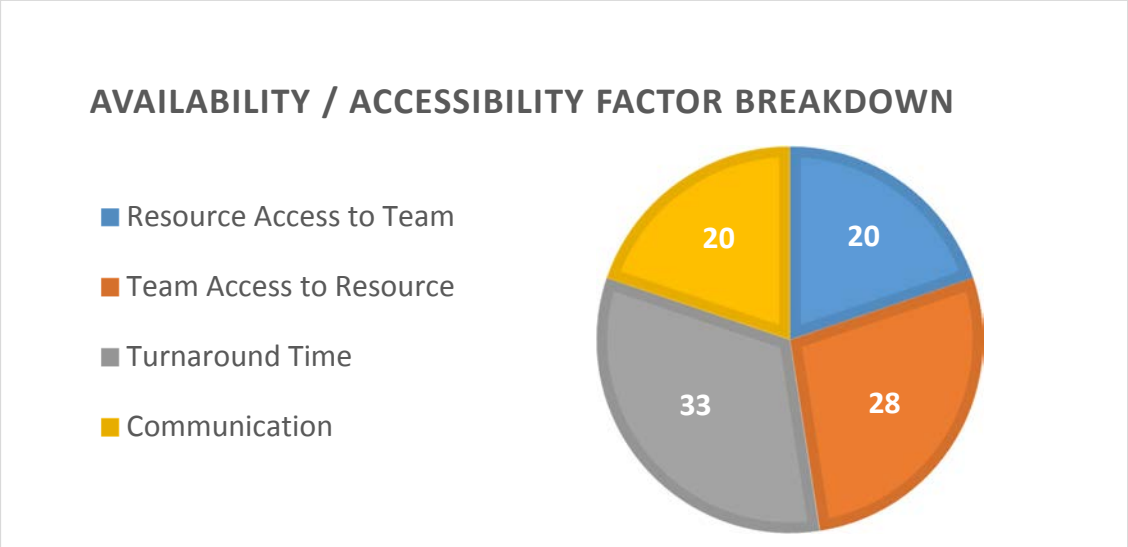

Figure 10: Availability / Accessibility Factor Breakdown

It can be observed in Figure 10 that turnaround time was determined to have the largest impact within Availability / Accessibility with a score of 33. Turnaround time was closely followed by the team's access to the resource with a score of 28. The resource's access to the team and communication were deemed about 30% less important than the other two factors.

These results emphasize the desire to have the resource produce work quickly and reliably. It also emphasized the need for the team to be able to contact the resource on

demand. However, it is recognized that being able to communicate effectively is still important and the resource's ability to get information from the team is still significant.

It should be noted that Expert 3 placed a significantly higher rating on communication than the other three experts. However, Expert 3 also assumed the lowest turnaround score. This is likely due to management style and as mentioned previously, how this manager uses the resources within their engineering group.

Longevity Factor

The Longevity criteria item consists of three factors: Length of Agreement, Turnover and Desire to use the resource in the Future.

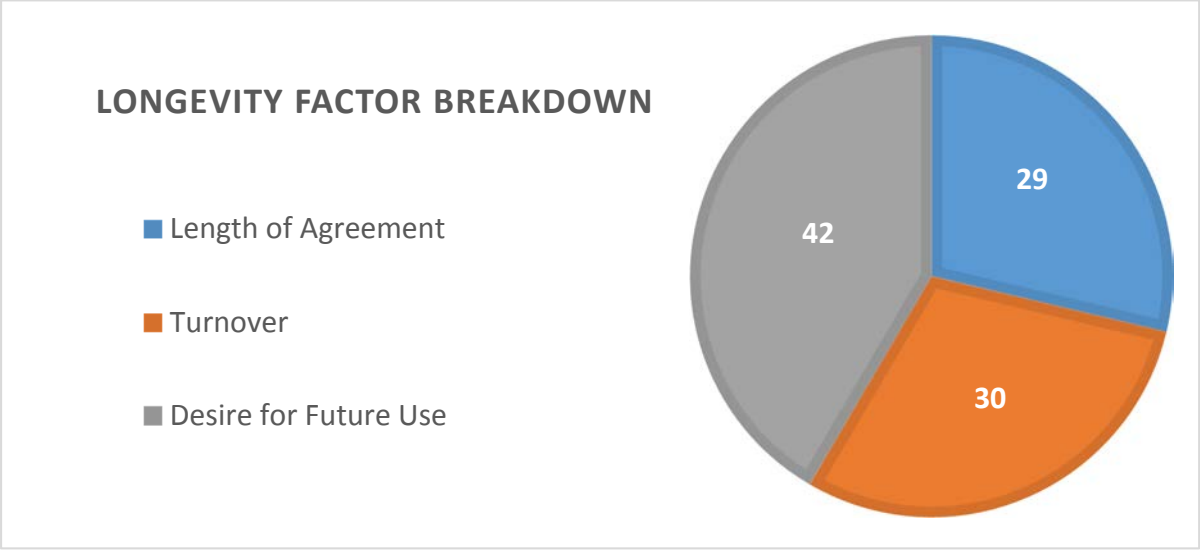

Figure 11: Longevity Factor Breakdown

It can be observed in Figure 11 that the desire to use the resource in the future was determined to have the largest impact within longevity with a score of 42. The experts placed an almost even value on turnover and length of agreement, with scores of 30 and 29 respectively, while both of these were deemed to be 25% less important than the desire for future use.

These results emphasize the desire to have stability within the working groups and parallels the desires seen in the experience factors. There is a significant desire to continue to use resources for future projects. Having the same resources means less training and less time spent integrating that resource into the existing team.

Criteria vs. Resource Scores

As part of the analysis, the criteria level scores for each of the resources was calculated. Figure 12 below shows the relationship between levels 2 through 4. This radar graph shows how each of the resources relate to one another at the criteria level.

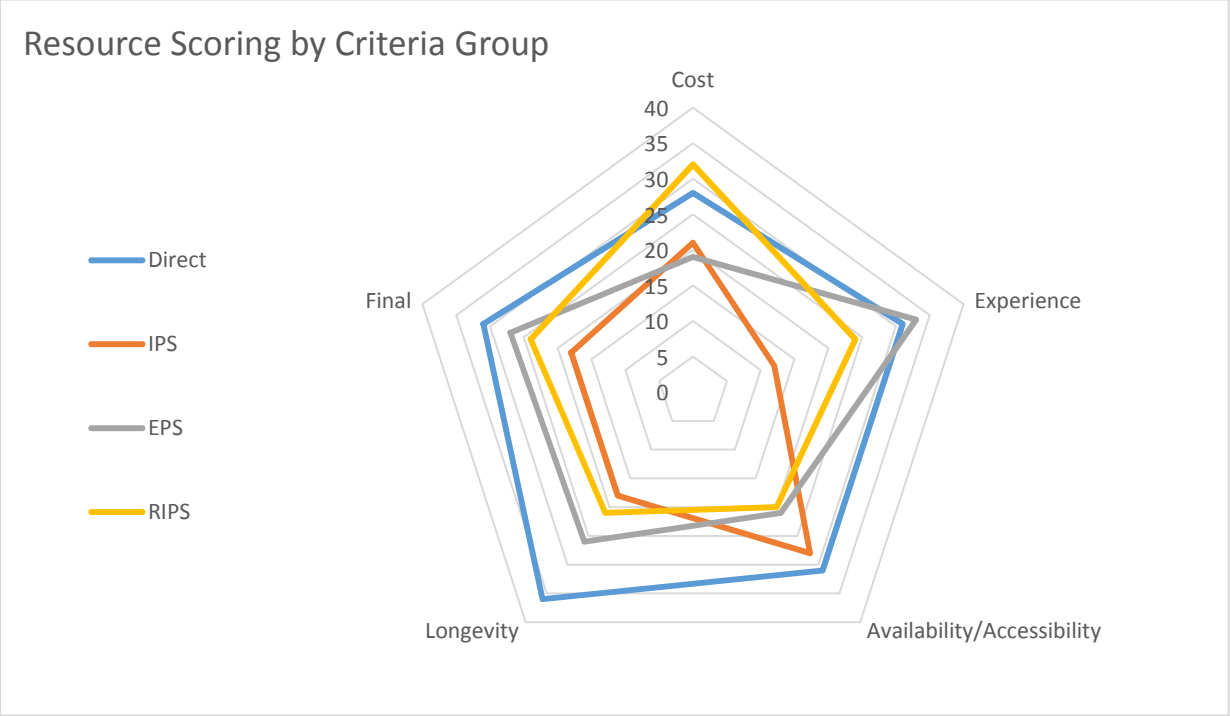

Figure 12: Resource Scoring by Criteria Group

Using Figure 12, it is obvious that the direct resource significantly outperforms the other resource types on average. It doesn't necessarily have the highest score in every area, but it is a top performer in all categories and has a well-balanced distribution. This reinforces the final score and its top ranking.

The internal professional service is lacking in almost all areas except for availability & accessibility. This makes sense since the resource would be on-site with the rest of the engineering team. This figure also helps to point out why its final score is so low. It has all-around a lower average score than all of the other resource types.

The external professional service scores highly in all areas except for availability & accessibility. This scoring makes sense considering that the resource would be off-site. The external professional service scores extremely high in experience, which also makes sense since this resource is managed outside of the company and requires little to no training by the company.

The remote internal professional service shows to be highly balanced in all areas, but scores lower on the scales on average. Where this resource excels is its cost rating. With the lowest costs of all of the resources this is not a surprising outcome.

Discrepancy

To check the validity of the data, an expert discrepancy score was calculated. Per Table 5, the final discrepancy score was determined to be 0.009. This score is measured on the following scale from 1 to 0, where 0 is full alignment and all scores are exactly the same and where 1 is full misalignment and all scores are drastically different. With a score of 0.009, these results and the data set are deemed to be acceptable. Additionally, the experts are seen as being in agreement with all criteria, factors and weightings.

Impacts of the model adjustment

In the Model Adjustment section of this analysis it was mentioned that this analysis would use a modified data collection method. This data collection method asked the experts to

spread 100 points across all related items at a specific level. The values would then be normalized back to a scale of 100 for the pairwise comparisons. The intent of the change was to increase the quality of the answers provided by the experts by asking them to provide pointed and specific comparisons in a short and concise survey.

The quality and consistency of the data can determined by 2 different values: the standard deviation of the results and the inconsistency score.

Standard deviation

The standard deviation measures how far from the mean score each expert's result is. The standard deviation value can be found in Table 5. With a maximum standard deviation from the mean of 0.01, all score are almost perfectly aligned. This means that while some experts may have weighted some of the criteria and factors differently, in the end their overall preferences were almost perfectly aligned and resulted in similar results.

Inconsistency

It was mentioned that the model adjustment would likely have a direct impact on the inconsistency scores seen from the experts. It was hypothesized that by collecting the expert data in this unique way that the expert inconsistency to would be minimal or completely eliminated.

The inconsistency score for all of the experts can be found in Table 5. Table 5 shows that the data for all 4 of the experts was obtained and entered so that their inconsistency scores were all zero. This result matches the hypothesis and validates the expected impact of the adjustment.

FUTURE RESEARCH & LIMITATIONS

Due to limitations in the current corporate policies, contractor resources were not considered as part of this exercise. This eliminates an entire sub-set of data from the comparisons and therefore should be reviewed at a later date. This is significant in that contractors typically have skill levels that are similar to that of direct resources and therefore would likely score fairly high within the results.

Another area of refinement would be to look at measured performance of the resources over time. All of the performance measures used in this analysis we based on expert experience or expectation and not the real world resource outputs. An additional analysis could be completed that measures the long-term performance of the resources. This model could then be updated with the measured values. Since these values were used to measure the overall performance of the resources, a small change could result in a different outcome. Also, since the deviation in final scores was relatively small, and would get smaller with contractors in the mix, these slight adjustments could change the overall rankings of the resources.

Lastly, this exercise does not take into account that there was a decision made on March 17th, 2017 by the engineering director to hire a remote internal professional service employee. At a later date, a gap analysis could be performed to determine the difference in decision making strategies and outcomes as the resource selected was ranked third based on this analysis. It should be noted that the management decision was made by one of the experts used in this analysis.

REFERENCES

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2. H. Chen and J. Li, “A sensitivity analysis algorithm for the constant sum pairwise comparison judgments in hierarchical decision models,” in Portland International Center for Management of Engineering and Technology -Technology Management in the Energy-Smart World, PICMET’11, July 31, 2001- August 4, 2011, 2011, p. Portland State University; PSU Office of Information Technologies

Appendix A

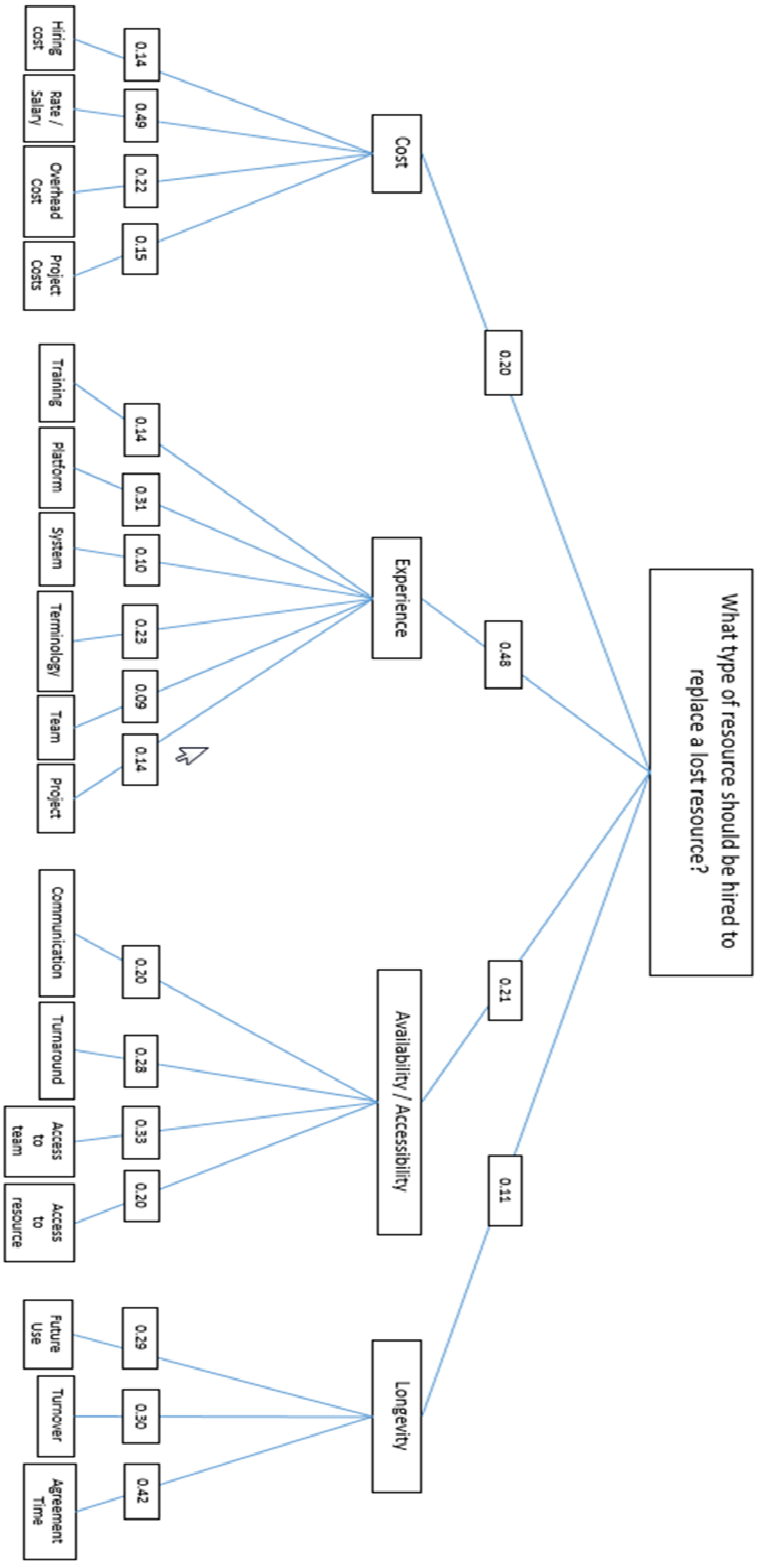

Figure A1: Level 1-3 HDM Model Values

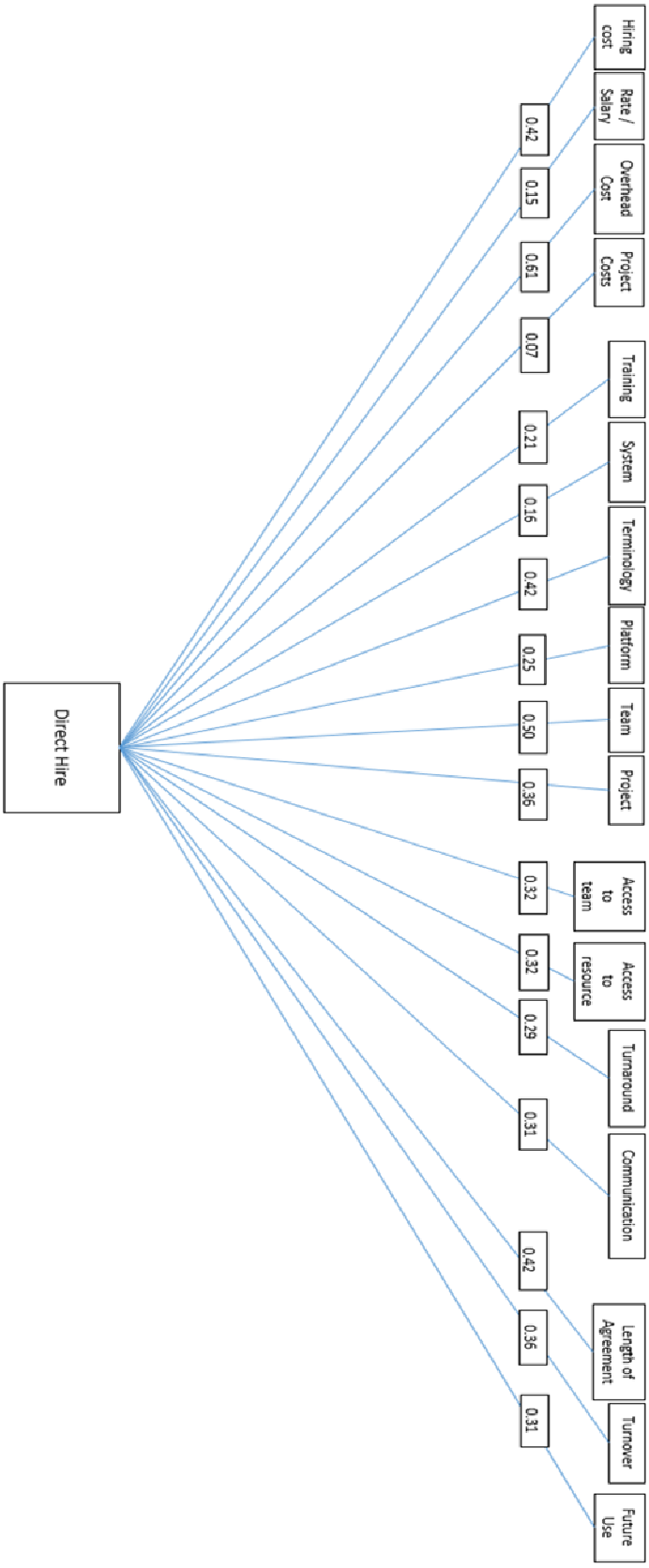

Figure A2: Level 4 HDM Model values for Direct Resource

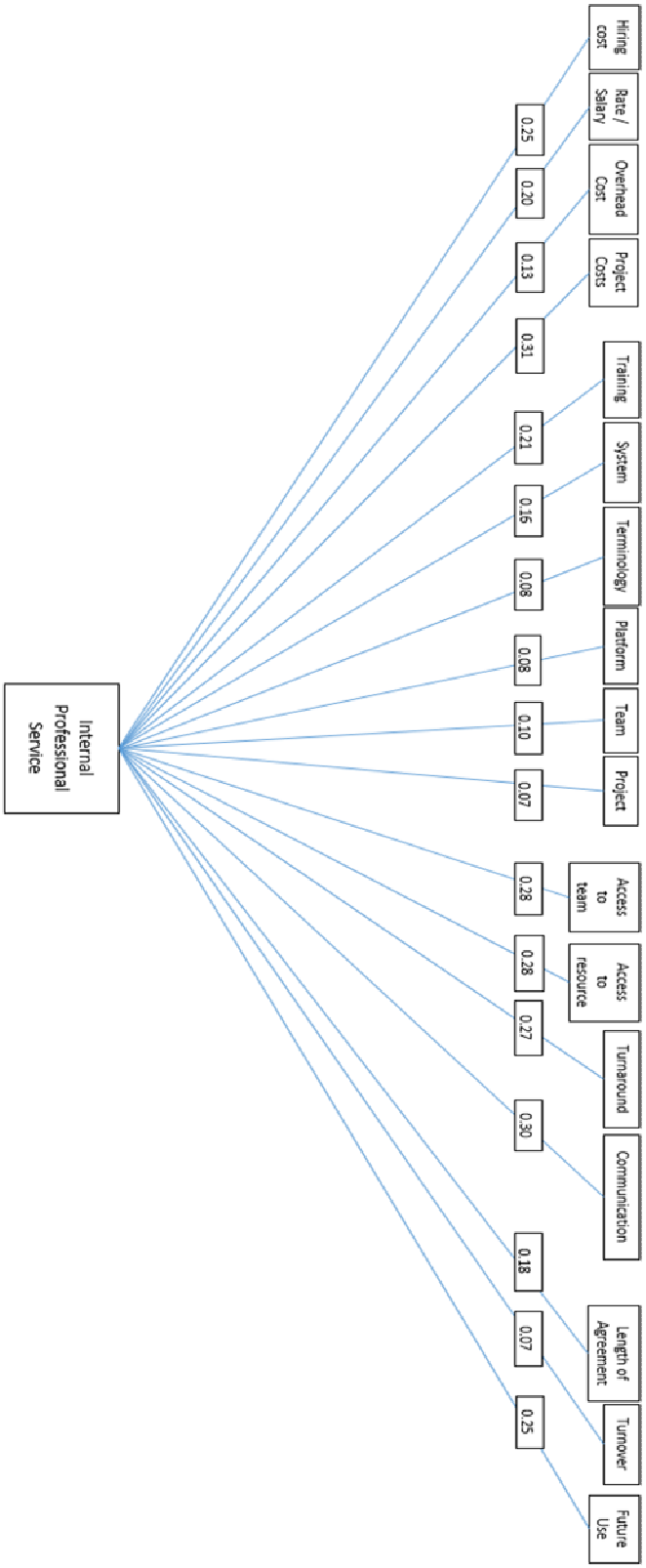

Figure A3: Level 4 HDM Model values for Internal Professional Service Resource

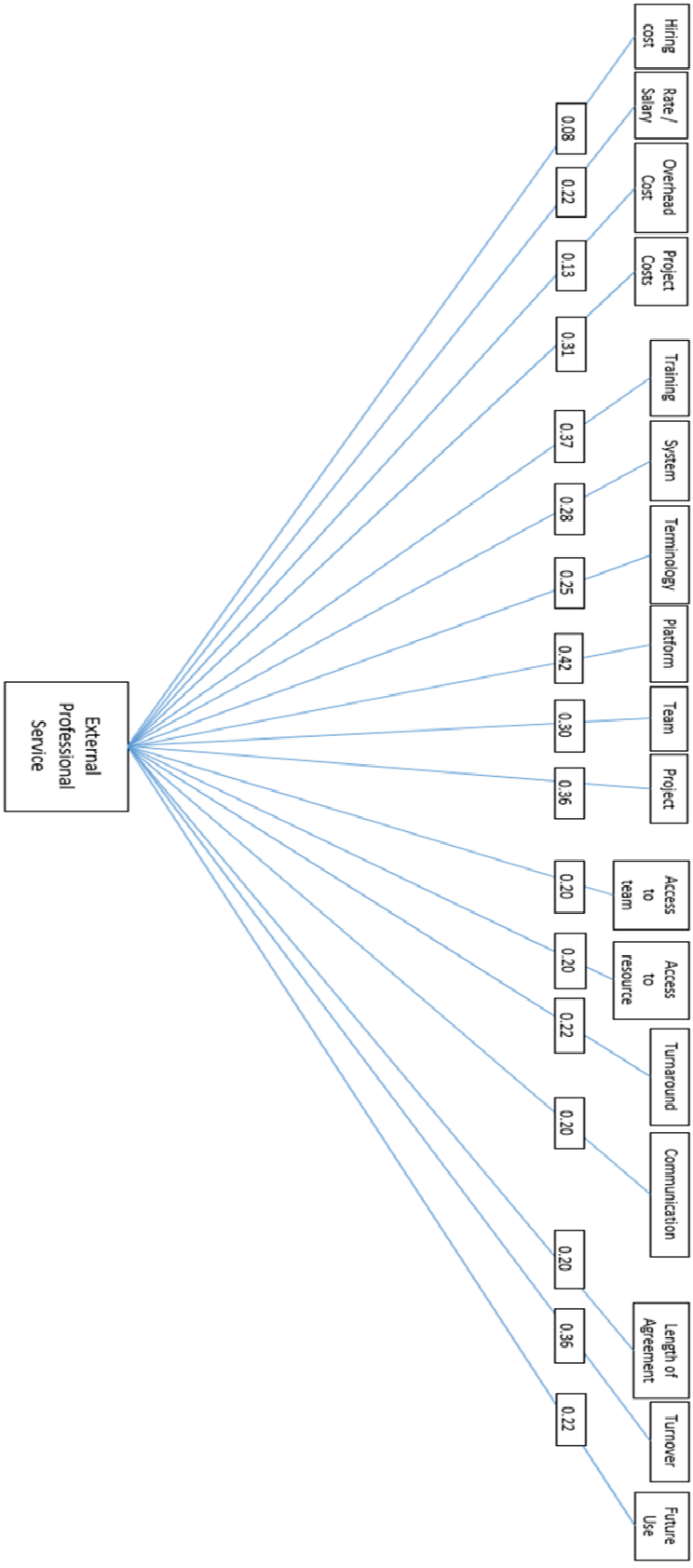

Figure A4: Level 4 HDM Model values for External Professional Service Resource

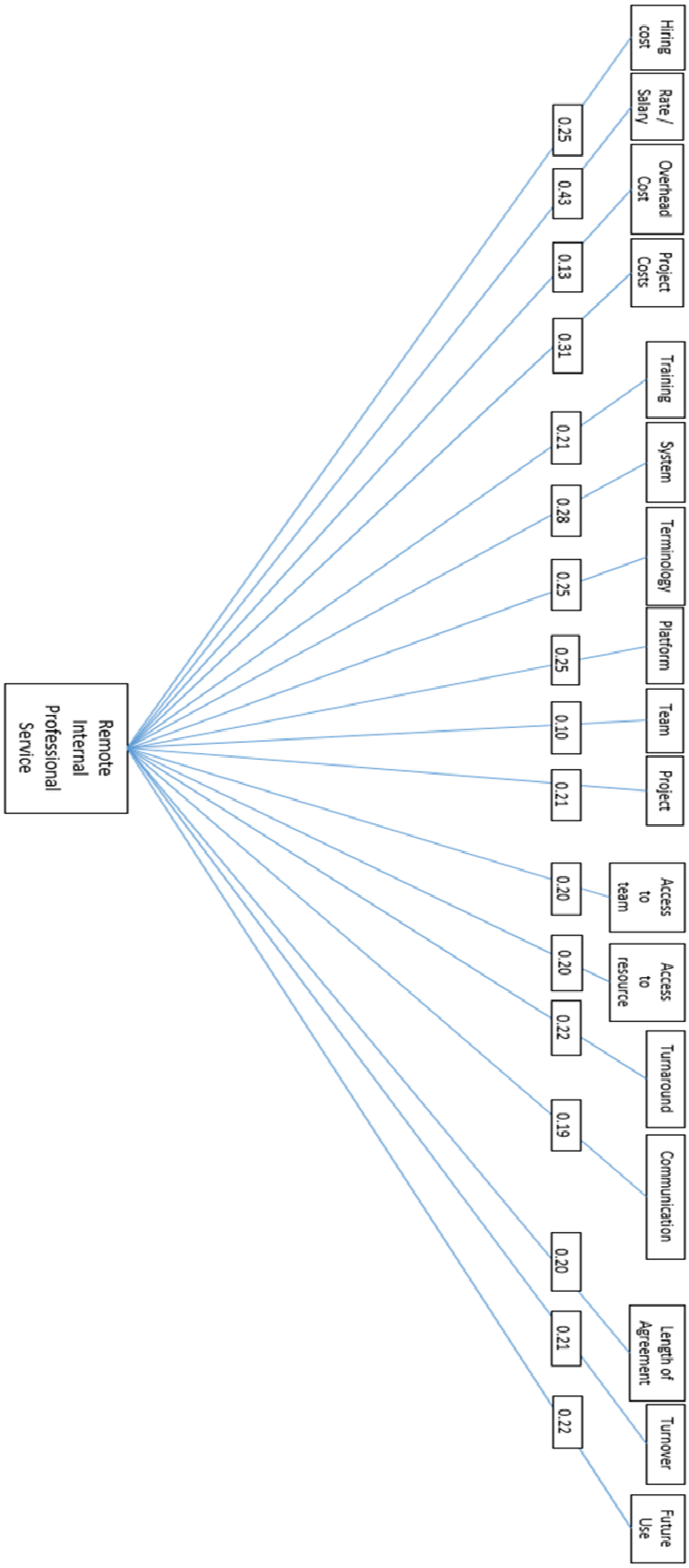

Figure A5: Level 4 HDM Model values for Remote Professional Service Resource

Appendix B

Level-1	Best Resource					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Cost	0.30	0.10	0.20	0.20	0.20	
Experience	0.50	0.50	0.40	0.50	0.48	
Availability / Accessibility	0.15	0.30	0.20	0.20	0.21	
Longevity	0.05	0.10	0.20	0.10	0.11	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B1: Level 1 Expert Input

Level-2	Cost					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Hiring Cost	0.10	0.10	0.31	0.05	0.14	
Hourly Rate / Salary	0.49	0.40	0.50	0.55	0.49	
Overhead Cost	0.20	0.30	0.19	0.20	0.22	
Project Cost	0.20	0.20	0.01	0.20	0.15	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B2: Level 2 Expert Input - Cost

Level-2	Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Training Needs	0.05	0.10	0.29	0.10	0.14	
System Experience	0.30	0.40	0.20	0.35	0.31	
Terminology Experience	0.20	0.10	0.01	0.10	0.10	
Platform Experience	0.30	0.20	0.20	0.20	0.23	
Team Experience	0.05	0.10	0.10	0.10	0.09	
Project Experience	0.10	0.10	0.20	0.15	0.14	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B3: Level 2 Expert Input - Experience

Level-2	Availability / Accessibility					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Resource Access to Team	0.20	0.20	0.20	0.20	0.20	
Team Access to Resource	0.30	0.30	0.20	0.30	0.28	
Turnaround Time	0.30	0.40	0.20	0.40	0.33	
Communication	0.20	0.10	0.40	0.10	0.20	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B4: Level 2 Expert Input – Availability / Accessibility

Level-2	Longevity					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Length of Agreement	0.30	0.30	0.34	0.20	0.29	
Turnover	0.20	0.30	0.33	0.35	0.30	
Desire to use in future	0.49	0.40	0.33	0.45	0.42	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B5: Level 2 Expert Input - Longevity

Cost Scores				
Resource:	Direct	IPS	ESP	RIPS
Hiring Cost	0.06	0.04	0.01	0.04
Hourly Rate / Salary	0.07	0.10	0.11	0.21
Overhead Cost	0.14	0.03	0.03	0.03
Project Cost	0.01	0.05	0.05	0.05
Score	28	21	19	32

Table B6: Level 2 Score by Resource - Cost

Experience Scores				
Resource:	Direct	IPS	ESP	RIPS
Training Needs	0.03	0.03	0.05	0.03
System Experience	0.09	0.05	0.09	0.09
Terminology Experience	0.04	0.01	0.03	0.03
Platform Experience	0.06	0.02	0.09	0.06
Team Experience	0.04	0.01	0.03	0.01
Project Experience	0.05	0.01	0.05	0.03
Score	31	12	33	24

Table B7: Level 2 Score by Resource - Experience

Availability Scores				
Resource:	Direct	IPS	ESP	RIPS
Resource Access to Team	0.06	0.06	0.04	0.04
Team Access to Resource	0.09	0.08	0.06	0.06
Turnaround Time	0.09	0.09	0.07	0.07
Communication	0.06	0.06	0.04	0.04
Score	31	28	21	20

Table B8: Level 2 Score by Resource - Availability / Accessibility

Longevity Scores				
Resource:	Direct	IPS	ESP	RIPS
Length of Agreement	0.12	0.05	0.06	0.06
Turnover	0.11	0.02	0.11	0.06
Desire to use in future	0.13	0.10	0.09	0.09
Score	36	18	26	21

Table B9: Level 2 Score by Resource - Longevity

Level-3	Hiring Cost					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.42	0.42	0.42	0.42	0.42	
Internal Professional Service	0.25	0.25	0.25	0.25	0.25	
External Professional Service	0.08	0.08	0.08	0.08	0.08	
Remote Internal Professional Service	0.25	0.25	0.25	0.25	0.25	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B10: Level 3 Expert Input – Hiring Cost

Level-3	Hourly Rate / Salary					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.15	0.15	0.15	0.15	0.15	
Internal Professional Service	0.20	0.20	0.20	0.20	0.20	
External Professional Service	0.22	0.22	0.22	0.22	0.22	
Remote Internal Professional Service	0.43	0.42	0.43	0.43	0.43	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B11: Level 3 Expert Input – Hourly Rate / Salary

Level-3	Overhead Cost					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.61	0.61	0.61	0.61	0.61	
Internal Professional Service	0.13	0.13	0.13	0.13	0.13	
External Professional Service	0.13	0.13	0.13	0.13	0.13	
Remote Internal Professional Service	0.13	0.13	0.13	0.13	0.13	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B12: Level 3 Expert Input – Overhead Cost

Level-3	Project Cost					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.07	0.07	0.07	0.07	0.07	
Internal Professional Service	0.31	0.31	0.31	0.31	0.31	
External Professional Service	0.31	0.31	0.31	0.31	0.31	
Remote Internal Professional Service	0.31	0.31	0.31	0.31	0.31	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B13: Level 3 Expert Input – Project Cost

Level-3	Training Needs					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.21	0.21	0.21	0.21	0.21	
Internal Professional Service	0.21	0.21	0.21	0.21	0.21	
External Professional Service	0.37	0.37	0.37	0.37	0.37	
Remote Internal Professional Service	0.21	0.21	0.21	0.21	0.21	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B14: Level 3 Expert Input – Training Needs

Level-3	System Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.28	0.28	0.28	0.28	0.28	
Internal Professional Service	0.16	0.16	0.16	0.16	0.16	
External Professional Service	0.28	0.28	0.28	0.28	0.28	
Remote Internal Professional Service	0.28	0.28	0.28	0.28	0.28	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B15: Level 3 Expert Input – System Experience

Level-3	Terminology Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.42	0.42	0.42	0.42	0.42	
Internal Professional Service	0.08	0.08	0.08	0.08	0.08	
External Professional Service	0.25	0.25	0.25	0.25	0.25	
Remote Internal Professional Service	0.25	0.25	0.25	0.25	0.25	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B16: Level 3 Expert Input – Terminology Experience

Level-3	Platform Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.25	0.25	0.25	0.25	0.25	
Internal Professional Service	0.08	0.08	0.08	0.08	0.08	
External Professional Service	0.42	0.42	0.42	0.42	0.42	
Remote Internal Professional Service	0.25	0.25	0.25	0.25	0.25	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B17: Level 3 Expert Input – Platform Experience

Level-3	Team Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.50	0.50	0.50	0.50	0.50	
Internal Professional Service	0.10	0.10	0.10	0.10	0.10	
External Professional Service	0.30	0.30	0.30	0.30	0.30	
Remote Internal Professional Service	0.10	0.10	0.10	0.10	0.10	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B18: Level 3 Expert Input – Team Experience

Level-3	Project Experience					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.36	0.36	0.36	0.36	0.36	
Internal Professional Service	0.07	0.07	0.07	0.07	0.07	
External Professional Service	0.36	0.36	0.36	0.36	0.36	
Remote Internal Professional Service	0.21	0.21	0.21	0.21	0.21	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B19: Level 3 Expert Input – Project Experience

Level-3	Resource Access to Team					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.32	0.32	0.32	0.32	0.32	
Internal Professional Service	0.28	0.28	0.28	0.28	0.28	
External Professional Service	0.20	0.20	0.20	0.20	0.20	
Remote Internal Professional Service	0.20	0.20	0.20	0.20	0.20	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B20: Level 3 Expert Input – Resource Access to Team

Level-3	Team Access to Resource					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.32	0.32	0.32	0.32	0.32	
Internal Professional Service	0.28	0.28	0.28	0.28	0.28	
External Professional Service	0.20	0.20	0.20	0.20	0.20	
Remote Internal Professional Service	0.20	0.20	0.20	0.20	0.20	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B21: Level 3 Expert Input – Team Access to Resource

Level-3	Turnaround Time					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.29	0.29	0.29	0.29	0.29	
Internal Professional Service	0.27	0.27	0.27	0.27	0.27	
External Professional Service	0.22	0.22	0.22	0.22	0.22	
Remote Internal Professional Service	0.22	0.22	0.22	0.22	0.22	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B22: Level 3 Expert Input – Turnaround Time

Level-3	Communication					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.31	0.31	0.31	0.31	0.31	
Internal Professional Service	0.30	0.30	0.30	0.30	0.30	
External Professional Service	0.20	0.20	0.20	0.20	0.20	
Remote Internal Professional Service	0.19	0.19	0.19	0.19	0.19	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B23: Level 3 Expert Input - Communication

Level-3	Length of Agreement					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.42	0.42	0.42	0.42	0.42	
Internal Professional Service	0.18	0.18	0.18	0.18	0.18	
External Professional Service	0.20	0.20	0.20	0.20	0.20	
Remote Internal Professional Service	0.20	0.20	0.20	0.20	0.20	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B24: Level 3 Expert Input – Length of Agreement

Level-3	Turnover					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.36	0.36	0.36	0.36	0.36	
Internal Professional Service	0.07	0.07	0.07	0.07	0.07	
External Professional Service	0.36	0.36	0.36	0.36	0.36	
Remote Internal Professional Service	0.21	0.21	0.21	0.21	0.21	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B25: Level 3 Expert Input - Turnover

Level-3	Desire to use in the future					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.31	0.31	0.31	0.31	0.31	
Internal Professional Service	0.25	0.25	0.25	0.25	0.25	
External Professional Service	0.22	0.22	0.22	0.22	0.22	
Remote Internal Professional Service	0.22	0.22	0.22	0.22	0.22	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B26: Level 3 Expert Input – Desire to Use in the Future

Level-4	Best Resource (Final Result)					Check
	Expert 1	Expert 2	Expert 3	Expert 4	Average	1.00
Direct Hire	0.30	0.31	0.32	0.30	0.31	
Internal Professional Service	0.17	0.19	0.19	0.18	0.18	
External Professional Service	0.27	0.27	0.26	0.27	0.27	
Remote Internal Professional Service	0.26	0.23	0.23	0.25	0.24	
Inconsistency	0.00	0.00	0.00	0.00	0.00	

Table B27: Level 4 Model Output – By Expert

Best Resource	Direct Hire	Internal Professional Service	External Professional Service	Remote Internal Professional Service	Inconsistency
Expert 1	0.3	0.17	0.27	0.26	0
Expert 2	0.31	0.19	0.27	0.23	0
Expert 3	0.32	0.19	0.26	0.23	0
Expert 4	0.3	0.18	0.27	0.25	0
Mean	**0.31**	**0.18**	**0.27**	**0.24**	
Minimum	**0.3**	**0.17**	**0.26**	**0.23**	
Maximum	**0.32**	**0.19**	**0.27**	**0.26**	
Std. Deviation	**0.01**	**0.01**	**0**	**0.01**	
Disagreement					**0.009**

Table B28: Level 4 Model Output – HDM Tool