Selecting a Weighting Criteria for System Allocation

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Abstract

The decision on whether to use software or hardware, or even a mixture of the two to implement a subsystem has perplexed many system engineers. One might venture to say that this should be taken out of the realm of system engineers and given to the design engineers, which brings us to the crux of the problem, on what came first the chicken or the egg, i.e., a good design irrespective of the problems of implementation, or an easily implemented design irrespective of the performance. If the hardware and software engineers were given the option we would have systems that are completely hardware or software respectively. This paper explores the weighting criteria for large-scale designs, specifically device and board-based systems.

1. Introduction

The decision process is not as simple as one might assume. The constraint of time and money is real, but the components that make up the criteria are not so. For example, to implement a very fast I/O from a custom card to write to a dual attached disk can be implemented by (a) Custom Hardware (b) Custom Software (c) Mixture of Custom Hardware and Software (d) Commercially Available Hardware, Software Components.

In all these options we have a very real concern, which is the subjective nature of the information that is available. For example, if we were to use option (a), could we really implement the system in custom hardware? If so, do we have the schedule and money to do so? Finally, do we have the expertise and knowledge to do so? The system engineer brings in the perspective of what is the most feasible solution given the constraints of time and money.

This paper suggests that the weighting criteria for large-scale designs, specifically device and board-based systems, can be selected. In addition to the omnipresent time and money constraints, the selection process is then tempered with expert opinion and success rate. The paper will show that this gives a more reliable selection process and presents a model that can be updated with new information.

2. Model Overview

To elucidate the model and its application to a traffic management system whereby the data is ingested and processed in near-real time to provide the optimal solutions for traffic management. The expert opinion in this development must have the experience in designing real-time systems, and the success rate must include the percentage of systems that have been successfully implemented. The basic traffic management system (TMS) has to be adaptive since unlike science-data based systems, human behavior is unpredictable. Thus even though the scenarios for most infractions have been studied and trends plotted, these patterns have to be constantly monitored and updated.

There are factors that influence a decision to select a certain option to implement the design. The process of quantifying these factors so that an educated decision can be made requires the consensus of engineers, scientists, managers, theorists, market researchers, and analysts. This paper is written from the engineer/analyst point of view, and proposes an equitable distribution of weights to incorporate the inputs of the experts in the other fields. Whereas it is not possible to poll the views of all the experts in the field, it is only necessary to poll the representative cross-section in the organization that has to implement the decision. This process does not preclude the reality of the decision-making, but provides a strong tool to aid the ultimate decision maker, in other words, the controller of the costs and schedule.

3. Model Description

The model will be based on an Analytical Hierarchical process (AHP) to evaluate the expert opinion and the design experience for this type of system development. The factors that are used to perform the pair wise comparisons are the objectives, which in this case are Success Rate (SR), Knowledge (K) and State of the Art (SOA) in the technology being considered.

The first step in the model development is to pair wise compare the objectives to arrive at a set of weights in the development process. The pair wise comparisons are based on the feedback from questionnaires and surveys sent to a representative cross-section in the organization. Since this is a model development process, the pair wise comparisons are based on a questionnaire that is framed as follows:

How much more important is the success of system implementation relative to the available knowledge?

Where the quantitative scale for measuring the relative importance may be qualified as follows:

1 = Equally Important
3 = Slightly More Important
5 = Strongly More Important
7 = Very Strongly More Important
9 = Absolutely More Important

Where 1 means it is equally important, 10 means it is ten times as important and 0.1 means that it is one tenth as important. Based on this these factors are qualified as follows:

Table 1. Pairwise Comparisons - Objectives

	SR	K	SOA
Success Rate	1	2	4
Knowledge	1/2	1	3
State of Art	1/4	1/3	1
Sum	1.75	3.33	8

Table 2. Normalized Comparisons - Objectives

	SR	K	SOA
Success Rate	0.571	0.600	0.500
Knowledge	0.286	0.300	0.375
State of Art	0.143	0.100	0.125
Sum	1.0000	1.0000	1.0000

Having calculated the relative priorities, the next step is to measure the consistency index or measure of inconsistency of the judgment. If the comparisons were ideally consistent, then the values for the weights in each row would have been the same. There are two methods of arriving at a more credible weighting system. The first is using Saaty's Eigen Vector method, the maximum value of the principal right Eigen Vector w, of the matrix,

$$A.w = \lambda_{max} w \qquad (1)$$

is calculated as follows:

$$w_i = \frac{\sum_{j}^{n} a_{ij} w_j}{\lambda_{\max}} \qquad (2)$$

for all i = 1,2,3,…….

Using the Eigen Value λ_{max}, the consistency index is defined as follows,

$$\text{Consistency Index C.I.} = \frac{\lambda_{\max} - n}{(n-1)} \qquad (3)$$

The second method of arriving at these weights is to simply average the normalized values per row as follows:

$$w_i = \frac{\sum_{j}^{n} a_{ij\,(normalized)}}{n}$$

In this case use w_{ave} instead of λ_{max} to calculate C.I.

$$\text{Consistency Index C.I.} = \frac{w_{ave} - n}{(n-1)} \qquad (4)$$

For each size n of a matrix, we can generate a random matrix with its own mean C.I. value, referred to as the Random Inconsistency Index R.I.[1]. In our case the size of matrix is 3 and the R.I. value from [1] is 0.58.

Table 3. Random Inconsistency Index (R.I.)

N	1	2	3	4	5
R.I.	0.00	0.00	0.58	0.90	1.12

The Consistency Ratio (CR) is thus defined as the ratio of the C.I of the matrix in question to the R.I value obtained.

$$\text{Consistency Ratio C.R.} = \text{C.I.}/\ \text{R.I.} \qquad (5)$$

Values of C.R.$\leq$ 0.1 are acceptable. If the values are higher than 0.1, then the judgments will need to be revised.

The next step in the analysis is to compare each of the alternatives with each other taking two at a time, with respect to each of the criterion. For example to ascertain which of the influencing factors, *Expert Opinion*, *Design Experience* or *Cost/Schedule*, are preferred to achieve the objectives with respect to the criterion *Success Rate*, and the relative preference of one alternative over the other is enumerated by calculating the ratio of the respective rating received for the alternative. Tables 5 through 8 contain the results of the pair-wise comparisons for *Success Rate* & *State Of Art.*

Table 4. Consistency Index & Ratio

Weight (w)	Product (A.w)	Ratios (w_{ave})
0.557	1.6881	3.0299
0.320	0.9667	3.0186
0.123	0.3687	3.0065
	CI	0.0092
	CI/RI	0.0158

The next step in the analysis is to compare each of the alternatives with each other taking two at a time, with respect to each of the criterion. For example to ascertain which of the influencing factors, *Expert Opinion*, *Design Experience* or *Cost/Schedule*, are preferred to achieve the objectives with respect to the criterion *Success Rate*, and the relative preference of one alternative over the other is enumerated by calculating the ratio of the respective rating received for the alternative. Tables 5 through 8 contain the results of the pair-wise comparisons for *Success Rate* & *State Of Art.*

Table 5. Pair-wise Comparisons – Success Rate

	EO	D E	C/S
Expert Opinion	0.286	0.273	0.333
Design Experience	0.571	0.545	0.500
Cost/Schedule	0.143	0.182	0.167

Table 6. Success Rate – C.I. & C.R.

Weight (w)	Product (A.w)	Ratios (w_{ave})
0.297	0.8943	3.0085
0.539	1.6248	3.0147
0.164	0.4921	3.0044
	CI	**0.0046**
	CI/RI	**0.0079**

Table 7. Pair-wise Comparisons – State Of Art

	EO	D E	C/S
Expert Opinion	0.545	0.500	0.571
Design Experience	0.182	0.167	0.143
Cost/Schedule	0.273	0.333	0.286

Table 8. State Of Art – C.I. & C.R.

Weight (w)	Product (A.w)	Ratios (w_{ave})
0.539	1.6248	3.0147
0.164	0.4921	3.0044
0.297	0.8943	3.0085
	CI	**0.0046**
	CI/RI	**0.0079**

In the case of Knowledge, the following equations describe the behavior and the corresponding preferences with respect to *Expert Opinion* & *Design Experience*.

Design Experience = f (Success, Years)

Expert Opinion = f (Expertise, Tech)

Where s, y, t and e are defined as follows:

s = Success = Success achieved within schedule
y = Years = Number of years in field
e = Expertise = Width of Knowledge
t = Tech = Age of Technology

In traffic management the technology has increased by approximately 10% per year. The expertise in using the technology has increased by approximately 60% per year. The success of the implementers on the other hand is proportional to the square root of the number of years in the field. The experience is influenced by the number of years in the same field by a factor of 20%.

Thus the equations may be stated as follows:

Design Experience $= \sqrt{s} + 0.2y$

Expert Opinion $= 0.6e + 0.1t$

However, it should be stressed that these parameters can be changed when more information is available, and hence can be used to formulate a Bayesian model for selecting Expert Opinion over Design Experience or vice versa. Using these equations, a Table of values for Design Experience and Expert Opinion can be generated. For Design Experience, Success *s* is measured as a function of years in the field, i.e. Success = 0.25 Years. Similarly, Technology *t* is measured as a function of Expertise, which in this case is directly proportional to the number of years in the field, i.e. Technology = 0.25 Expertise.

The Ratio of Expert Opinion to Design Experience gives the preference of the former to the latter. As the Knowledge level increases this ratio should vary, since the Expert Opinion gets stronger faster than the Design Experience of the developer. This is due to the fact that the tools and opportunities to implement the design and hence obtain the success rate are slower than the simulating the newer technologies and obtaining a more credible opinion. Thus as a first guess, assuming Knowledge to be directly proportional to the Number of Years and Expertise,

Knowledge = Years = Expertise

The ratio EO/DE denotes the degree of preference of Expert Opinion over Design Experience. If it is less than 1, then EO has less importance than DE; and if it is greater than 1, then EO has more importance than DE. This ratio can be calculated for a range of values for Knowledge. The EO/DE ratio is calculated for Knowledge set to 2 and 5 and shown as Row 1 Column 2, i.e. 0.261 in Table 10 and 0.414 in Table 12.

Table 9. Expert Opinion vs. Design Experience

EO	DE	EO/DE	Knowledge
0.64	1.20	0.53	1
1.28	1.81	0.71	2
1.92	2.33	0.82	3
2.56	2.80	0.91	4
3.2	3.24	0.99	5
3.84	3.65	1.05	6
4.48	4.05	1.11	7
5.12	4.43	1.16	8
5.76	4.80	1.20	9
6.4	5.16	1.24	10

Table 10. Pair-wise – Knowledge = 2

	EO	D E	C/S
Expert Opinion	0.324	0.261	0.429
Design Experience	0.460	0.370	0.286
Cost/Schedule	0.216	0.370	0.286

In Tables 11 and 13 it is shown that greater the body of knowledge, better the CI and CR Ratios and hence lower the inconsistency.

This knowledge base can be applied both in terms of the age of the technology and the breadth of the information available.

This is defined in terms of newer algorithms, better optimization tools, and greater funding avenues

Table 11. C.I. & C.R. for Knowledge = 2

Weight (w)	Product (A.w)	Ratios (w_{ave})
0.338	1.0358	3.0658
0.372	1.1410	3.0702
0.290	0.8874	3.0547
	CI	**0.0318**
	CI/RI	**0.0548**

Table 12. Pair-wise – Knowledge = 5

	EO	D E	C/S
Expert Opinion	0.439	0.414	0.517
Design Experience	0.444	0.419	0.345
Cost/Schedule	0.117	0.167	0.138

Table 13. C.I. & C.R. for Knowledge = 5

Weight (w)	Product (A.w)	Ratios (w_{ave})
0.457	1.3828	3.0275
0.402	1.2164	3.0223
0.141	0.4236	3.0082
	CI	**0.0097**
	CI/RI	**0.0167**

When the Combined Scores are evaluated the overall selection, moves from an indifference between Expert opinion towards a trend to selecting the Expert Opinion over the Design Experience.

Table 14. Combined Scores for Knowledge = 2

	Success Rate	Knowledge	State of Art	Combined Scores
Expert Opinion	0.330	0.338	0.539	0.358
Design Experience	0.392	0.372	0.164	0.357
Cost/Schedule	0.278	0.290	0.297	0.284
Sum	1.000	1.000	1.000	1.000

Table 15. Combined Scores for Knowledge = 5

	Success Rate	Knowledge	State of Art	Combined Scores
Expert Opinion	0.330	0.457	0.539	0.396
Design Experience	0.392	0.402	0.164	0.367
Cost/Schedule	0.278	0.141	0.297	0.236
Sum	1.000	1.000	1.000	1.000

4. Results

As a living system, human perception and judgment are subject to change when the information inputs or psychological states of the decision maker change. Thus it is conceivable that many of the judgments made by the team of decision makers will change. It is imperative to note that this will and should influence the outcome. For example, the traffic engineer could very well have formulated an algorithm based on a neural process whereby the behavior of a road user is strongly influenced by traffic congestion. Thus the same road user in a similar circumstance but in a different environment would react differently to the stimuli. Thus this type of learning has to be captured in an adaptive algorithm. It makes sense then to presume that the responses to the survey could also be changed in a marked manner. This model allows the infusion of changes whereby the equations governing the Expert Opinion and Design Experience change. These changes will then produce a different overall selection score and enable a solution based on the current state of knowledge rather than historical fact. A case in point being that the technology increase may be 20% rather than the predicted 10%, and the success may be 0.35 years as opposed to 0.25 years.

These differences would give rise to different tables and hence could rearrange the priorities for system weighting.

5. References

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