A HYBRID METHOD FOR THE MULTICRITERIA EVALUATION OF NETWORK TECHNOLOGIES

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ABSTRACT

In this paper, the selection problem of telecommunication technology is discussed, and a method to perform a comprehensive evaluation and selection of the best telecommunication technology in today's Internet environment is proposed. The proposed evaluation method is a practical and easy to use decision support tool which does not require the knowledge of a sophisticated mathematical model.

INTRODUCTION

The evaluation of emerging information technologies has proven to be a great challenge for managers and technical experts alike. The most knowledgeable "expert" on a new information technology often cannot predict the upcoming changes for more than a few months into the future. This problem is compounded when the technology in question deals with telecommunications. The major reason for this is that telecommunication technologies have advanced at a much faster pace than the methodologies used to analyze the cost/benefit evaluations associated with their investments. New technologies and unplanned changes in older ones are not embraced due to a lack of proper assessment procedures. "Many opportunities arise for organizations, but some are passed over because they appear too costly, too risky, or just too hard to pursue," (Kim and Wang, 1995). Possibly even worse is the scenario where a new telecommunication technology is touted as the "silver bullet," with large amounts of resources being clumsily invested without a comprehensive analysis of potential returns. The results of these types of erroneous decision procedure are often a collection of incompatible computers and software, along which other office technologies that should, but don't, "link together," (Znaty, 1993).

Presently, investment analyses of telecommunication technologies, as with other information technologies, typically hinge on cost savings and do not reflect any strategic returns such as increased sales through better customer service, or better quality products or services, or risks involved with security and obsolescence. The inclusion of such intangible socio-technical and risk factors may cause some technologies to be embraced that would otherwise have been neglected with traditional cash flow-based analyses. The tendency of overlooking these intangible factors, which is present in a large percentage of companies with respect to other information technologies as well, is the antithesis of a rigid structure that looks naively at cash flows as the only available option for deciding which technology should be embraced.

This paper proposes a comprehensive IT evaluation methodology combining a web of system performance (WOSP) together with a quantitative evaluation and selection methodology (QESM) for evaluating and selecting from among alternative Asynchronous Transfer Mode (ATM) technologies. ATM is an emerging telecommunication technology that has been hailed as the key to true integration of the Internet and networking with all facets of corporate operations. Currently, there is no published methodology or model, which includes both subjective and objective evaluation criteria, combined with socio-technical criteria under one unified approach, to deal directly with this important problem. Due to

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page number restriction, this paper gives an overview of WOSP followed by a summary of the steps involved in QESM procedure when evaluating such alternatives network technologies. The detailed presentation of the implied network technologies is omitted here due to the same limitation of space.

THE WEB OF SYSTEM PERFORMANCE (WOSP)

The WOSP model suggests a cross-disciplinary view of information network systems' performance based on general systems theory approach (Bertalanffy, 1968). WOSP's view of systems theory view of technology acceptance does not just apply to the technology evaluated but also to the user views of such systems. Indeed, while the evaluated application is normally "the system", the evaluator also constitutes a system a human system especially for information network systems. In this view, technology evaluation is one (human) system evaluating another (IT) system. Further, people always operate in a social context, so the organization is another system.

We view the technology application as a system; we also view the technology user as a system, and the surrounding organization is also a system. This suggests three variable categories in technology evaluation, acceptance and adoption (Hu, Chau, Sheng, & Tam, 1999):

1. *Technical system performance characteristics*: Is it useful, easy to use, secure, etc?
2. *End-User characteristics*: Age, gender, experience, attitude to computers, etc
3. *Social/Organizational characteristics*: Corporate values/goals, technology infrastructure, social structure/statuses, normative influences, etc.

The Web of System Performance (WOSP) model is not grounded in any specialty, but derives the goals of system performance from general systems principles. It defines "system performance" as the overall goal, then decomposes this into a multi-goal orientated approach to system requirements engineering, as suggested by Chung (Chung, Nixon, Yu, & Mylopoulos, 1999). A detailed justification has been presented elsewhere (Mahinda, 2007, Whitworth, et. al., 2007; Whitworth & Zaic, 2003).

The WOSP model takes system performance as *how well the system survives and prospers in its environment* (Whitworth & Zaic, 2003). By this definition, system performance is relative not absolute, as risk and opportunity can change, so performance that succeeds in one setting may fail in another. Hence, because IT networks are also human machine systems, they cannot escape from multi-goal orientated assessment. In line with this multi-goal assessment, WOSP model argues that any advanced system, including IT network systems must have four elements:

1. *A boundary*: To separate itself from its environment.
2. *An internal structure*: To support and coordinate its operations.
3. *Effectors*: To act upon its environment to gain benefit and avoid damage.
4. *Receptors*: To receive and analyze environment information to know when to act.

Each system element contributes to system performance, to maximize gains, minimize risks, or both. For example, the boundary controls system entry, and so can deny unwelcome outside entities (*security*), or make use of useful ones (*extendibility*). In IS, the latter requires either standards or open source disclosure. Equally a system's internal structure can reduce internal changes, to reduce faults (*reliability*), or enable change, to match environment shifts (*flexibility*). System effectors use system resources to act upon the environment, so can aim to maximize effects (*functionality*), or to minimize the rate of resource use – the relative "cost" of action (*usability)*. Finally, receptors analyze input to enable information or meaning exchanges, and so can aim to enable exchanges (*connectivity)* or to limit or control them (*privacy)*. The eight goal definitions are seen in Table 1.

Table 1. WOSP System Performance Goals

Dimension	Similar Terms (attributes)
Extendibility	Openness, interoperability, permeability, compatibility, scalability.
Security	Defense, protection, safety, threat resistance.
Flexibility	Adaptability, portability, customizability, plasticity, agility, modifiability.
Reliability	Stability, dependability, robustness, ruggedness, durability, availability, maintainability.
Functionality	Capability, effectualness, usefulness, effectiveness, power, utility.
Usability	Ease of use, simplicity, user friendliness, efficiency, accessibility.
Connectivity	Networkability, communicativeness, interactivity, sociability.
Privacy	Confidentiality, secrecy, camouflage, stealth, social rights, ownership.

Four system elements by two environment outcomes (gain and loss) gives eight performance goals, as shown in Figure 1, where:

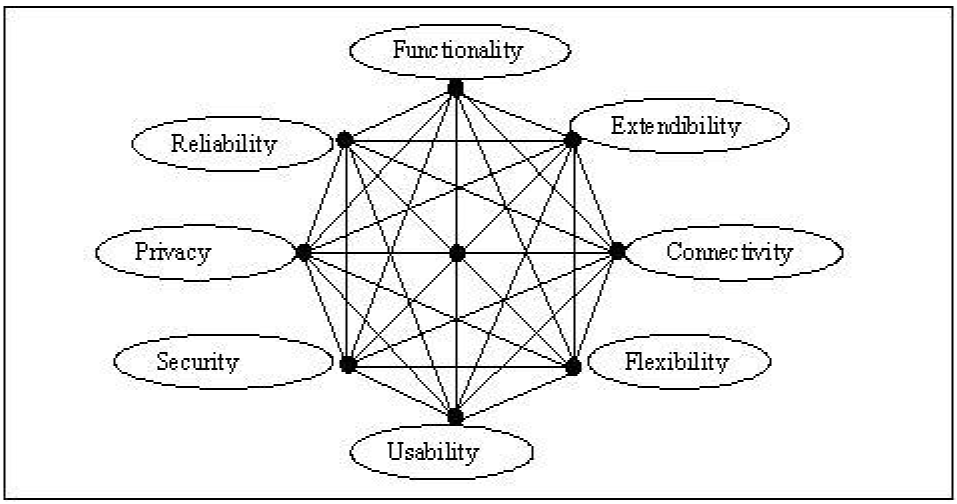

Figure 1. The Web of System Performance

• *Web area.* The web area represents *system performance* in general. The bigger the area, the greater the system's general performance potential.
• *Web shape.* The web shape represents the *performance sub-goal criteria weights*, which vary with the environment, e.g. a threat environment may favor the risk reducing goals of security, reliability, usability and privacy.
• *Web lines.* The lines represent *goal tensions*, and can be imagined as a set of rubber bands connecting the goals, so increasing one performance dimension can reduce another. For new systems the web begins "slack", but as performance (the web area) increases, so do the tensions.

The eight WOSP system performance goals are not new, as these and similar terms are widespread in the IS/IT literature, but their integration into a common theoretical framework is new.

The above analysis suggests three distinct aspects to reliability (say network technology):

- *Reliability by modular design:* System is designed to minimize coupling so if one part fails others still continue.
- *Reliability by redundancy:* System is designed to have independent means to the same end, so if one fails another can take over.
- *Reliability by recovery:* System is designed to deal with any failure by some recovery technique.

These aspects are distinct and not alternatives. A system advanced in all three would be maximally reliable in being modular so no failure cumulated, in redundancy so no failure was critical, and in recovery so no failure was permanent. Reliable systems should continue to operate under conditions of high stress, and if they are affected, should only suffer a gradual and graceful degradation in performance, rather than crashing instantaneously. Moreover, even after failing, it should be possible to repair them within a short duration.

Much of the system design in computer systems, including information systems networks, goes into the design of software protocols. Errors may come in at any stage of its production: requirements specification, design, implementation, testing and debugging, or in the maintenance (Borning 1987). It is however at the requirements specification level that the interaction of the system with the outside world is expressed. This implies anticipating all the circumstances for the use of the system. (Cortellessa, Singh et al. 2002) note that while early validation of functional requirements is supported by well-known approaches, that of non-functional requirements such as reliability is not.

NETWORKS EVALUATION METHODOLGY USING WOSP & QESM

In general, the decision factors relevant to top management confronted with economic evaluation of IT network technologies include the following tangible performance criteria: (1) cost, (2) capability, (3) "upgradability," (4) service quality, (5) vendor availability and maintenance support. As discussed in previous sections, WOSP prescribes other technical factors which may be considered equally important, however, they may be perceived as non-economic factors, and are most directly dealt with by those concerned with socio-technical assessment, which could either be evaluated using rubric and examples shown in Tables 2 and 3, or use the QESM procedure discussed in the next section. Here, we assume that all technical considerations have been resolved about the limited alternatives under consideration by technical telecommunication support staff for the decision maker (i.e., the manager). Thus, the manager is interested ranking the choices based on all the 13 factors discussed above.

Alternatively, all the above 13 decision criteria (i.e., factors) can be considered as a set of problems, P = $\{p_1, p_2, \text{-----}, p_{13}\}$ for management, all of which must be met by the telecommunication technology alternatives under consideration. Let us assume that management has to make a choice between three choices, for example an ATM, an FDDI, and an Ethernet technology. Thus, we can consider these to be the three network choices (i.e., solutions) that management is contemplating for the above problems. Each problem P_i can be considered to have a set of *n* attributes which form a vector A_i,, such that A_i = $\{a_{i1}, a_{i2}, a_{i3}, \text{-------}, a_{in}\}$, which must be met by the solution alternatives (i.e., alternative technologies under evaluation). Table 1 provides example of attributes for each criteria. The attributes can be listed

Table 2 Scoring WOSP performance criteria

Dimension	Detail	Value%
Functionality	To act effectively upon the environment.	
Usability	To operate efficiently or easily.	
Security	To resist or avoid outside attack or take-over.	
Extendibility	To use outside components or data.	
Reliability	To avoid or recover from internal failure.	
Flexibility	To change to fit outer circumstances.	
Connectivity	To communicate with other systems.	
Privacy	To control internal information release.	
Performance	To interact successfully with its environment.	**100%**

Table 3 WOSP Dimension Examples

Dimension	A Car	Network Hardware	Network Software	HCI/CHI
Functionality	Speed, ability to turn	Chip capacity, memory	Output change rate, frames/sec	Task ability (e.g. to change documents)
Usability	Miles per gal, comfort	Heat, power consumption,	"Lite" s/w, less cpu resources to run background	Intuitive s/w, need no manual/training
Security	Locks, keys, door codes	Sealed, secure, insulated	Firewall, virus checks	User ID/Password, bio-id
Extendibility	Tow-bar, roof rack	Standard plugs & connections,	S/w compatible with other s/w	User plug –ins, extensions
Reliability	Starts, maintenance	Uptime, easy to repair	Error recovery	Reduce operator errors
Flexibility	4 wheel drive	Switchable, e.g. 110-240 volts	Platform independence	Control panel, set language
Connectivity	GPS, crash sensors	Network card, comms outputs	Bandwidth, no of connections	Can exchange meaning (email)
Privacy	Detect radar tint windows	Shielded, tempest proof	Encrypt PINS in online buying	Anonymous web surfing

(i.e., arranged) in the order of importance starting with the most important. Furthermore, for each element of attribute A_i, a requirement set $R_i = \{ r_{i1} , r_{i2} , r_{i3} ,--------, r_{in}\}$, is defined in which an entry r_{ik} represents the amount required for the attribute a_{ik} in the attribute set A_i of problem $p_{i.}$ That is, the extend to which attribute a_i is satisfied by the solution choice. Thus, for the set of problem P, we can arrange the requirement sets in an R matrix of size n by l dimensions, where the i^{th} row represents the requirement set of the i^{th} problem, such that each row comprises a row vector R_i as seen in equation 1.

$$R_i = \begin{bmatrix} r_{11} & r_{12}\cdots & r_{\ln} \\ r_{21} & r_{22}\cdots & r_{2n} \\ \cdots & \cdots\cdots & \cdot\cdot \\ r_{l1} & r_{l2}\cdots & r_{\ln} \end{bmatrix} \qquad (1)$$

Management is required to provide the measures defining how much each alternative solution meets the attribute requirements of each problem p_i. Thus, management must provide a three dimensional quality attainment array Qi = [Q_{ijk}], where the indices i = 1, 2, ---, m, defines the set of problem under consideration by management (here m=13), j = 1, 2, ----, l, (here l =3 solution alternatives), and k = 1, 2, ---, n are for the n attribute elements in the attribute set as defined above. For instance, management could set q_{ijk} to a number less than 1.00 ($q_{ijk} < 100\%$) if requirement r_{ik} of attribute A_k of problem p_i is not met 100% by the technology solution j. Management could also set q_{ijk} to 1.50 (or to 1.00) if he/she estimates the particular requirement is met 150% (or 100%) by the technology solution j, etc.

Management must also provide a two dimensional matrix of weights, w_{ik} to evaluate the relative importance of attributes a_{ik}. For each problem p_i, the factors q_{ijk}, r_{ik} and w_{ik} can be used to obtain normalized weighted differences for each attribute as:

$$d_{ijk} = \frac{\left|q_{ijk} - r_{ik}\right|}{r_{ik}} w_{ik} \qquad (2)$$

For all requirements, the above expression can be simplified and rewritten to evaluate how each alternative solution S_j (here j = 1,2,3) performs in meeting the requirements of problem p_i (i = 1,..,6) overall as:

$$D_{ij} = \sum_{k=1}^{n} d_{ijk} \text{, which can be written as}$$

$$D_{ij} = \sum_{k=1}^{n} \left|\frac{q_{ijk} - r_{ik}}{r_{ik}}\right| w_{ik} = \sum_{k=1}^{n} \left|Y_{ijk} - 1\right| w_{ik} \text{,} \qquad (3)$$

where $$Y_{ijk} = \frac{q_{ijk}}{r_{ik}}. \qquad (4)$$

A figure of merit can be derived from the above to evaluate how the technology alternative S_j deal with the whole set of problems of interest to management. The expression of the figure of merit measure is of the form:

$$F_j = \sum_{i=1}^{m} D_{ij} = \sum_{i=1}^{m} \sum_{k=1}^{n} \left|Y_{ijk} - 1\right| w_{ik} \qquad (5)$$

The weight, w_{ijk}, associated with the attainment element q_{ijk}, represents the relative importance to satisfying the requirement r_{ik} of attribute A_i of problem p_i. Sylla and Bay (1992) discussed four possible weighting strategies for use in deriving a figure of merit. Several other possible models for selecting weights are available in the published literature (e.g., see Saaty, 1980, 1994). Once the data of the weights are obtained, management can evaluate a figure of merit using the above equation for each alternative technology. The alternative solution resulting in the smallest value of the figure of merit is the best candidate solution for management as it closely matches the requirements established for the system at the cheapest cost.

CONCLUSION

The paper presents a methodology for quantitative evaluation and selection of complex IT systems such as networks related technologies satisfying a number of problem requirements being considered by management. The problem of evaluating and deciding among network technologies is complex due to the difficulties inherently involved in providing data directly comparing one technology against another and to include WOSP socio-technical factors, generally omitted in current generally accepted IT evaluation methodology, such the two decades old TAM model (Davis, 1989; Venkatesh and Morris, 2003). Both WOSP and QESM avoid directly comparing alternatives against each other as done in many quantitative evaluation schemes, such as AHP and other multi-criteria models. Instead, they describe the evaluation factors in terms of problem requirements, and the degree to which the proposed alternatives meet those requirements. Management priority and preference are accounted for by measures of weights which can be reassessed once a final ranking based on a set of weights is computed by QESM.

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