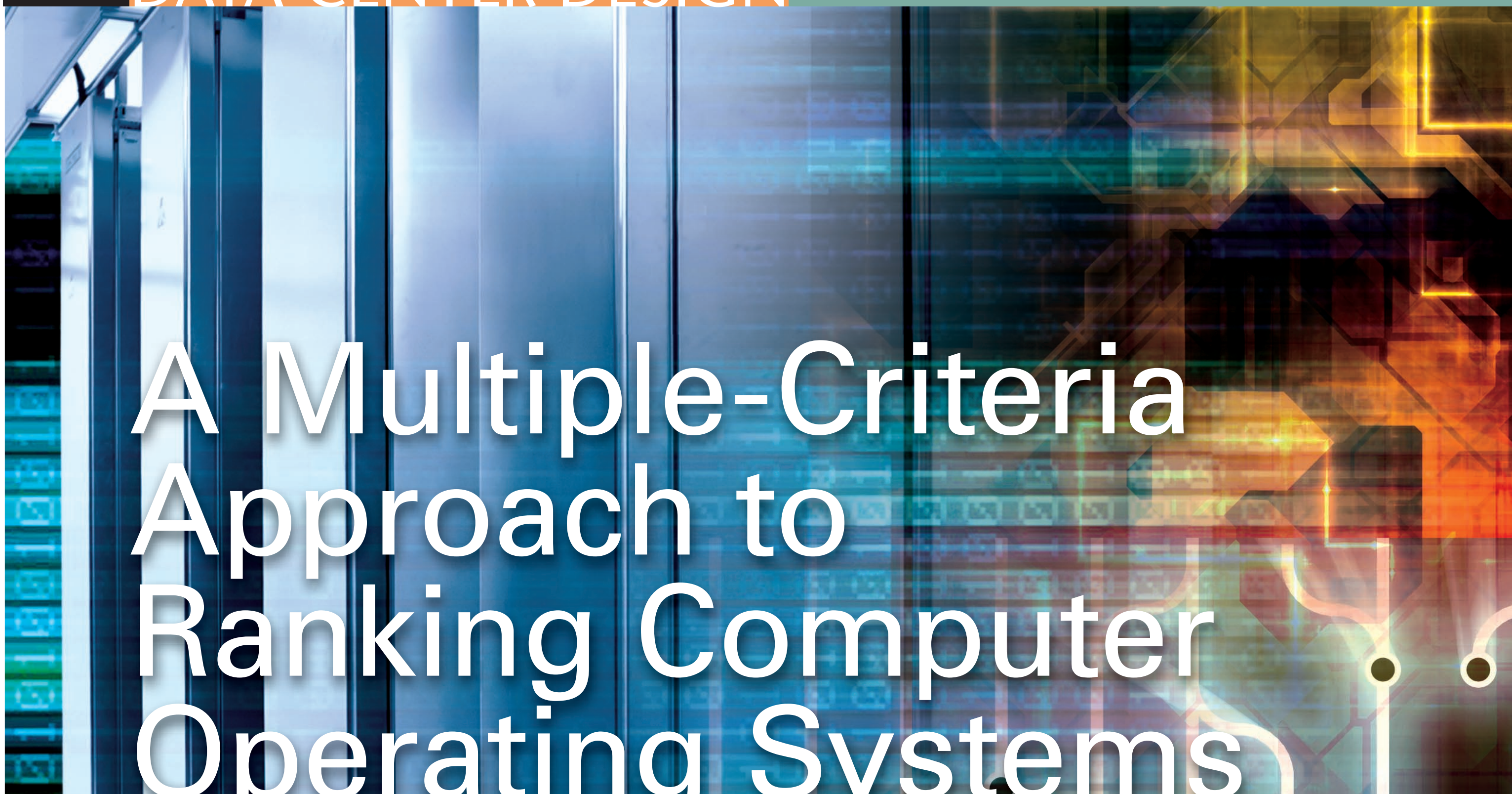

A Multiple-Criteria Approach to Ranking Computer Operating Systems

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To select an operating system, an organization must consider several essential characteristics during its initial evaluation process. The analytic hierarchy process (AHP) offers an appropriate solution; the author illustrates it with a realistic case study in which an organization evaluates and ranks Windows XP, Linux, and Mac OS X 10.4.

To evaluate a computer user's total satisfaction with his or her system, we must first evaluate the computer's operating system. Application programs affect user satisfaction, but overall application performance ultimately depends on the operating system on which it runs—for example, the main cause of any substantial reliability or security problem is usually related to the operating system, not a bug.[1]

Interest in operating system evaluation might be growing among computer users because of three new computing options:

- The release of Windows Vista, which Microsoft claims has much better security in addition to several new features such as built-in desktop search.
- The introduction of Dell's new open source *n* series, which provides customers with a desktop that doesn't have a Microsoft operating system already installed. Customers have the flexibility of installing an alternative, such as Linux, which drops the computer's total price.
- The introduction of an iMac computer powered by an Intel core duo processor. This addition significantly enhances the iMac's performance and makes it easier to use a wider variety of application programs than the earlier pre-Intel iMac version.

The criteria for evaluating operating systems vary according to computer usage. Such criteria typically include

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- security;
- stability or reliability;
- ability to use open source or proprietary software developed by other companies;
- user friendliness, particularly the ease of finding and using various features and of performing multiple tasks;
- compatibility with peripheral devices produced by a variety of companies;
- spectrum and usefulness of features; and
- expected cost over time for the computer system, application software, security software, and software updates. Some updates might require an upgrade of the operating system as well as of the hardware.

To evaluate and rank operating systems, we need a methodology that incorporates a mixture of both tangible and intangible criteria.

Some of the data for these criteria might be tangible because we can objectively determine them; other data, however, are highly subjective and thus intangible. To evaluate and rank operating systems, we need a methodology that incorporates a mixture of both tangible and intangible criteria.

Many organizations require the same operating system for all computers in the enterprise. In such cases, multiple decision-makers might want to be involved in the decision-making process, and each person might have a different judgment about subjective criteria. The analytic hierarchy process (AHP) that Thomas Saaty first developed in 1970 is a useful methodology for evaluating and ranking operating systems because it can incorporate input from multiple decision-makers as well as handle both tangible and intangible criteria.[2] Researchers have used the AHP to solve all sorts of problems having multiple criteria[3] because it's designed to handle those decision environments in which subjective judgments are part of the decision-making process. In this article, I briefly explain how to apply the AHP. To illustrate its efficacy, I use a case study of an organization ranking and evaluating three popular operating system environments: Windows XP, Linux, and Mac OS X 10.4.

A Brief Description of the AHP

The AHP has two stages: structuring the hierarchic design and evaluating and synthesizing pairwise judgments.

Hierarchic design is the identification of those factors important to a particular decision and the arrangement of those factors in "a hierarchic structure descending from an overall goal to criteria, sub-criteria and alternatives in successive levels."[2] The design provides an overall decision-making process and delineates the relationship among various factors involved in a decision-making problem.

The design of hierarchies requires that decision-makers be exceptionally clear and knowledgeable about a particular problem. Theoretically, different decision-makers could arrive at different designs because of each individual's unique experiences and knowledge. If a group is involved in decision-making, they can pool their knowledge and experience to find the most relevant and meaningful hierarchic design.

The second phase of the AHP is elicitation of pairwise judgments, with the assumption being that a judgment is most effective and meaningful if it compares one pair on a single criterion without concern for other criteria. With the AHP, the decision-maker translates the available information into paired comparisons by answering a basic question: Given a specific criterion and two alternatives, A and B, which one is preferred and to what level of intensity? The decision-maker makes this comparison using the following semantic scale:

- 1: equal importance (A and B are equally important),
- 3: weak importance over one another (A is slightly more important than B),
- 5: strong importance (A is strongly more important than B),
- 7: very strong importance,
- 9: absolute or extreme importance, and
- 2, 4, 6, 8: intermediate values between two adjacent judgments.

At each level of the hierarchy, the decision-maker establishes scores by constructing a matrix of pairwise comparison judgments about the relative importance or preference between any two elements. The matrix's a_{ij} value represents the relative importance of the ith elements over the jth element. The AHP allows for inconsistencies in pairwise judgments, too, so that, for example, $a_{ij} \times a_{jk}$ need not be equal to a_{ik}. The reflexivity condition is assumed—that is, $a_{ij} = 1$ for all $i = 1, 2, \ldots, n$. The decision-maker's choice regarding the strength of his or her preference must satisfy the reciprocal condition. If A is x times more preferred than B, then B is $1/x$ times more preferred than A.

Initially, the decision-maker develops the pairwise comparisons matrix for the elements in the first level in the hierarchy; then, he computes the principal eigenvector, which, when normalized, becomes the vector of priorities (say, vector α); next, the decision-maker develops pairwise matrices for the second level with respect to each element in the first, resulting in a priority matrix (say, β). Finally, he develops pairwise matrices for the third level with respect to each element in the second level, resulting in the priority matrix γ. This process is continued for the subsequent levels; the overall score for each alternative is arrived at by multiplying the matrices, that is, $\alpha \times \beta \times \gamma$.

A Case Study

In light of Linux's increased popularity[4] and Microsoft's release of Vista, the CIO of a Midwestern organization decided to investigate which of the major operating systems was the most suitable for his company's needs, so he contacted colleagues at other companies to get their opinions. Although some indicated an intention to immediately upgrade from XP to Vista, others were concerned that the upgrade would require such a significant investment in both hardware and software that it didn't currently justify the purchase, despite potential advancements in security and reliability. The Vista operating system needs at least 15 Gbytes of disk space for installation, which eliminates the possibility of upgrading for most notebooks and many desktop computers. Consequently, many users will have to purchase new hardware to use it. Moreover, the kernel patch protection (KPP) that Microsoft added to the Vista kernel is likely to affect compatibility with some third-party software systems, and it might be quite some time before third-party software vendors can bridge that gap. Until then, users who have upgraded to Vista will have no technical support. Based on this information, the CIO decided that Windows XP was still an appropriate option for his organization. Mac OS X 10.5 (Leopard) wasn't yet available, so he needed to evaluate three operating systems: Windows XP, Linux, and Mac OS X 10.4 (Tiger).

When employees affected by a change in organizational operations are involved in the decision-making process, the success of implementing the change potentially increases. A large body of literature verifies this hypothesis.[5–7] The CIO was aware of the importance of involving the company's computer users in major decisions affecting the work environment, so he initiated the following steps:

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1. Consultants conducted tutorial sessions on how to use Linux and Mac OS X 10.4.
2. Two computers running Linux and two others running the OS X 10.4 operating system were made available for three weeks to company employees so that they could experiment with the unfamiliar systems. Consultants were available to answer individual questions throughout.
3. An internal Web bulletin board gave users the opportunity to discuss their experiences while experimenting with the two new systems.
4. Individuals who asked for additional training received personalized tutorial sessions with consultants (approximately 15 percent of the company's computer users asked and received individual tutorials).
5. The CIO surveyed users after the experimentation and tutorial sessions to get their thoughts on the potential effect that a change in operating system would have on their jobs.

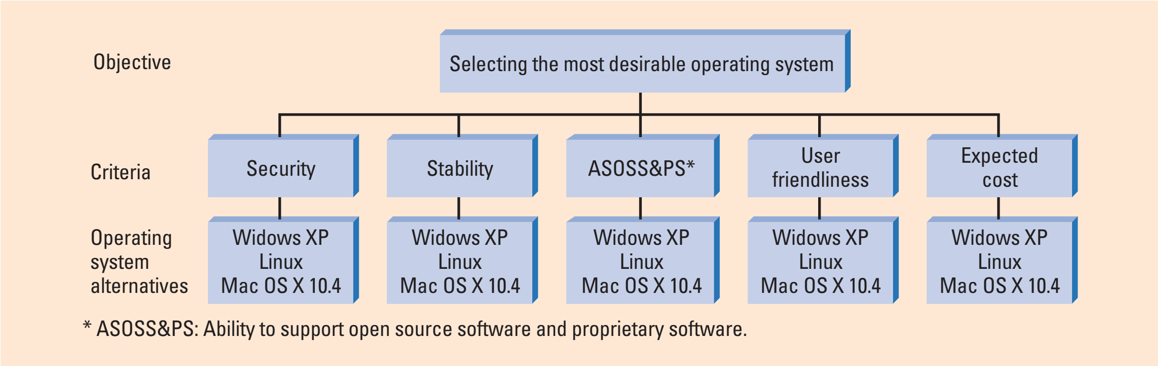

Figure 1. The hierarchy of the operating system selection problem. The first level shows that the overall objective is the selection of the most desirable operating system. The criteria at the second level contribute to the overall objective's achievement. Finally, each decision alternative at the third level uniquely affects each criterion.

Although 62 percent of the company's computer users indicated that a change to Linux would have no effect on their job-related computer functions, 38 percent indicated that such a change would have a minor negative effect. No users indicated the potential of a major negative effect on job function by switching to Linux. Survey results differed substantially with the Mac OS X 10.4. Only 39 percent of the company's computer users indicated that a change to the Mac system would make no difference to their job-related computer functions. To the contrary, 43 percent believed that such a change would create a minor positive effect, and 18 percent believed it would create a meaningful improvement.

As a next step, the CIO created a seven-member task force composed of organization executives and key members of the IT department. Their first task was to identify the pertinent criteria to be used in the operating system evaluation process. They selected

- security;
- stability;
- the ability to support open source and proprietary software (ASOSS&PS);
- user friendliness; and
- expected cost over time for both hardware and software, including security software and software updates.

The task force members were all familiar with Windows XP, but most had limited knowledge of or experience with the Linux and Mac OS X 10.4 operating systems, so they hired consultants to help with ranking and evaluating all three. Given the characteristics of the operating systems they had to rank, everyone settled on the AHP as the most appropriate methodology for the task. Figure 1 shows the hierarchy of the operating system selection problem graphically. To use the AHP, task force members had to compare all pairs of criteria and operating systems using a ratio scale.

The core seven-member task force (the organization's executives and IT professionals; task force I) compared all pairs of the criteria, and a five-member task force of hired consultants (task force II) focused on comparing all pairs of the three operating systems for each of the security, stability, and user friendliness criteria. These comparisons require in-depth knowledge and experience with all three operating systems that only the consultants had. The two task forces then combined into task force III to compare all pairs of the three operating systems for each of the remaining criteria. This joint effort required both groups because the ASOSS&PS and expected cost over time criteria require knowledge of all three operating systems, plus the organization's specific computing needs were also important to this comparison process.

Because each task force member came with a different knowledge and understanding of the operating system ranking problem, input was expected to vary widely. To consolidate and integrate the various opinions of each task force member, they followed a group decision-making process that followed a set procedure.[8] The CIO conducted individual interviews with each task force's members and then analyzed, summarized, and shared this collected data as part of a feedback process. Members of each of the three task forces gained new perspectives as they learned

Table 1. Task force I's criteria pairwise comparison matrix.

	Security	Stability	ASOSS&PS*	User friendliness	Cost
Security	1.000	2.900	4.300	6.800	5.400
Stability	0.345	1.000	5.200	4.900	6.100
ASOSS&PS	0.233	0.192	1.000	0.345	0.526
User friendliness	0.147	0.204	2.900	1.000	2.100
Cost	0.185	0.164	1.900	0.476	1.000
Total	**1.910**	**4.460**	**15.300**	**13.521**	**15.126**

**ASOSS&PS stands for ability to support open source and proprietary software*

Table 2. Summary of criteria priorities as determined by the analytic hierarchy process (AHP).

	Security	Stability	ASOSS&PS*	User friendliness	Cost	Priority
Security	0.524	0.650	0.281	0.503	0.357	0.463
Stability	0.181	0.224	0.340	0.362	0.403	0.302
ASOSS&PS	0.122	0.043	0.065	0.026	0.035	0.058
User friendliness	0.077	0.046	0.190	0.074	0.139	0.105
Cost	0.097	0.037	0.124	0.035	0.067	0.070

**ASOSS&PS stands for ability to support open source and proprietary software*

the rationale of their colleagues regarding each aspect of the operating system evaluation assignment. Opinions changed and were polled until it became clear that each task force member felt confident with his or her assessment of the assigned criteria or the operating system evaluation assignment. After two rounds—once no further consolidation of opinions was possible—the CIO used averages to represent each group's opinion regarding their assigned criteria or the operating systems' pair comparisons. Table 1 shows task force I's pairwise comparison matrix.

The pairwise comparison between security and user friendliness given in Table 1, for example, was 6.800, which was obtained by implementing the group decision-making process using the semantic scale described earlier. Table 2 shows the criteria priorities as calculated by following the standard AHP. The consistency ratio for the five criteria resulted in an acceptable value of 0.0904. Table 3 shows task forces II and III's pairwise comparison matrices of the operating systems, based on each of the five criteria, and Table 4 summarizes the operating system priorities for each criterion.

For each criterion, the CIO calculates the overall rank of each operating system by multiplying a criterion priority by an operating system priority for each criterion and then adding the results for all the criteria. Table 5 gives the final operating system ranking.

In this particular case, the task forces found that the security criterion had the highest priority, followed by the stability criterion; the expected cost over time criterion had the lowest priority, and the user friendliness criterion had a higher priority than the ASOSS&PS criterion. The Mac OS X 10.4 had the highest priority for the security, stability, and user friendliness criteria, and Linux had the highest ranking for the ASOSS&PS and the expected cost over time criteria. Windows XP had a higher ranking than Mac OS X 10.4 for these two criteria and a higher ranking than Linux for the user friendliness criterion. Omitting the input obtained from the consultants (task force II) about the ASOSS&PS and the expected cost over time criteria produced no meaningful changes in the conclusions. Overall results indicate that the Mac OS X 10.4 had a ranking far higher than either Windows XP or Linux, but Linux had a clear advantage over Windows XP.

Despite these findings, the CIO initially decided to postpone changes until experience with using Microsoft Vista became widely obtainable, but with the release of Mac OS X 10.5 at a time when no new information was available to suggest a definitive preference for Vista over Windows XP in meeting his organization's needs, the CIO decided to purchase the current Mac OS X 10.5 (Leopard) operating system and the required hardware. The system would be purchased bit by bit over a period of 12 months to replace the

Table 3. Task force II and III's pairwise comparison matrices.

Security criterion (task force II)

	Windows XP	Linux	Mac OS X 10.4
Windows XP	1.000	0.161	0.141
Linux	6.200	1.000	0.435
Mac OS X 10.4	7.100	2.300	1.000
Total	**14.300**	**3.461**	**1.576**

Stability criterion (task force II)

	Windows XP	Linux	Mac OS X 10.4
Windows XP	1.000	0.208	0.222
Linux	4.800	1.000	0.526
Mac OS X 10.4	4.500	1.900	1.000
Total	**10.300**	**3.108**	**1.748**

Ability to support open source and proprietary software criterion (task force III)

	Windows XP	Linux	Mac OS X 10.4
Windows XP	1.000	0.233	4.900
Linux	4.300	1.000	6.200
Mac OS X 10.4	0.204	0.161	1.000
Total	**5.504**	**1.394**	**12.100**

User friendliness criterion (task force II)

	Windows XP	Linux	Mac OS X 10.4
Windows XP	1.000	1.700	0.169
Linux	0.588	1.000	0.164
Mac OS X 10.4	5.900	6.100	1.000
Total	**7.488**	**8.800**	**1.333**

Cost criterion (task force III)

	Windows XP	Linux	Mac OS X 10.4
Windows XP	1.000	0.128	3.700
Linux	7.800	1.000	8.400
Mac OS X 10.4	0.270	0.119	1.000
Total	**9.070**	**1.247**	**13.100**

existing operating system. He based his decision to take this course of action on the study recommendations, the input received from colleagues at various organizations, and the high level of excitement about the product exhibited by his company's computer users.

Because evaluation results depend heavily on the criteria used for ranking, other organizations with different computing requirements will come to different conclusions. The case study described here illustrates the practicality of applying the AHP to the selection of operating systems; ultimately, the operating system selected by using this process is likely to better serve an organization's overall computing needs.

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Table 4. Summary of operating system priorities for each criterion.

Security criterion

	Windows XP	Linux	Mac OS X 10.4	Priority
Windows XP	0.070	0.047	0.089	0.069
Linux	0.434	0.289	0.276	0.333
Mac OS X 10.4	0.497	0.665	0.635	0.599

Stability criterion

	Windows XP	Linux	Mac OS X 10.4	Priority
Windows XP	0.097	0.067	0.127	0.097
Linux	0.466	0.322	0.301	0.363
Mac OS X 10.4	0.437	0.611	0.572	0.540

Ability to support open source and proprietary software criterion

	Windows XP	Linux	Mac OS X 10.4	Priority
Windows XP	0.182	0.167	0.405	0.251
Linux	0.781	0.717	0.512	0.670
Mac OS X 10.4	0.037	0.115	0.083	0.078

User friendliness criterion

	Windows XP	Linux	Mac OS X 10.4	Priority
Windows XP	0.134	0.193	0.127	0.151
Linux	0.079	0.114	0.123	0.105
Mac OS X 10.4	0.788	0.693	0.750	0.744

Cost criterion

	Windows XP	Linux	Mac OS X 10.4	Priority
Windows XP	0.110	0.103	0.282	0.165
Linux	0.860	0.802	0.641	0.768
Mac OS X 10.4	0.030	0.095	0.076	0.067

Table 5. Final operating system ranking.

Operating system	Ranking
Windows XP	0.106
Linux	0.368
Mac OS X 10.4	0.529

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