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Technology acquisition and research prioritization

Acquisition de technologies et établissement des priorités en recherche

Technologieaquisition und Forschungspriorisierung

科学技術に関する研究優先順位

Michael P. Manahan

Senior Research Scientist, Batelle Columbus Division, 505 King Avenue, Columbus, Ohio, USA 43201–2693

Abstract: This paper reports on recent developments in the area of research prioritization. The analytical hierarchy process (AHP) has been advanced to solve the problem of research prioritization. These developments are discussed and a case study presented. Applications for this new approach in the area of strategic planning and implementation are also discussed.

Keywords: technology acquisition, research prioritization, strategic planning, decision theory, analyticalk hierarchy proces.

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Biographical notes: Dr Manahan earned his ScD from the Massachusetts Institute of Technology, his MS from Columbia University and his BA and BS from Michigan State University. A Senior Research Scientist at Battelle Columbus Division, he has for the last six years applied his experience in strategic R&D planning for energy technologies to the development of Battelle's SMART-PAKT process. He led the programme to apply this method to severe accident research prioritization for the Nuclear Regulatory Commission, developed advanced analytical hierarchy process techniques, and used the method to prioritize Battelle's internal research and development.

Résumé: L'article décrit les développements récents dans le domaine de l'établissement des priorités en recherche. Le Processus d'Analyse Hiérarchique (PAH) été proposé pour résoudre le problème de l'établissement des priorités en recherche. Ces développements sont examinés, et un cas concret est présenté. L'utilisation de cette nouvelle approche dans la définition et la mise en oeuvre de la stratégie d'une entreprise est également examinée.

Mots-clés: acquisition de technologies, établissement de priorités en recherche, stratégie d'entreprise, théorie de la décision, processus d'analyse hiérarchique.

Zusammenfassung: Dieser Beitrag berichtet über jüngste Entwicklungen auf dem Gebiet der Prioritätssetzung in der Forschung. Ein analytischer

Hierarchieprozeß (AHP) wurde zur Lösung der Problematik der Prioritätssetzung in der Forschung weiterentwickelt. Die damit zusammenhängenden Entwicklungen werden diskutiert und eine Fallstudie wird durchgefuhrt. Weiters werden die Anwendungen dieses neuen Lösungsweges auf den Gebieten der strategischen Planung und Implementierung diskutiert.

Sachwörter: Technologieaquirierung, Forschungspriorisierung strategische Planung, Entscheidungstheorie, analytischer Hierarchieprozeß.

要約　ここでは，研究の優先順位決定方法における最近の展開について報告している。分析階属法（ＡＨＰ）はこの問題を解決するために開発された。かかる新事情についての論議と，ケース・スタディが紹介されている。さらに戦略的計画立案と実施という領域へのこの新しい方法の適用について論じている。

キーワード　科学技術の開発，研究優先順位，戦略的計画立案，決定理論，分析階層法

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1 Introduction

Several advanced tools have been developed over the past two decades to assist management in making business decisions. Some apply a rigorous evaluation scheme and are based on robust mathematical models, while others rely more on intuition. In any case, the goal is one and the same: to choose from a set of options based on well-defined decision criteria.

One prioritization tool that has found fairly broad application is the analytic hierarchy process (AHP). Strongly based in decision theory, AHP was developed as a general-purpose aid for prioritizing any set of comparable items or options, subject to a well-defined set of criteria [1]. AHP is recognized as an important decision-making tool by government and industry. The Nuclear Regulatory Commission (NRC) used AHP to prioritize severe accident research [2], and the Department of Energy's Office of Science and Technology Policy (OSTP) applied AHP to select a nuclear waste concept and to choose the site for a foreign government's nuclear waste storage [3]. Managers have also used AHP to assist in salary administration. And in the broader industrial setting, AHP can be used in conjunction with desirability analysis to select the optimum material, component or system design [4]. For example, Battelle Columbus Division (BCD) assisted a tyre company with a new tread formulation design. Ranges of key material and tyre performance parameters such as road noise, hydroplaning, handling, rolling resistance, and wear were defined. AHP was used to weight these criteria, and desirability analysis was then performed. The result was the best combination of material constituents to achieve the desired performance objectives. This approach can save costly field characterization studies and the associated time loss.

The basic AHP has been upgraded, developed further, and used in conjunction with other tools at Battelle to address the problem of research prioritization. Battelle's integrated approach to technology acquisition and research prioritization is called 'Strategic Market Assessment and Research Technology Prioritization for Acquisition of Key Technologies', or SMART-PAKT. It represents an extremely effective tool for dealing with rapidly changing environments in research and development.

2 SMART-PAKT for research prioritization

The SMART-PAKT methodology can be used in strategic planning to identify and prioritize corporate operational criteria. Once those criteria are identified, accepted, and prioritized, business plans can be designed to meet the corporate goals and objectives. The SMART-PAKT approach can then be used to identify and prioritize research and key technology acquisitions. While the plan is being implemented, this dynamic method can be used to assess performance and adjust the plan subject to the results achieved.

2.1 Research prioritization techniques

To use the SMART-PAKT approach for research prioritization or corporate operational criteria weighting, a user organization typically follows four basic steps:

1 Construct a hierarchy
2 Determine between-level priorities (i.e. obtain pairwise ratings)
3 Calculate overall priorities
4 Perform sensitivity and uncertainty analyses.

The following discussion draws its examples from research project prioritization. A similar approach, however, can be used to prioritize any set of elements (e.g. technology acquisition alternatives) evaluated according to a defined set of criteria.

2.1.1 Construct a heirarchy

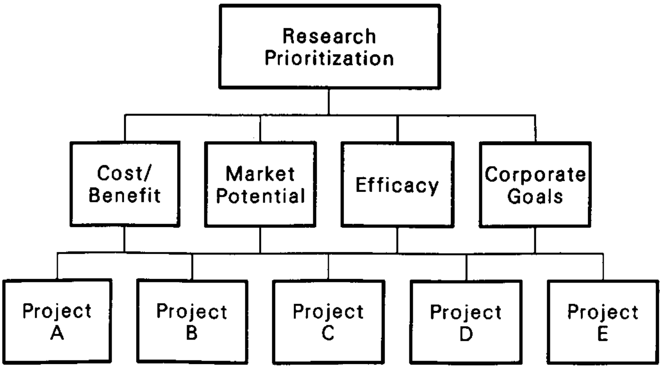
A hierarchy identifies and arranges criteria by which elements (e.g. research projects) will be rated. AHP is particularly useful in cases where the items to be prioritized are subject to two or three criteria. In the AHP, only pairwise ratings are made. This makes the process relatively straightforward and especially effective, because most decision makers find it easier to focus on pairs or small groups of items than to apply all the information and criteria at once.

The criteria are arranged in hierarchical levels, with the most general criterion or objective at the top level. The next level reflects a partitioning of the main objective into less general or subordinate criteria. These criteria in turn are subdivided into more specific criteria at the next lower level, continuing until the criteria reach the desired degree of specificity. The hierarchy, often drawn as a chart, readily demonstrates divisions and subdivisions (Figure 1).

The hierarchical structure of AHP guides the decision-making process. Each level of the hierarchy contains like elements. The overall goal of the effort, in the case of research prioritization, is the ranking of research projects — the top level of the structure. Note that elements in each level of the hierarchy are comparable and are prioritized subject to the upper-level criteria.

Such a multilevel structure takes into account the different areas of expertise that are included in the decision-making process. Decision makers at all levels — from corporate executives to engineers — can provide information to assist in defining the elements of the hierarchy and contribute to the pairwise rating process.

Figure 1 Schematic representation of hierarchical structure for research prioritization



Defining the criteria often involves a group dynamic effort [5,6]. High-level corporate officials may, through the process of criteria selection, be able to agree on goals, but they may not necessarily agree on the path to achieving them. With SMART-PAKT, the lower levels of the hierarchy, and consequently the route to the goals, become clarified by the personnel who provide the pairwise ratings for the levels of their own expertise or specific technical knowledge. The SMART-PAKT analyst can then design and run a personal computer program to calculate the priorities.

In the case illustrated in Figure 1, upper management might help define and provide pairwise ratings for the upper decision criteria based on the relationahip between the criteria and corporate strategic planning. Senior technical staff, in turn, might rate the lower level research projects on a technical basis. As a result of SMART-PAKT, everyone involved with or affected by the decision can readily understand the process. This aspect of the methodology can make it easier for managers to inform staff members of an internal R&D proposal's rejection. When people know the reasons behind the rejection of an idea, creativity is not stifled.

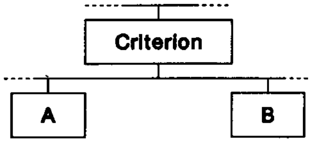
2.1.2 Determine priorities

After the hierarchy is constructed, it provides the framework necessary to prioritize the elements identified at the lowest level. Priority is reflected in a numberical value that is between 0.0 and 1.0. The value, which indicates the relative importance of each individual project (or research need), is one measure of the resources that should be expended to develop or acquire various technologies. The sum of all priorities for all projects must be 1.0.

The priorities are evaluated in a stepwise fashion. First, the between-level priorities are determined for each level of the hierarchy. They represent the priorities of the elements in one level with regard to elements in the next higher level. Pairwise ratings specified by the user define the between-level priorities for every level of the hierarchy. Then between-level priorities are systematically combined to provide the overall priorities.

Ratings may be based on quantitative information — e.g. 'research project A costs $100 000 and research project B costs $50 000' — or on subjective judgements. The type and degree of comparative effects are typically expressed using a five-point rating scale, as defined in Table 1. In this numerical rating system, the number itself indicates the comparative level of importance of two elements in the hierarchy. One of AHP's major strengths

Table 1 The five-point scale typically used for pairwise ratings



Alternative descriptions	*Rating*[1]
A and B 'are equally important'	+1 (−)
A 'is weakly more important than' B	+3 (−)
A 'is strongly more important than' B	+5 (−)
A 'is demonstrably or very strongly more important that' B	+7 (−)
A 'is absolutely more important than' B	+9 (−)

[1] A negative sign is used to indicate the inverse rating.

is evident here. Application of the hierarchy makes it possible to compare several items two at a time, always subject to one criterion. Thus, the problem of setting priorities among a large number of elements subject to multiple criteria becomes tractable.

Saaty [1] has shown that the between-level priorities are the eigenvector of the pairwise comparison matrix having the maximum eigenvalue. This eignevector approach entails systematic combinations of all the different between-level priorities implied by the pairwise comparisons to obtain the overall priorities of the research projects. The resulting priorities are robust. Further, as part of the eigenvector evaluation, an index is computed to indicate the degree of inconsistency in the pairwise ratings. If a high degree of inconsistency is indicated, then it is desirable to reassess the pairwaise ratings.

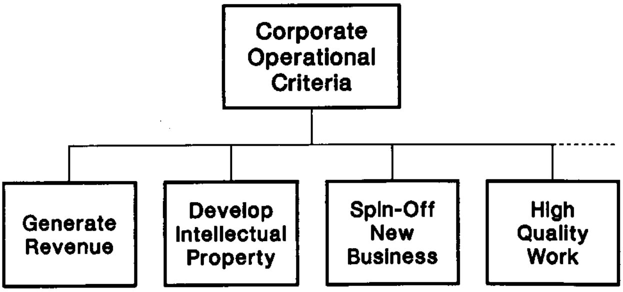
2.1.3 Perform sensitivity and uncertainty analyses

Once the overall priorities are established, senstivity and uncertainty analyses, among other analyses, can be performed. For example, a criterion such as 'cost' could be deleted and the priorities recalculated. The analysis would yield the priorities that would exist were unlimited funds available. This feature enables management to study the decision process from different viewpoints.

Another useful feature is the ability to update existing analyses. Let's say, for instance, that the initial analysis had identified project A as more important than project B. As a result, project A got more funding. That first analysis, however, might have contained a great deal of subjective input. Six months later, a second analysis could be run using actual project expenditures and technical results. With much more objective information available, the latter analysis might indicate that although project A was a good idea, it is not producing useful results. An AHP analysis could be run again and resources could then be reallocated accordingly.

Relationships among levels need not be reformulated each time an analysis is updated. But, as in any formal decision-making process, AHP is very sensitive to criteria omissions and hierarchical structure. The SMART-PAKT approach must be used with caution until the decision maker gains experience.

Figure 2 Partial hierarchy for prioritization of corporate operational criteria



2.2 *Strategic planning*

The methodology described above can also be used in strategic planning. Many corporations have well-defined corporate operational criteria. However, high-level managers often do not agree on the weights that sould be assigned to each criterion. An example of a partial hierarchy is shown in Figure 2. The SMART-PAKT approach requires that management agree on the criteria as well as the weights. An iterative procedure can be used to arrive at the final set of weights for the operational criteria. Once these are established, middle management can use this information on a day-to-day basis as a guide in decision-making.

The next step would be to extend the corporate operational criteria down to further levels so that corporate internal research and development (IR&D) investments can be prioritized. Another hierarchy can be established to prioritize new business investment or marketing activities. This method provides a very effective means by which senior management can 'reach down' into the organization and control resource expenditure. Since the method is transparent, the rationale for decisions can be easily understood by all affected staff.

3 Internal research and development planning application — case study

The hierarchy shown in Figure 3 was developed by Battelle's Office of Corporate Technical Development (CTD) to prioritize research in advanced materials for 1988. The criteria were identified and agreed during several group dynamic sessions [5,6] with senior management. A decision was made to use the CTD managers' ratings alone to determine the priorities. However, techniques are available for forcing consensus at certain levels (e.g. decision criteria) when it makes sense to do so. Also, priorities can be combined, subject to prescribed weighting factors.

Another technique available when using SMART-PAKT is to partition the research projects into three categories, as shown in Figure 4: existing technologies, key technologies (those which will replace existing technologies within the next few years), and emerging technologies (those which may become key technologies). Partitioning the proposed research projects into these categories has several advantages. In cases where there are many projects to prioritize, the rating process is simplified. Also, by prioritizing within each category, company resources can be allocated by technology classification (e.g. 10% to existing, 80% to key, 10% to emerging technologies).

Figure 3 Hierarchy used to prioritize internal R&D projects

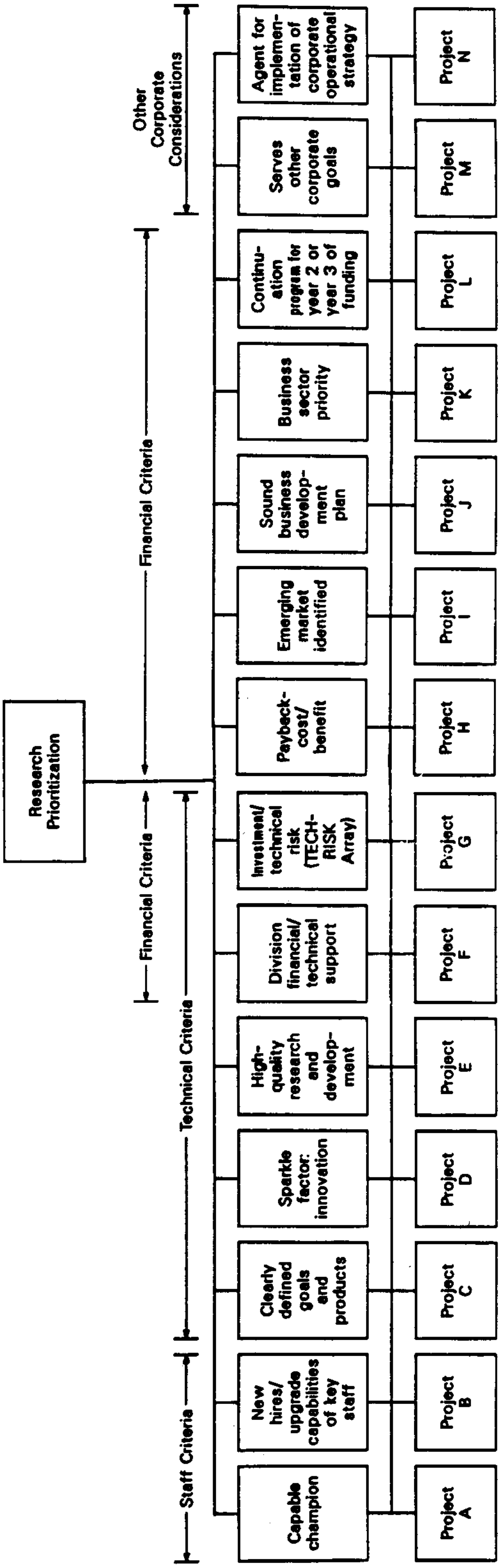
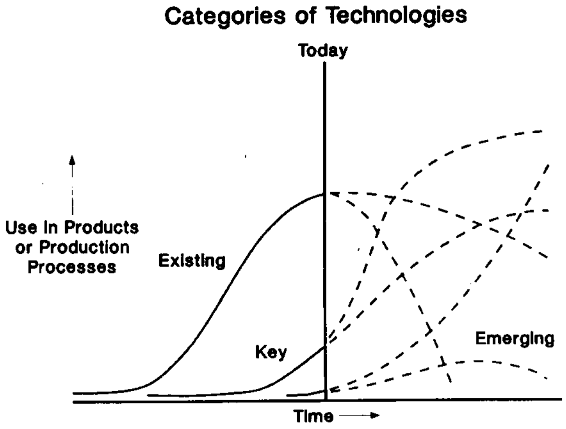
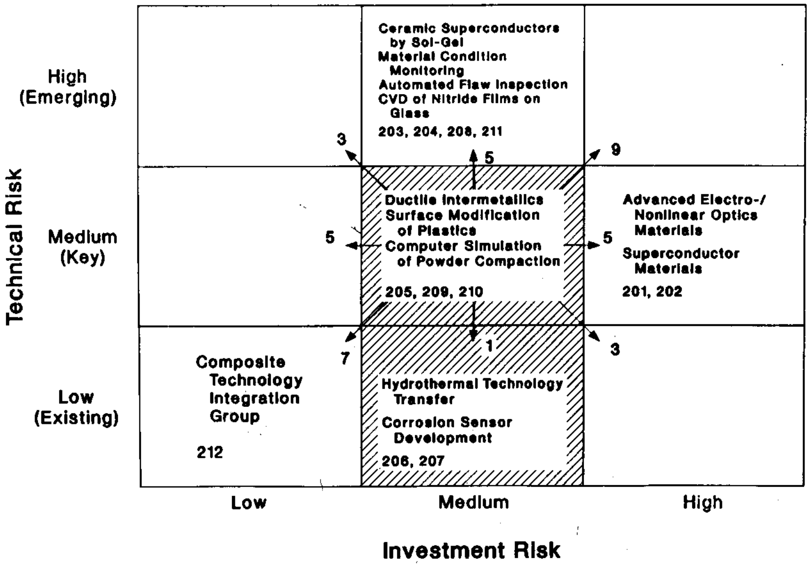


Figure 4 Schematic representation of the relationships among existing, key, and emerging technologies



Most of the criteria shown in Figure 3 are well-known. The criterion labelled 'investment/technical risk', however, needs further explanation, since it is a two-dimensional criterion. The rating process is facilitated by the use of the TECH-RISK array [7]. A typical array is shown in Figure 5. The research projects are plotted on the TECH-RISK array according to technical risk profile and cost; then the most desirable risk space (the hatched region in Figure 5) is identified. CTD prefers to fund projects that are in the medium investment risk range and that are medium to low in technical risk. The vectors indicate the pairwise ratings for the desired space compared to the other zones.

Figure 5 Specific technique to assess technological risk profile — TECH-RISK array



The advantage of performing a SMART-PAKT analysis becomes clear when results are compared to those from the numerical assessment scheme that had been used at Battelle in the past. The criteria used for the numerical assessment are listed in Table 2; each project could score 0, 1, 2 or 3 for each criterion. The total points were then summed. As with most techniques such as this, the results rarely show any statistically significant differences. In contrast, the SMART-PAKT data do show statistically significant differences (Table 3 and Figure 6). Consequently, the resources were allocated to the highest-priority

Table 2 CTD numerical assessment criteria

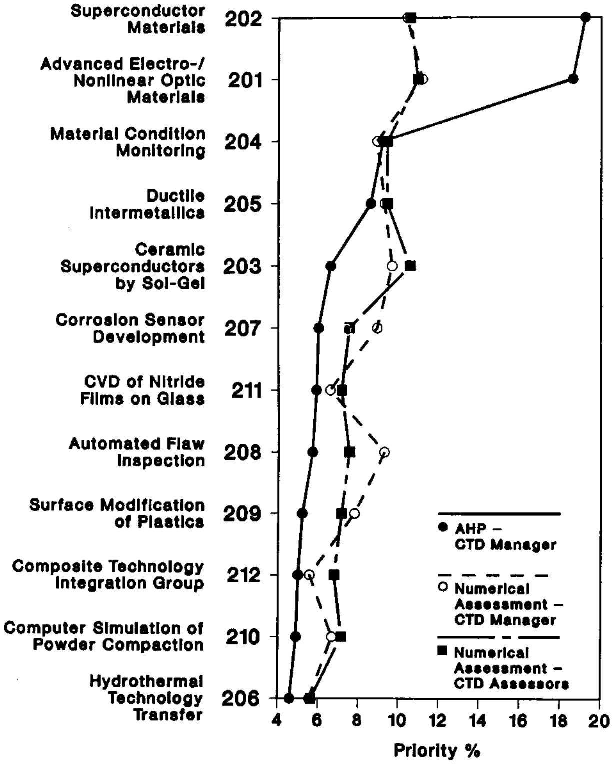
- Payback
- Champion
- Well defined product
- Intellectual property development
- New hires
- Improve current staff
- Business plan
- Competitiveness/innovation
- Sparkle factor
- Sector priority
- Continuation programme

Table 3 Results of CTD materials technology prioritization

Proposal		*AHP priority (%) CTD Manager*	*Numerical assessment (%) CTD Manager*	*Numerical assessment (%) CTD Assessors*	*Funded*
202	Supercondutor materials	19.2	10.4	10.6	Yes
201	Advanced electro/nonlinear optics materials	18.6	11.2	10.9	Yes
204	Material condition monitoring	9.2	8.9	9.4	Yes
205	Ductile intermetallics	8.6	9.3	9.4	Yes
203	Ceramic superconductors by sol-gel	6.7	9.7	10.6[1]	No
207	Corrosion sensor development	6.0	8.9	7.5	No
211	CVD of nitride films on glass	5.9	6.7	7.2	No
208	Automated flaw inspection	5.7	9.3	7.6	No
209	Surface modification of plastics	5.3	7.8	7.2	No
212	Composite technology integration group	5.0	5.6	6.8	No
210	Computer simulation of of powder compaction	4.9	6.7	7.2	No
206	Hydrothermal technology transfer	4.7	5.6	5.7	No

1 Not funded due to early advance in 202.

Figure 6 Results of CTD materials technology prioritization showing statistically significant data obtained using SMART-PAKT



projects until all the money was committed. As a result of early breakthroughs in the superconductor materials projects (No. 202), for example, Battelle's superconductor sol-gel project (No. 203) was not funded.

4 A practical look ahead

Several current and very well received applications of the SMART-PAKT approach illustrate its flexibility. In one project addressing severe accidents in commercial nuclear power plants, application of SMART-PAKT generated several five-level hierarchies, each one developed to address a specific concern. One hierarchy dealt with the research projects' relevance to needs in probabilistic risk assessment (i.e. reducing risk and uncertainty); another dealt with the projects' technical contributions to reducing uncertainty in severe accident sequences. The approach was also adapted to help a foreign government select a site for its nuclear waste repository.

In addition, SMART-PAKT can be used to optimize a manufacturer's new product design. The SMART-PAKT approach is combined with desirability analysis, which structures the requirements for the product in terms of desirable ranges and values for technical specifications. The software then arranges the specifications by priorities and indicates the best combination.

For situations where decisions must be made to rank any set of issues, items, or subjects, the SMART-PAKT method is ideal, especially when the task requires sensitivity analyses. An important incentive for using SMART-PAKT is the ease with which it allows senior management to participate in setting priorities from the beginning.

In the future, the value of SMART-PAKT will increase as governments and industries seek efficient means to deal with rapidly changing environments while at the same time restructuring their priorities accordingly. These needs suggest an expanding role for decision-making tools with the broad applicability of SMART-PAKT.

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