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A Report

DEVELOPMENT OF A RESEARCH PROJECT SELECTION MODEL: APPLICATION TO A CIVIL HELICOPTER RESEARCH PROGRAM

Final Report

NASA Grant No. NSG 1274

Submitted to:

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Submitted by:

Michael B. Schoultz
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Report No. UVA/528051/ESS77/102

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ABSTRACT

A model is developed for research project selection planning and decision making. The model combines evaluations of each project's direct and indirect benefits, uncertainty in achieving these benefits, and schedule priority with resource budget and program balance constraints. The combination of the interactive effect of project selection, resource allocation and scheduling considerations into one model permits tradeoff alternatives to be studied. An additional asset of the model is its use of clients' value judgments in evaluating the benefits from each proposed project. The model is applied to the NASA Civil Helicopter Technology Program. Research project priorities for this program are established, strengths and weaknesses of the model are discussed, and areas of future development are recommended.

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CHAPTER I

INTRODUCTION

The purpose of this research is to develop a model for research project selection planning and decision making and to apply it to NASA's Civil Helicopter Technology Program. The actions prescribed by a plan can be chosen from among several possible alternatives, any one of which could be selected. In the field of research and development, each alternative "plan of action" must include the related problems of project selection, resource allocation, and schedule priority. In situations where research programs are narrow in scope, planning decisions involving these problems are typically made implicitly. In such situations, the decision maker identifies the criteria relevant to each decision, evaluates each alternative relative to the criteria, and integrates the information to achieve the overall evaluation. This evaluation results in an outline of the project tasks, an allocation of resources and a schedule to "best" achieve the program objectives.

Problems of larger scope result in a more complex planning environment. One such problem is the need to encompass a wide range of technologies to achieve program goals. In this case, it is unlikely that any one individual would have the necessary expertise in every required area of technology. A second problem is the need to consider the value structure of many research clients. In the past, there has been a noted absence of effort to identify the requirements of the technology users. Even less effort has been devoted to identifying the effect of the technology on the non-user. The past conflicts between society and its technology emphasizes the lack of this type of information and its potential value. The importance of the requirements of both users and non-users dictates that their views be identified and weighed in planning future technology. A final problem creating a more complex planning environment is that there are simply too many considerations to be integrated with an implicit model.

In situations where any of these conditions occur, there are several reasons why management should rely on a more explicit project selection planning model. First, by defining the decision process and criteria before evaluations begin, the decision maker can help to insure that the projects are consistently evaluated. Second, an intuitive process cannot deal effectively with the wealth of information involved in the decision. Third, the model provides a logical mechanism to explain the reasons project selection decisions were made as they were. Finally, by placing emphasis on the decision process, the model makes management more aware of the information that should be acquired when making project selection decisions.

There have been numerous project selection planning models developed in the past twenty years. Recent bibliographies (1,2,3) list many different models which treat this problem, ranging from subjective scoring models to highly analytical programming models. The proposed model is different in two basic ways. First, the model provides a value structure framework for using the subjective judgments of both users and non-users of the required technologies as inputs to the planning process. An understanding of the requirements of these groups is essential in order to identify, as well as to establish the relative worth of, research objectives. A model whose objective is to establish research project priorities must therefore incorporate inputs from these groups. Second, the model incorporates resource allocation and project scheduling information into the project selection decision process so that the tradeoffs between resource allocation, scheduling and project selection decisions may be considered. The majority of past planning models have dealt with these decision processes independently, giving little consideration to the interacting effects of each decision on the other. As Shaller (4) states:

> "Formulation of an analytical description or a tractable model of the entire problem of research planning so that one could proceed in a systematic manner...is not yet in sight. Herein lies the challenge."

The proposed model is a first step in achieving this objective.

To incorporate the realities of a complex planning environment, emphasis has been placed on maintaining close coordination with management of a "real life" research program (the NASA Civil Helicopter Technology Program), to which this model will be applied. This program meets all the conditions that require a documented project selection planning model, previously discussed. The proposed model must therefore incorporate the features essential for real world applicability.

This study is subdivided into five chapters. Chapter I has defined the problem that will be addressed. In Chapter II, characteristics of the research and development planning environment are discussed, several previously developed project selection planning models are reviewed and their strengths and weaknesses identified, and desirable attributes of a project selection model are recommended. Chapter III is directed at the development of the model. The application of this model to a "real life" problem is the topic of Chapter IV and research project priorities are identified. In addition, emphasis is placed on evaluating the effectiveness of the model as a planning aid. Finally, in Chapter V, a summary of the research findings, conclusions, and recommendations for further research are presented.

CHAPTER II

DESIRABLE ATTRIBUTES OF A SELECTION MODEL

The preceding chapter demonstrated the need for a research and development project selection planning model. This chapter is concerned with identification of desirable attributes of a planning model. Considerations of user needs dictates several apparent attributes. First, the model must be easy to implement and simple to use. It is apparent that to obtain the maximum utilization of such a decision making procedure, formal or informal, one should place emphasis on its being understood and accepted by the user. Second, the model should be capable of combining subjective and objective information. That is, it should insure a consistent means to convert information obtained by subjective judgment into a form suitable for use by quantitative analysis. Third, the method should force explicit consideration of all the elements which constitute the decision problem and therefore incorporate many sub-strategies. These sub-strategies should include both the direct and indirect contributions of projects to the achievement of program goals, the uncertainty inherent in the process, considerations of schedule priority, as well as projects costs and budget constraints. Fourth, because these sub-strategies are often interdependent, the model should provide the means to identify tradeoffs in various ways in order to promote visibility in the decision making process. Fifth, the method should be capable of identifying the effects of value judgments on decisions at all levels of the analysis, not just the final results. In addition, it should focus on the identification of critical information gaps in the decision process and therefore permit crucial questions to be structured to refine the information interface between the analyst and the various users of the system. Finally the model should insure the effective utilization of all the expertise available to the organization. This is especially important when the program spans a wide range of technical disciplines. The usefulness of these attributes becomes much more apparent when one considers the characteristics of the research and development environment and the strengths and weaknesses of previously developed project selection planning models in dealing with the constraints imposed by this environment.

A. Characteristics of the Planning Environment

Ideally, research project selection decisions should be based on a quantitative tradeoff of known facts about the parameters concerned with the various alternatives. Realistically, however, many factors combine to erode this situation. One factor is that the projects being evaluated and compared are quite often in different stages, ranging from basic to applied research to advanced development. The nature of the stage dictates, to a large extent, the information that is available for project selection planning. In basic research projects, the primary goal is a more complete knowledge or understanding of the subject under study. Applied research projects are directed toward practical application of knowledge with the solution of specific problems in mind. Finally, in development projects, the objective is the systematic use of knowledge for the production of useful materials, devices, systems and the like.

At their inception, many facets of basic research projects are ill defined and difficult to formalize and evaluate on an objective basis. In this situation it is difficult to clearly identify objectives, payoffs, costs and performance criteria simply because of the many technical unknowns, the continual discovery of new facts, the constantly changing constraints, and criteria that are often qualitative in nature. In addition, there is often a lack of information regarding methods to be used to achieve the research objectives (5). Therefore the variance between estimates and actual achievement is frequently large.

As a project moves from the basic to applied stage and then to development, the amount learned about the subject increases and information and judgment become more quantifiable. That is, the data on which to base decisions and the decision criteria themselves become more easily defined and meaningful. Also, as Rubenstein (6) suggests, decision criteria not only become better defined, but they may also change from the time of the initial decision to begin to final development. Thus, both data and criteria can be time variant, another factor contributing to the difficulties in decision making. These problems are compounded in research environments where the need exists to compare projects which are in different stages. In this situation, complexity is introduced due to the differences in output from each project type and the differences in the degree to which activities in each phase can be related to and measured in terms of overall program objectives. In addition, as Brandenburg and Stedry (7) note, the three R & D stages are interrelated, even though only loose coupling may exist among them.

The research and development process is in many ways heuristic in nature. Each sequential step provides knowledge useful in the next step. Therefore it is often difficult to establish a clear action orientation for the extended program. In addition, each step in the process often involves significant uncertainties about feasible solutions. Uncertainty is, in fact, an integral characteristic of the work (1). Therefore the decision maker should accept the uncertainty and attempt to incorporate estimates of it in the decision process.

Another characteristic of this environment is that the project selection problem is not independent of other decisions faced by research management. The project selection decision, is, in fact, related to both resource allocation and scheduling decisions. Therefore it is necessary for a model to provide a mechanism to permit the tradeoffs between these decisions to be identified and evaluated.

A final factor creating complexity in the decision process is that research is often characterized by a multitude of goals which are neither independent nor always consistent. Some of these goals cannot be stated in operational form; that is, they only lend themselves to qualitative descriptors that are not easily quantified. Even those goals which are amenable to quantification rarely can be expressed by a common measure, thus posing the problem of incommensurabilities (8). In addition, the value structure underlying these goals is an equally important facet of the problem. It is the value structure that determines the long range worth of the program results. Therefore these values should be identified and incorporated into the method of assessing the overall worth of each project. Value analysis and worth assessment reinforce the need to incorporate subjective, qualitative inputs. As Miller (9) states, the assessment of worth is, by definition, a subjective process, therefore while it is important to make this process objective and free from bias, it is impossible to eliminate individual judgment values.

B. Review of Project Selection Models

Many studies of the project selection problem have been made in the past fifteen to twenty years and many formal models have been proposed. These models can be generally classified into five categories according to the basic approach used. These categories are economic models, decision theory models, scoring models, mathematical programming models and operations research models. The approach underlying each type of model is discussed in the following paragraphs.

1. Economic Models

Economic models are based on forecasts of the profitability of the project being considered, in terms of the expected revenue and the investment required to generate this revenue. They utilize principles of discounted cash flow and seek to optimize an economic objective function which is normally profitability. Therefore they are dependent on the ability to accurately predict the amount of investments required by the project and the forecasted revenues. This type of model does not incorporate a subjective value structure and normally only includes a single economic goal. As a result, these models are mainly employed to select projects which are in later stages of development where data on investment and project income are available. Examples of this type of model are ones developed by Cramer and Smith (10) and by Dean and Sengupta (11).

2. Decision Theory Models

The decision theory type of model portrays the decision maker as making a choice from among a set of alternatives $A = \{a_1, a_2, \ldots, a_m\}$, given: (1) a set of objectives or goals $O = \{o_1, o_2, \ldots, o_n\}$ which the decision maker wishes to achieve, (2) a set of probabilities p_{ij} representing the chances of each objective being realized by each alternative and (3) a measure of the relative worth or a cardinal ranking, of each objective $W = \{w_1, w_2, \ldots, w_n\}$. The optimum course of action is specified as that alternative which yields the maximum expected worth, or utility

$$E(U)_i = \max \sum_{j=1}^{n} (p_{ij}) w_j .$$

This type of approach is simple to use and is capable of combining both subjective and objective information, including the value structure of several decision makers (see for example, the work of Litchfield et al (49)). However, this approach does not incorporate the resource allocation and scheduling facets of the selection problem and therefore it can not be used to study the tradeoffs between these substrategies.

3. Scoring Models

Project scoring models are one of the most widely used methods for project selection (12). Moore (12) has presented an excellent summary of the structure of this type of model:

(1) A number of criteria ($i=1,2,3...n$) are identified; these should include all considerations relevant to the selection decision and should be independent.

(2) For each criterion, a scale having m scale points is developed. Each scale point ($j=1,2...m$) is defined by a descriptive phrase and a numerical score, with the score denoting the value or contribution of the describing phrase.

Each project proposed ($k=1,2...q$) is evaluated with respect to each criterion by a process that determines which phrase best indicates what the project is "most likely" to achieve. The appropriate scale point score is then assigned. Let V_{ik} be the value of the k^{th} project when rated on the i^{th} criteria.

(4) The V_{ik} scores are combined over all criteria to yield an overall project score, V_k, for the k^{th} project.

(5) The V_k scores form the basis for the process of selecting projects from among the alternatives.

(6) In some cases, weights, Wi, are assigned to each criterion to reflect relative differences in importance among criteria. The higher the score, the more desirable the project. The rationale behind the concept of this model is that there are knowledgeable persons within the research organization that have the quantity and quality of information to make the judgments required for successful implementation of the model.

One of the earliest applications of this approach to project selection modeling is the work of Mottley and Newton (13). In their model, projects are rated on a scale of poor, unforeseeable, fair, and high, relating to a 0,1,2 or 3 score on a numerical scale. Five criteria are used; promise of success, time to completion, cost of the project, stragetic need and market gain; with each criterion stated in the form of a question to be answered for each project being evaluated. For example, considering the time to completion criterion, the evaluation seeks to determine how long it would take to completed each research project. It is assumed, that, other things being equal, a project that can be completed within a predetermined specified time is more valuable than one that requires more time. The individual scores of each criterion are then combined into a multiplicative index by which the projects are ranked. Projects are selected by their relative rank until the research budget has been consumed.

The model of Dean and Nishery (14) utilizes a five point scale for thirty-six different project criteria which are separated into market value and technical categories. Weights for each criterion are employed and a separate score for each category calculated. Weights are then attached to each category score and an additive project score computed. Other project scoring models worthy of note are those of Hitchcock (15) and Chiogioji (16).

There are several advantages to this type of approach. Its main advantage is its ability to treat non-quantifiable inputs. As Moore (12) notes, even in the later stages of a project's life, non-quantifiable criteria play a significant role in project selection. One may therefore conclude that a scoring model formulation which integrates quantitative data with subjective data is capable of yielding meaningful project evaluations at all stages of project development.

Another advantage of this type of model is its simplicity. By using a mathematical simulation to compare the working of several types of selection models, Moore and Baker (17) showed that the simpler scoring models performed almost as well as the more sophisticated models. From the results of their study, they concluded that the costs and complexity entailed in more sophisticated, quantitative selection models are generally not warranted.

A third advantage is its diagnostic capabilities. In this type of approach, weak as well as strong points of specific projects can be flagged for special attention. Therefore, this type of approach is particularly well suited in identifying information gaps where further study is required.

There are three major deficiencies in this type of model. The first is that the selection of projects from a ranked list offers no assurance of an optimal allocation. A second deficiency is that selection from a ranked list permits only one constraint to be considered, usually a research budget constraint. The fact that this type of model does not consider resource allocation or scheduling facets of the decision is a third deficiency.

4. Mathematical Programming Models

Various models have been proposed which used mathematical programming techniques to formulate the project selection problem. This type of approach deals with the interaction of many variables which are subject to restraining conditions; the objective is to maximize the total value of all the projects being considered subject to the prescribed constraints. Typically, the value of each project proposal is measured in terms of financial worth, although there is nothing inherent in the theory of these programming schemes which necessitates limitation to solely economic value. Both linear and dynamic programming formulations have been used, but the complexity and data normally available (see, for example, the work of Hess (18) and Rosen and Souder (19)).

A representative example of the linear programming approach to the project selection problem is the model developed by Bell and Read (20) and used by the Central Electricity Generating Board in England. In this model, each project or alternative version of a project is represented by a variable that may take any value between zero (not selected) and unity (fully selected). The objective is to select a subset of versions of projects that maximizes an economic benefit function, subject to given resource constraints in each of several future time periods.

Each project is allowed several project versions that correspond to: a) different rates of accomplishing the project, to b) different technical versions, or to c) different times for initiating the project. The objective function for the model is:

$$\text{Maximize } \left[\sum_{i=1}^{n} \sum_{j=1}^{m_i} b_{ij}\, x_{ij} \right]$$

where:

x_{ij} is the allocation variable for the j^{th} version of project i,

b_{ij} is the expected benefit for the j^{th} version of project i,

n is the number of projects being evaluated for possible inclusion in the research program, and

m_i is the version number of project i.

Limited availabilities of both money and manpower resources are defined for each future time period, p, by constraints of the form:

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} a_{ijkp} x_{ij} \leq A_{kp} \qquad \begin{array}{l} k = 1,2,\ldots N \\ p = 1,2,\ldots P \end{array}$$

where

a_{ijkp} is the amount of the k^{th} resource type required by version j of project i, in future time period p.

A_{kp} is the resource budget of the k^{th} resource in the time period p.

N is the number of resource categories.

P is the number of time periods.

To insure that each project appears at most once in the solution, the following constraints are added:

$$\sum_{j=1}^{m_i} x_{ij} \leq 1.$$

An advantage of this particular model is its use of different project versions, reflecting different approaches to accomplish the same project objective. Thus, for example, the options of starting a project in planning periods other than the current one may be examined. The value of this feature is that it enables a study to be made of accomplishing projects in series or parallel, thus permitting one to relate project selection and resource allocation decisions with schedule priority considerations.

One weakness of this model is its sole reliance on economic factors for definition of project benefits. No consideration is given to project benefits that may not be expressed in terms of economic benefits. A second weakness is the model's use of partially funded projects. Bell and Read (20) argue that this form of output is valuable because it permits further insight into the optimal allocation of resources to each project. However, they assume that a continuous function can be defined to relate resources expended and benefit obtained. In most cases, this is an unrealistic assumption. The problem of partially funded projects can, however, be avoided by the use of integer programming, which insures complete rejection or acceptance of a project.

The most important asset of the linear programming approach to the problem selection problem is that it deals with the problems of project selection and resource allocation as one interrelated problem. This approach is not as effective in incorporating subjective information as other techniques; however, when combined with other techniques for benefit measurement and value analysis, it can be a particularly valuable tool.

5. Operations Research Models

Requirements for large scale research in advanced weapon systems has led to several innovative project selection schemes. Most of these schemes use no one single mathematical technique nor are based on one common approach; rather they usually combine several techniques into one framework. They are generally best classified as operations research models.

This type of model may best be described through the use of an example. TORQUE (Technology or Research Quantitative Utility Evaluation) (21), a model developed for the Department of Defense to provide a better coupling between future desired military capabilities and research efforts, represents a good example of an "O.R." model. It is essentially a method to quantitatively convert statements about desired future military operational capabilities into system descriptions, which can then be translated into research requirements. This model combines the use of linear programming with the utility assessment of each area of technology to allocate resources to research projects.

There are seven major tasks involved in the model. In the first task, the operational objectives are identified relative to the roles and missions of each service and then ranked in order of relative importance. At that point, the description, performance, and operating environments of each objective are identified so that the alternative system/subsystem options of each can be defined. Next, each of the options is time phased; that is, a determination is made when the current system and new option will cease to support the objective. In the fourth step, each of the technological advancements required to bring each of the system options into being is identified. In TORQUE, these technological advances are referred to as levels of difficulty (LOD). At the same time, the criticality of this technology to each system or subsystems it supports is evaluated and the dates when the technology must be available are identified. In the next task, the resources required to obtain each technology by the date desired are determined. The utility of each LOD is then computed using the following multiplicative index:

$$U = \sum_{j=1}^{n} C_j \; W_i \; C_f \; t_j$$

where

U = LOD utility coefficient

n = number of systems supported by the LOD

C_j = criticality of the LOD to the j^{th} system supported.

W_j = relative normalized weight or importance of the objective supported by the j^{th} system.

C_f = the ratio of first year resource allocation to the total allocation required to completely achieve the objective.

t_j = timeliness function, relating the completion date of the LOD to the date the j^{th} system is required.

Finally, a linear objective function is derived using the utilities of the LOD as coefficients of the allocation decision variables. Given the research budget constraint, the objective is to select that combination of allocation levels for the technological requirements which provides the maximum total utility.

The disadvantages of this model are that it does not consider technical uncertainty, does not incorporate resource balance constraints, and does not account for possible synergistic effects or conflicts between research objectives and/or technological requirements. The models developed by Dean (22) and Cetron (23) provide a method to deal with the last disadvantage of TORQUE, that is, being able to account for the interactions between projects and between research objectives. In their models, matrices are used to document the direct as well as the indirect relationships between projects, sciences, and technologies, and the objectives that these projects are designed to achieve. Other significant O.R. models are those developed by Nutt (24) and Martino (25).

In summary, the operations research approach to the project selection problem has two distinct advantages. First, since it usually utilizes several different techniques to treat this problem, it is capable of dealing with the tradeoffs between project selection, resource allocation and schedule priority decisions. Second, of all the types of models discussed, this approach best combines subjective and quantitative assessment techniques. The disadvantages of this approach are that it: (1) does not include the means to incorporate the decision maker's value structure, (2) provides very little visibility in the analysis techniques and (3) usually does not consider synergistic effects such as project to project interactions, etc.

C. Summary

In this chapter, important characteristics of the research planning environment have been identified and related to several selection models previously developed.

These characteristics, reflecting the realities of the planning environment, dictate several essential attributes necessary for improving the models used in project selection.

One such attribute is that the model should be easy to implement and simple to use. A second is that it should be designed so that qualitative subjective assessment can be integrated with quantitative analysis techniques. This is important because projects exist in different stages, from basic research to advanced development, each with unique qualities, and because many criteria and goals cannot be measured quantitatively. A third attribute is that the model should incorporate many sub-strategies of the decision process, including measures for a project's benefits, benefit uncertainty and schedule priority. In addition, the model should provide the means to identify and emphasize the tradeoffs that exist between these sub-strategies. A fifth attribute is that the model should evaluate the effects of value judgments on decisions at all levels of the analysis. Values are inherent in goal determination and worth assessment and they reinforce the need to incorporate subjective, quantitative input. In addition, the model should emphasize the identification of critical information gaps in the decision process and therefore permit crucial questions to be raised to improve the information interface between the analyst and the system users. A final important attribute of the model is that it should permit the effective utilization of all the expertise available to the organization.

A review of the five general categories of previously developed models reveals that no one approach effectively incorporates all of these attributes. Figure 1 shows, in summary fashion, the attributes incorporated by each type of model. Given the requirement that these seven attributes are important to the project selection decision problem, it is evident that a new model must be developed to deal with this problem. The development of such a model is the topic of the next chapter.

MODEL APPROACH → MODEL ATTRIBUTE ↓	Economic Models	Decision Theory Models	Scoring Models	Mathematical Programming Models	Operations Research Models
Easy to Use	Yes	Yes	Yes		
Combines Subjective and Objective Information		Yes	Yes		Yes
Incorporate All Facets of Decision Problem					
.Contributions Toward Goal Achievement	Lmtd	Yes	Yes	Limited	Limited
.Scheduling Priority				Limited	Yes
.Resource Allocation				Yes	Yes
Evaluate Substrategy Decision Tradeoffs				Limited	Yes
Incorporate Decision Makers Value Structure		Limited			
Identify Information Gaps			Yes		Limited
Incorporate Views of Many Decision Makers			Yes		Yes

FIGURE 1 Attributes of Previously Developed Project Selection Models

CHAPTER III

MODEL DEVELOPMENT

In the previous chapter several desirable attributes of a project selection model were identified. In this chapter, the discussion focuses on developing a model which will incorporate these attributes so as to provide a flexible decision-making aid. The chapter is divided into several sections. In the first section, the information requirements of the decision maker are identified and reviewed. In the second section, the model framework is presented and the workings of the individual elements of the model described. In the final section, key characteristics of the model are identified and discussed including how input information is obtained, judgment reliability, and scale definition.

A. Information Requirements

A key task in developing a project selection model is to identify the information that should be considered in the decision process. Previous models provide few guidelines as to the type or amount of information that should be included. The only clear guideline is that all information relevant to the selection decision should be incorporated as long as it is not highly overlapping. Although there is no limit to the amount of information which can be included, it is clear that as the amount increases the model becomes more unwieldly. In addition, as Moore (12) notes, there is a great deal of subjectivity in the selection of the proper information for use in a model. As he concludes, the model builder is operating on rather arbitrary grounds when identifying the relevant information requirements. Four general types of information are particularly important: project benefits, uncertainty evaluation, scheduling considerations, and cost estimation.

One important type of information that should be part of the selection decision is the expected benefit to be achieved from the proposed project. One of the barriers encountered in previous attempts to develop models as selection decision aids is the absence of an effective procedure for measuring the potential benefits. Crucial to this task is the requirement that a base be selected as the measure of success, since a benefit contribution cannot be measured unless the objective that is being contributed to is known. Dollars of profit may be the easiest measure of success, but not a particularly effective measure when other than economic objectives must be considered. Perhaps the best real measure of success is the extent to which the objectives have been met. In this regard, the client's value structure is particularly important in determining the priorities placed on each of the objectives. This value structure is important not only in helping to prioritize objectives but also in helping to identify the objectives themselves.

A second requirement for information is the need to evaluate the impact of scheduling considerations on the selection decision. Scheduling considerations are important because the probability of successfully accomplishing project A may be significantly dependent on the successful completion of project B. That is, the timing of some projects may be particularly crucial to the objectives of the total program. This will be particularly true when time constraints are placed on the achievement of these objectives. Therefore scheduling information must be identified and evaluated in the context of the overall selection decision process.

An evaluation of the uncertainty in the analysis is a third element of the selection decision information requirement. An analysis of uncertainty is important simply because information is more accurately interpreted when some indication is given of the range of confidence one can place on it. Two levels of uncertainty need to be considered. The first is the result of the uncertainty in the data and the subjective evaluation information that is used in the model. The second and higher level of uncertainty exists as a result of the integration and synthesis of information that is itself uncertain. A sensitivity analysis, where one can examine the sensitivity of the model outputs as a function of changes in model inputs, provides the means by which both of these levels of uncertainty may be evaluated.

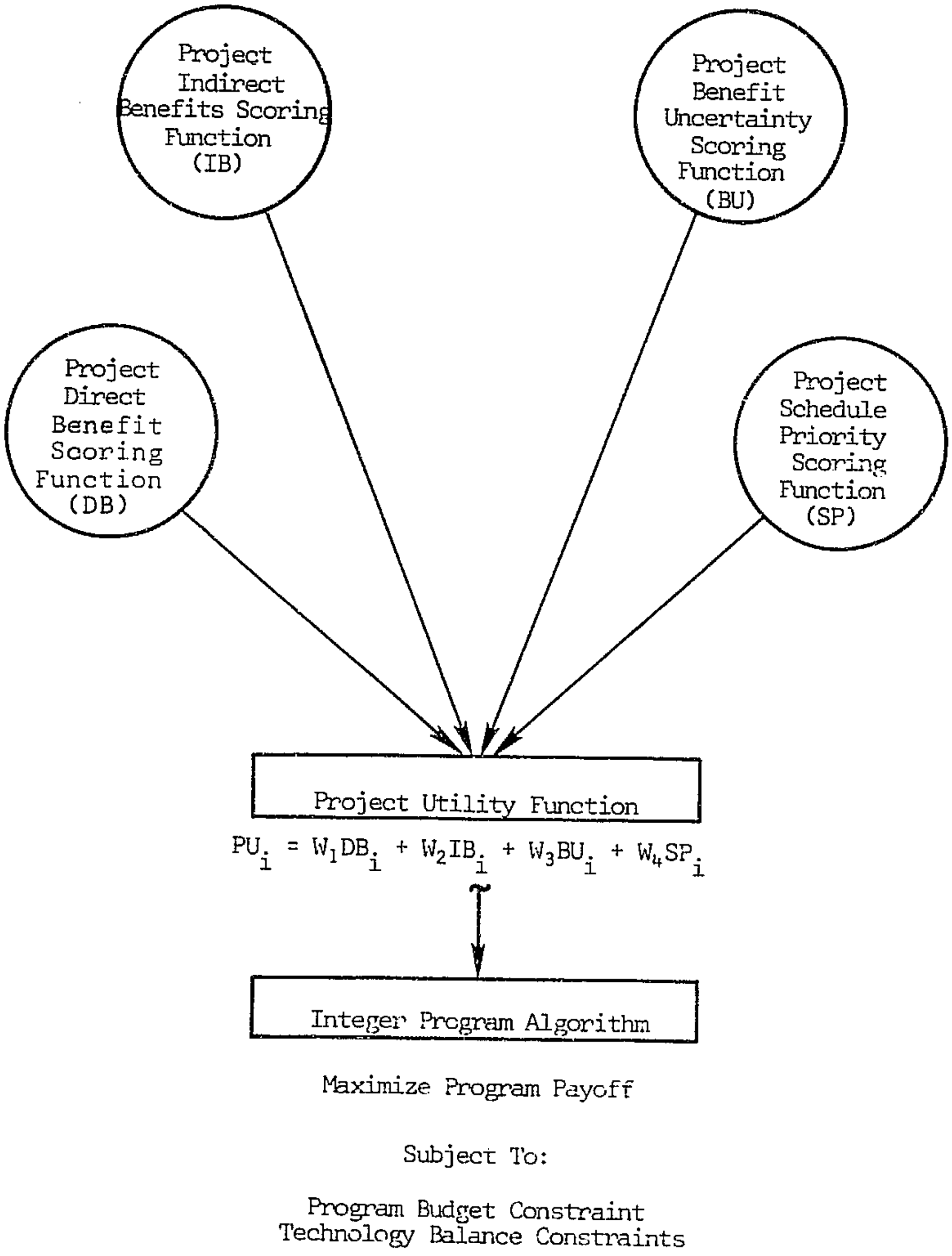
A final type of information that is important to this type of decision is cost estimates. Project costs are critical in selecting projects to establish maximum payoffs subject to resource constraints. Project costs are not, by themselves, enough however. It is also necessary to define the relationship between the expected benefits and the feasible funding levels associated with each proposal under consideration. Estimating this relationship is complicated by many factors, including the lack of precedent, unpredictable technical problems, project changes resulting from new knowledge or shifting requirements, the uncertainty of the schedule and the possible bias of the estimators, among others.

In summary, it should be added that the relevance and accuracy of the data to be used in the model determine, to a large degree, its ultimate effectiveness in providing useful information to the decision maker. The capability of the proposed model can only be as good as the input data.

B. Model Framework

The purpose of research project selection models is to provide a mechanism to integrate the necessary information so that research projects may be selected for funding. In the preceding paragraphs it has been shown that there is a great deal of information that goes into the selection decision. The framework of the proposed model needed to integrate this information is shown in Figure 2. The premise of the model is straightforward: given that every research program has a payoff, P, the objective is to select those projects that collectively maximize this payoff, while achieving the program resource and balance constraints. The payoff of the research program comes from the utility of each of its individual projects. It is assumed that each project has utility due to the benefit it provides, the certainty in achieving these benefits, and the priority it should be afforded as a result of scheduling considerations. Each component of this utility is measured by a separate scoring function, which will be discussed in the paragraphs that follow. A component score, once normalized, is assigned a weight which reflects the relative priority that the decision-maker attaches to that utility component. The scores are then combined by means of the project utility function. This function thus provides a numerical score for each

Figure 2 Model Structure



project, reflecting that project's benefits, uncertainty in achieving these benefits, and schedule priority. The formulation of the model is as follows:

Let P = program payoff

(1) Maximize $P = a_1x_1 + a_2x_2 + \ldots + a_jx_j$

subject to:

<u>Program budget constraints</u>

(2) $c_1x_1 + c_2x_2 + \ldots + c_jx_j \leq B$

<u>and Program balance constraints</u>

(3) Technology A projects

$c_1x_1 + c_6x_6 \leq 0.3\ B$

(4) Technology B projects

$c_3x_3 + c_4x_4 \leq 0.4\ B$

(5) Other

where

a_j = project j utility score = $W_{DB}(DB)_j + W_{IB}(IB)_j + W_{BU}(BU)_j + W_{SP}(SP)_j$

DB = project direct benefit score, normalized to a value of 0-1

IB = project indirect benefit score, normalized to a value of 0-1

BU = project benefit uncertainty score, normalized to a value of 0-1

SP = project scheduling priority score, normalized to a value of 0-1

W_{DB}, W_{IB}, W_{BU}, W_{SP} = weighting factors for DB, IB, BU, and SP, $W_{DB} + W_{IB} + W_{BU} + W_{SP} = 1.0$

x_j = project selection decision variable, $x_j = 0$ or 1

c_j = cost of project j

B = program budget

j = number of projects being evaluated

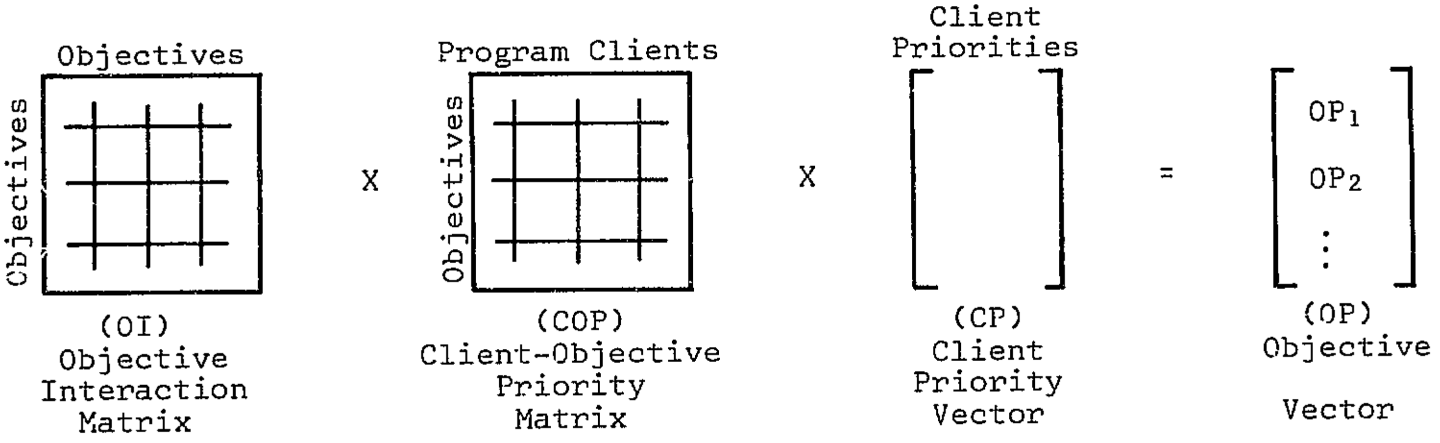
As the formulation above indicates, the scores from the project utility function provide the coefficients for each project in the model's objective function. The integer program algorithm provides the mechanism to evaluate the cost-utility tradeoffs for all possible combinations of projects so that the maximum program payoff is achieved for the given amount of resources. Optimization is achieved by solution of the resulting integer programming problem. Two types of constraints must normally be considered: a program budget constraint that limits the selection process to a total resource budget, and program balance constraints that stipulate resource allocations to various technology areas be balanced with respect to the program goals. The question of balance is one of deciding at what rate each area of technology should be advanced, recognizing that advances in one area are obtained at the cost of slower advance in some other area.

1. Project Benefit Scoring Function

The purpose of the project benefit scoring function is to provide a mechanism for measuring in numerical terms the expected benefit from each proposed project. The concept of benefit measurement requires that benefit attributes be defined and a scoring function established to relate these benefits to a numerical evaluation or score. The proposed scoring function is separated into two processes. In the first process, the priorities of the research objectives are evaluated. There are two key assumptions on which this process is based. First, the direct worth or priority of a given objective is assumed to depend on the degree to which it is preferred by a client to satisfy his needs and requirements. This worth or priority need not be the same for two or more clients since not everyone possesses the same frame of reference or the same value structure. Second, the indirect worth or priority of an objective depends on the degree to which one objective contributes to other objectives, as well as the relative worth of these objectives to the different clients. The actual numerical assignment procedure is a three step process. In the first step, the person doing the evaluation rates the interaction of each objective with other program objectives. The effect one objective may have on another can be either beneficial (or positive), neutral (representing a lack of interaction), or detrimental (or negative). These ratings are recorded in the objective interaction (OI) matrix, a non-symmetrical matrix since the effect objective A may have on objective B may not be the same as the effect objective B has on objective A. In the second step, the relative value or priority of the objectives is obtained from each client. The clients include those who use the technology and those who do not use the technology but may be affected by it. (A discussion of different means of achieving this information is deferred to later in this chapter.) These priorities are recorded in the client-objective priority (COP) matrix. Finally, the relative importance of each client to the research program is established. These values are recorded in the client priority (CP) vector. A matrix multiplication as shown in Figure 3, results in the objective priority (OP) vector. As stated previously, direct and indirect priorities are derived separately. Mathematically, the expressions for each are shown in the same figure. The only difference in these two expressions is that the direct objective priorities do not consider value resulting from objective interaction with other program objectives. These priorities are next employed in the second part of the benefit scoring function.

In the second process, the expected benefits of each

Figure 3 Quantification of Objective Priorities



OP_k = Priority of objective k

$$OP_k \text{ Direct} = \sum_{i=1}^{n} \sum_{j=1}^{m} (O_k O_i)(O_i C_j)(C_j W)\ \delta_{ik}$$

$$OP_k \text{ Indirect} = \sum_{i=1}^{n} \sum_{j=1}^{m} (O_k O_i)(O_i C_j)(C_j W)(1-\delta_{ik})$$

project are evaluated. As in the objective priority evaluation, both direct and indirect benefits are analyzed. There are three assumptions on which this process is based. First, the direct benefits of a given project depend on the degree to which it contributes to the success of each program objective, as interpreted by the relevant technology experts. Second, the indirect benefits of a project depend on the degree to which one project contributes to other projects, as well as how these projects contribute to the program objectives. Finally, both direct and indirect project benefits depend on the relative priority of the program objectives. As in the method for determining objective priorities, this scoring function also entails a three step procedure. In the first step, the value of the results of one project to other projects is evaluated. The project interaction (PI) matrix records these evaluations. This matrix is non-symmetrical since the manner in which project A contributes to project B will not usually be the same as the contribution of project B to project A. In the second step, the evaluator rates the contribution of each project to each of the program objectives. These ratings are recorded in the contribution (C) matrix. Finally, the objective priority (OP) vector obtained in the first process is introduced into the scoring function. A matrix multiplication yields the vector of project benefit scores. The matrix formulation is shown in Figure 4. Direct and indirect project benefit scores are derived separately, with the direct benefit scores representing a project's contribution to each program objective times the direct priority of that objective. The indirect benefit scores reflect the value of a project's contribution to other projects of the same program. Mathematically, the expression for each scoring function is shown in Figure 4.

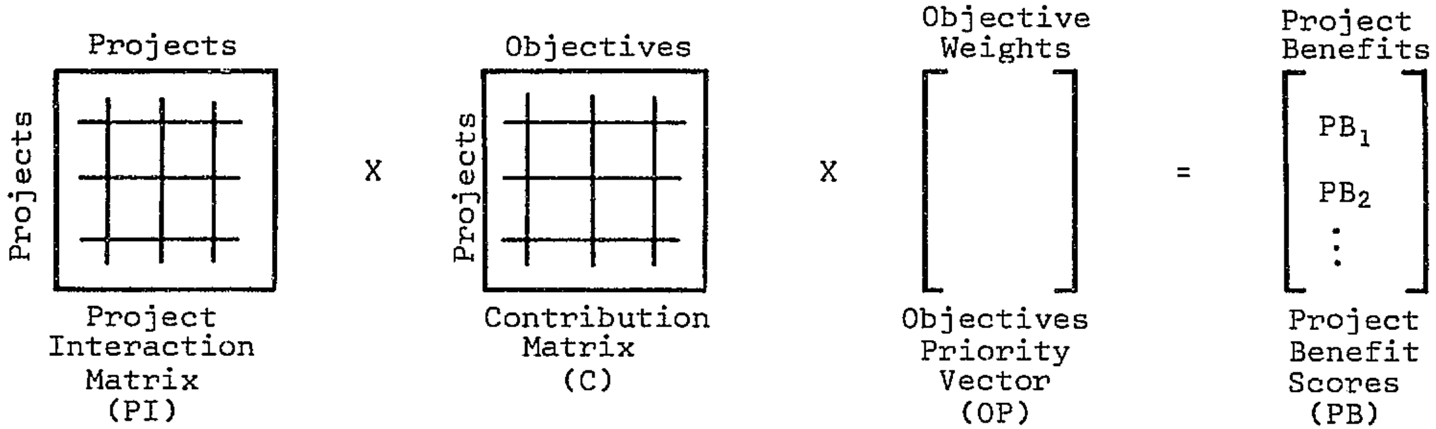
In both the objective priority and benefit evaluation processes, detailed descriptions of the numerical rating scale values are defined in advance and care is taken to ensure that the scales, and the arithmetic manipulation of them, conform to the laws of scaling. Further discussion of the scales employed is deferred to a later section in this chapter.

2. Project Benefit Uncertainty Scoring Function

An assessment of project benefits is an important part of the information needed to select research projects for funding. The value of this assessment can be increased, however, if one could provide an evaluation of the certainty with which these benefits could be expected. This is the purpose of the project benefit uncertainty scoring function.

Uncertainty, of course, involves conditions ranging from highly confident on the one hand, to extreme

Figure 4 Project Benefit Scoring Function



PB_k = benefit score of project k

$$PB_{k\ \text{Direct}} = \sum_{i=1}^{n} \sum_{j=1}^{m} (P_kP_i)(P_iO_j)(OP_j)_{\text{Direct}}\ \delta_{ik}$$

$$PB_{k\ \text{Indirect}} = \sum_{i=1}^{n} \sum_{j=1}^{m} (P_kP_i)(P_iO_j)\ (OP_j)_{\text{Indirect}}\ (1-\delta_{ik})$$

uncertainty on the other. Many relevant data may be available on which estimates of uncertainty may be used. On the other hand, it is often the case that very few data are available on which to base an evaluation. In cases where little data are available, the estimator is, more often than not, forced to rely on his experience and best judgment; that is, a highly subjective estimate. Previous studies with the use of these estimates show that they can be reliable indicators. Souder (27), in a study conducted at the Monsanto Company, studied the accuracy of highly subjective probability estimates. He concluded that with a group of research managers who were knowledgeable about subjective probability, the ratings of subjective probability of success were found to correlate very well with the eventual success and failure of these projects.

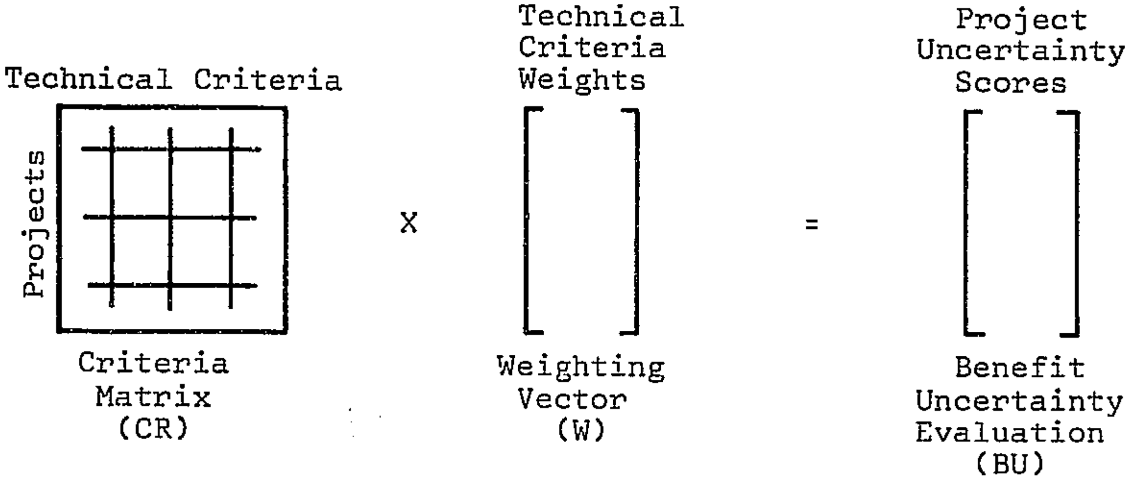
As the initial step in the proposed approach for obtaining estimates of the uncertainty in the estimates of project benefits, the evaluators are provided with a list of technical criteria with which they can rate each project. Nine criteria are suggested and are listed in Table 1. The first three criteria deal with estimating different components of the uncertainty directly: technical uncertainty, schedule uncertainty, and cost uncertainty. The next two criteria are concerned with the

Table 1 Uncertainty Technical Criteria

- Technical Uncertainty
- Schedule Uncertainty
- Cost Uncertainty
- Availability of Necessary Technical Expertise
- Availability of Necessary Research Facilities
- Quality of Technical Approach
- Flexibility of Technical Approach
- Technology Transfer
- Intangible Factors

organization proposing to conduct the research: are the necessary research facilities and the technical expertise available to successfully complete the research? Two additional criteria reflect the need to evaluate the proposed approach to accomplishing the task: what is the quality or detail described and is the necessary flexibility planned to accommodate unforeseen failures? The final two criteria reflect: (1) the need for the research results to be transferable to other technologies, thus increasing the chances for an increased information exchange, and (2) the intangible elements of a project that may influence its chances for success. A prime example of such an intangible factor would be a project sponsored jointly by two or more research organizations for mutual benefit. In such a case, technical uncertainty may be reduced due to the amount of expertise available to the project. Ratings on the projects with respect to these criteria are recorded in the criteria (CR) matrix. Next the relative importance of these technical criteria to the overall uncertainty evaluation is estabilished. These values are recorded in a weighting (W) vector. A matrix multiplication yields the benefit uncertainty (BU) ratings of each project. The matrix formulation and the corresponding mathematical expression are shown in Figure 5. Again, detailed descriptions of the numerical rating

Figure 5 Project Benefit Uncertainty Scoring Function



BU_k = Benefit uncertainty score of project k

$$BU_k = \sum_{i=1}^{n} (P_k TC_i)(TCWi)$$

scale values are defined in advance. Further discussion of scale definition is deferred to later in this chapter.

3. Project Schedule Priority Scoring Function

In a previous section in this chapter, the importance of identifying the interactions among projects was discussed. It was pointed out how project interdependencies introduce terms of higher order that may well affect the measurement of the benefits expected from each project. The assumption was simply that synergistic effects could increase the expected benefits. That is, in certain situations, two or more projects, when performed in coordination with each other, would produce results that are greater than the sum of the results which each project alone would have produced. However, in addition to increasing a program's expected benefit through synergistic effects, these project interdependencies are important for another reason. This reason is that the probability of successfully completing project A may be increased if the results from project B were known *a priori*. In such instances, some consideration should be given to scheduling considerations when making project selection decisions.

The project schedule priority scoring function serves the objective of identifying the scheduling dependencies between projects and measuring their overall relative value. In this scoring function, a project interaction matrix is again utilized, except in this case, the elements of the matrix represent a schedule priority relationship. The value of a matrix element, SP_{ij}, may take a value of -1, meaning that the i^{th} project should not begin until the completion of project j; 0, meaning there is no schedule relationship between project i and project j; or 1, meaning that project i should be completed before initiating project j. The transitivity condition must hold for elements of this matrix. That is, if project i should be completed prior to project j and project j should be completed prior to project k, then project i should also be completed before project k. A summation across matrix row i yields a score representing the relative schedule priority of project i. These evaluations represent a first iteration analysis. As such, they represent initial estimates of project scheduling relationships. They do not represent prohibitive constraints on project scheduling plans. Likewise, overlapping schedule relationships are not considered.

C. Model Characteristics

There are several characteristics of this model that are not particular to any one component. That is, they apply in a general fashion to all the model components. These characteristics include how the input information is obtained, judgment reliability and scale definition. Although they are not, of course, unique to this model, they do play an important part in determining the effectiveness of the model in accomplishing its function. These characteristics will be discussed in the following paragraphs.

1. Identifying Information Input

One aspect of the project selection model that has received relatively little attention to this point is the input information required for use in the model. As Hertz and Carlson (28) indicate, the more information available concerning all of the criteria, and the more accurate the information is, the more likely will be the success of the selection model.

Two levels of information are generally required, the normative level and the descriptive level (50). At the normative level, the focus is on the perceived needs, requirements and desires of the users and non-users of the technology, in both the current and future environment. From this information, the initial program goals and objectives are derived, as well as candidate projects. It is very difficult to over-estimate the importance of setting program objectives. The underlying reason for project selection planning is to help the program achieve its objectives. As long as they are not well defined, any method will have difficulty in achieving its purpose. The objectives should be statements of things to be done rather than statements of the means by which things are done. There are various methods to obtain the information by which these objectives are derived, ranging from surveys and questionnaires to follow-up interviews to detailed experiments and data gathering in the user environment. The process typically begins with informal, low level exchange of ideas between the client and the research technologist. As the researcher begins to learn about the clients' problems, more detailed questioning and information exchange is necessary. There are two important aspects of obtaining this information. First, it is not a one time process. As the facts are obtained, new questions arise and new data are required. In addition, objectives and value structure change with time and therefore must be revised from time to time to reflect these changes. Second, these needs and requirements reflect the client's value structure. Therefore, the research technologist must take care to reflect the client's values and not his own (50).

The program objectives stimulate the requirements for the descriptive level of information. This level begins with the organizational base of knowledge and proceeds outward to encompass other available expertise so as to ultimately identify and evaluate the alternative project tasks necessary to achieve the program objectives. There are several tasks inherent in obtaining this information. First, the objectives need to be classified into discipline areas that lend themselves to analysis by experts in these areas. Next, the experts in each technology within that discipline need to be identified. Third, research project proposals must be solicited to achieve the program objectives. Finally, to evaluate these project options it is necessary to provide information for and direct the judgments of these experts, so that their evaluation output is compatible for use in the selection model.

There are several techniques that may be used to obtain a reliable consensus of opinion of a group of experts. Perhaps the most widely known is the Delphi method. This technique attempts to achieve consensus by a series of questionnaires interspersed with controlled opinion feedback. The questions are designed to identify the reasoning that went into the reply, the factors considered relevant to the problem, an estimate of these factors, and information as to the kind of data required for a better appraisal. By systematically exploring the factors which influence the judgment of the individual expert, it becomes possible to correct misconceptions regarding empirical factors or theoretical assumptions underlying these factors and to draw his attention to other factors which may have been overlooked (29). This method can be applied to the level of detail desired. Additional information on the advantages and disadvantages of the Delphi procedure as well as other similar procedures can be found in references (30,31).

2. Judgment Reliability

Judgments from individual experts in the various technologies can be more accurately interpreted when some indication is given of the reliability or the range of confidence the evaluator has in his estimate. One approach that would lend additional meaning to these estimates is to include a factor to reflect the confidence or degree of accuracy with which that estimate is made. Another feasible approach would be to obtain from each expert three estimates, a highest possible, a most likely, and a lowest possible, thus providing the bounds of one's estimate. In either approach, additional information would be provided to identify estimates which require further investigation and to indicate on which inputs a sensitivity analysis should be performed.

3. Scale Definition

At the core of most subjective analysis is some form of scaling. Although the construction of the scale or scales may be accomplished by means of many response mechanisms (e.g. questionnaires, interviews, and the like), the output is typically a numerical representation of an object or stimulus that somehow describes that object or stimulus as better than, equal to, or worse than, others of the same or a different class. In subjective scaling, the number replaces semantics as a way of communicating one's judgments concerning vague, qualitative concepts. The number of scale intervals utilized is an important consideration in the scale design and ultimately impacts the effectiveness of the scale in a given situation. The number chosen is based on several factors. Moore (17) points out that an increase in the number of scoring intervals improves the accuracy of the model by permitting the incremental improvements in discriminatory power, in the effective range of the model, or in both. The only apparent limit to the number of intervals is the ability of the estimator to assign performance estimates for each of the graduations of the scale. Since intermodal consistency increases with the number of scoring intervals, the scale should have as much discriminatory power and effective range potential as is reasonable for the evaluator to effectively utilize, based on his knowledge of the subject being evaluated.

In the case of the scales used in the scoring functions of this model, several scales have been defined, as shown in Appendix I. In each case, the number of scale intervals represents a compromise between the range of the attributes in question and the knowledge of the "experts" in the subject under study.

D. Summary

The broad range of factors that influence the selection of research projects may be best identified and evaluated if a uniform, consistent method is utilized to perform this function. The intent of the proposed model is to make the project selection process an explicit, documented procedure to facilitate the integration of several interacting decisions so that tradeoffs can be evaluated. The model uses four types of project information: project benefits, the uncertainty in achieving these benefits, the project schedule priority and the project costs, and a scoring function is derived to measure and evaluate each. It is assumed a project has utility based on the benefits it provides, the certainty in achieving these benefits and its schedule priority.

In evaluating a project's utility emphasis is placed on assuring maximum utilization of the expertise available to the organization. Two different approaches are employed in identifying this expertise. In the normative approach, emphasis is placed on identifying the value structure of the client. In the descriptive approach, the focus is on using technical expertise to identify and evaluate research tasks needed to accomplish the objectives identified in the normative approach. One of the most important assets of the model is to refine the information interface between the research analyst and the system user, in order to bridge the gap between the research and development and the application of the results.

CHAPTER IV

MODEL APPLICATION

The technical literature presents a plethora of models and methods for evaluating and selecting research and development projects, as discussed in Chapter II. The model proposed in the previous chapter is only one among a list of well over a hundred previously developed (32). Although many models have been proposed, few references indicate any attempts to ascertain the feasibility of using a particular technique, much less the utility gained from that technique. Still fewer methods have seen even limited formal use (1). Therefore one of the major objectives of this research effort is to apply the proposed project selection model to NASA's Civil Helicopter Technology Program in order to study its utility in a real world environment. The application of the model is important for two additional reasons. First, the management of this program requires a list of research project priorities that reflect the needs of helicopter users as well as the local communities from which helicopters must operate. Second, it is impossible to fully develop a model to aid in research project selection planning without evaluating its effectiveness in a real life situation. The objective of this chapter is to document and discuss the application of the proposed model to NASA's Civil Helicopter Technology Program.

This chapter is divided into eight sections. First, an overview of NASA's Civil Helicopter Technology Program is presented. Next, the sources and types of information, from which client values are derived, are identified and discussed. In the third and fourth sections, the research program objectives and project alternatives are presented. Next, the application of project utility scoring functions is discussed and the sensitivity of these scoring functions to input data is assessed. In the seventh section, an integer programming algorithm is applied using various project utility vectors, project costs and program budgets. Finally, the results of the analysis are discussed and project research priority recommendations are presented.

A. Overview of NASA's Civil Helicopter Technology Program

During the past decade, the air transportation system has experienced a rate of growth resulting in the present situation where the system is being constrained by its own success. The combination of the effects of airport and ground access congestion have created a situation where passengers and cargo may spend more time in terminal area operations and ground transportation than they do on the actual air portion of the trip. This is particularly true on short-haul intercity trips. In addition, with major airports moving greater distances from downtown, with the continuance of urban sprawl, and with the increased urbanization of our population, the seriousness of this problem is becoming increasingly apparent. The situation highlights the need for improvements in both intercity and intraurban transportation.

The helicopter represents an air transportation system with unique capabilities that make it possible for the general public to travel to the heart of the downtown environment. Its inherent agility and steep climb and descent capability can be used routinely to (1) gain access to high density areas, (2) permit use of trajectories optimized for noise abatement and (3) utilize available airspace more efficiently. Therefore it represents an air vehicle that could potentially be used in both intra-urban as well as short haul intercity transportation. In addition to the potential use of the helicopter in public transportation, there has been a significant increase in the application of this vehicle to other civil sectors in recent years. Examples include offshore oil operations, medical evacuation, search and rescue, remote logging operations, and law enforcement. However, all of these applications are hampered by certain deficiencies that limit the capabilities of this aircraft.

In the past, civil helicopter technological improvements have, on the large part, been in response to technology transfer from military research and development. Therefore it is not unexpected to find certain deficiencies in helicopter technology that impact civil applications quite severely. One such area is safety, where the occurrence of accidents early in the use of a new transportation system can significantly impact system acceptability. The experience in Los Angeles, California serves as an example, where two helicopter crashes in the late 1960's greatly dampened the use of the helicopter in public transportation. Other areas of concern include the impact of the system on the surrounding environment, operating costs, system maintainability and reliability, passenger and community acceptance, and instrument flight operating procedures. While most of these problem areas are shared by military helicopter technological requirements to varying degrees, environmental, institutional and operating constraints make them particularly critical for operations in the civil environment. Therefore if helicopter applications in this environment are to be fully achieved, emphasis is required on these types of problems. With these thoughts in mind, NASA created the Civil Helicopter Technology Program.

The ultimate goal of this program is to develop the technology to make the helicopter more acceptable for civil applications. There are three major facets of this goal: to improve passenger, community and operator acceptance. Each of these objectives is pursued through four types of effort, as outlined in the program research and technology operating plan (RTOP):

1. To identify the projected requirements and associated criteria for achieving acceptable civil operations and to evaluate existing vehicles in meeting these requirements.
2. To assess the extent to which existing technology can be applied to meet projected requirements, and to identify areas requiring additional research.
3. To conduct vehicle and systems design application studies utilizing projections of advanced technology.
4. To perform key experimental evaluations which are deemed critical to the acceptance and use of promising advanced technology concepts.

This program, which places emphasis on applied research, is a key link between the goal of increased acceptance and utilization of helicopters for civil applications and the research and development needed to achieve this goal.

There are several important reasons why this program could benefit from a formal, documented method to select research projects for funding. First, there are simply not enough funds to achieve all program objectives. Therefore the values of the clients must be identified in order to prioritize these objectives. When there are many clients potentially affected by research payoffs, as in this program, it becomes particularly important to document their needs and requirements and incorporate them in the decision process. Second, the wide range of technologies required to achieve program objectives makes it highly unlikely that any one individual will have the necessary expertise to make all of the necessary evaluations. Therefore, it is important to provide a mechanism to combine evaluations from many experts in a consistent fashion. Finally, by placing emphasis on the decision process, a documented procedure helps to insure that management is more aware of the information that should be acquired when making project selection decisions. This is particularly important when the program covers a broad range of objectives and requires a great deal of information in the decision process, as this program does.

B. Deriving Normative Information Inputs

A key task in applying a project selection model is to generate the information on which evaluations can be based, particularly at the normative level. At this level the focus is on the perceived needs, requirements, and attitudes of both the users and non-users of this technology. In this section the sources and types of this information are identified and discussed.

1. Passenger Inputs

In the highly competitive field of public transportation, it has become apparent that consideration of the needs of the passenger is essential. Accordingly, to accomplish the objective to make the helicopter a feasible alternative in public transportation, one must, among other things, understand how to design the system to be attractive to the potential user. To do this,it is important to focus on the development of the relationship between the attributes of this type of system and the passenger's evaluation of the effects of these attributes, as they relate to his satisfaction.

One of the more important attributes of a transportation system and especially of the helicopter, is the ride environment. The multi-harmonic nature of helicopter vibration presents a special problem in evaluating subjective evaluation of this type of environment have shown that in any given situation, the levels at each of the component rotor harmonics can be well within acceptable limits and still combine to produce an unacceptable ride (33). Therefore it is important to develop tools to account for passenger discomfort in this multi-axis, multi-frequency environment. An equally important factor of this environment is the noise. To date, little research has been accomplished to investigate the effect of different combinations of noise and vibration on passenger ride satisfaction. Therefore, ride quality research should be extended into these areas and passenger response to this type of environment identified and evaluated. The modifying effects of other ride quality variables such as flight duration, low-frequency motion, temperature and visual cues, as well as such passenger psychological variables as anxiety, attitude toward flying and flight experience also require study. In addition, there is a need for a quantitative description of the aircraft cabin environment (such as motion, noise, etc.) particularly with respect to how the environment varies as a function of the aircraft operation. This description, when coupled with subjective passenger evaluation, will permit an assessment of the acceptance requirements for future technology and will help to identify areas where technological improvements are most required.

In addition to the ride environment, passenger attitudes on other system attributes need to be investigated. These attitudes play an important role in a passenger's choice for his mode of transportation. Therefore they must be identified and analyzed in order to understand and predict the acceptance of, and hence the demand for, this system. The relationship of these attitudes and passenger satisfaction is important, for example, in determining if travelers are willing to exchange the relative comfort and lower cost of conventional systems for the reduced travel time and greater convenience of the VTOL system.

The assessment of attitudes toward system attributes from which individuals make modal choice decisions is an important research tool. The rationale for this concept is based on the assumption that personal behavior in the selection of an alternative can be determined in advance by an understanding of the perceptions that individuals have of their options (34). While there have been several attitudinal studies (35,36,51) of VTOL systems in the past, few have been based on passengers with experience on these systems. Such studies are not completely satisfactory, since it has been shown that passengers may not be able to respond to questions on the importance of system attributes if they have had no experience on that system (37). That is, attitudes may be expected to change once a passenger has experience with the new system relative to his position on the system prior to this experience. Therefore it is important that the behavioral questions of passenger acceptance of this proposed system be studied in a simulated real life operation.

To obtain information on the needs of potential helicopter passengers, NASA's Civil Helicopter Technology Program conducted a series of twenty-five flights utilizing volunteer subjects on its CH-53 research aircraft. These research flights encompassed two separate but somewhat overlapping phases. The purpose of the first phase was to focus on an investigation of the ride environment. In this effort, eight flights were conducted, each with a complement of 15 passengers. Two groups of passenger complements were selected, with each to fly four flights (one flight at each of four durations: 25, 50, 75, and 100 minutes). Each group reflected equivalent mixes of four passenger types, where passenger types are determined by attitudes toward flying and previous flight experience. At different points during each flight, the passengers were asked to rate the comfort of the environment to which they were being exposed and to identify which factors they found most objectionable. These evaluations were designed to investigate the importance of the ride environment variables as well as to identify possible changes in the passenger's perception of these variables as a function of the flight duration and the passenger's experience with the system. At the completion of each flight, they were asked to complete a post-flight questionnaire to evaluate their overall reaction to the system and to identify where they felt improvements could best be made.

To augment the ride-quality research, phase two of this effort was designed to stimulate more realistically the operational environment of a public transportation system. Flights were made as trips to area airports, stops were included, and the ride environment was not changed during the flights. In addition to studying the ride environment, the objective of this phase was to include an investigation of passenger attitudes on other system attributes, such as travel time, safety, reliability of destination achievement, travel cost and the like. They are studied by means of passenger questionnaires used during and after the flight. Just as a passenger's perception of noise, motion, temperature, and other environmental factors leads to his evaluation of the ride quality, his perception of these factors leads to an evaluation of the overall satisfaction with the helicopter as a mode of transportation. A summary of some of the results of this flight program is found in Appendix II.

2. Operator Inputs

An important client to the Civil Helicopter Technology Program is the user of the helicopter. That is, the operator who utilizes this type of vehicle in passenger transportation, service to offshore oil rigs, logging operations, law enforcement and the like. This is the person who expects certain specific qualities from the vehicle and who is able to identify, from a normative, operational point of view, weaknesses in the technology. To obtain information concerning this client, three tasks were accomplished. First, visits were made to several helicopter manufacturers to discuss operator problems from the point of view of members of their technical and marketing staff. Second, discussions were held with the staff of the Helicopter Association of America, an organization representing the majority of helicopter operators in the United States. These discussions focused on the technical and operating problems of concern to their member organizations. Finally a survey of the helicopter operator community within the United States was conducted. This survey was designed with three objectives in mind:

(a) To identify operational problems inherent in the current helicopter technology used in the civil environment.

(b) To assess the impact of the helicopter on its surrounding environment as viewed by the operator and to identify operating procedures effective in alleviating this impact.

(c) To identify and evaluate operator opinion on what improvements in technology could most improve their operation.

To achieve these objectives, a questionnaire was designed, tested, and then sent to 500 operators throughout the United States (representing a 20% sample). Seventy percent of the questionnaires were sent to managers of helicopter operations, that is, persons who would have knowledge of the total operation, while thirty percent were sent to helicopter pilots. Very few differences exist between the questionnaires sent to each group. In addition, the sample was further stratified by the type of operation (commercial, corporate or civil government), and by the size of the operation. The sample stratification was designed to obtain information from all segments of the operator community. A summary of the results of this survey is presented in Appendix III.

3. Community Input

The issues of community acceptance are associated with the problems of: (1) locating convenient heliport sites from which to conduct helicopter operations; and (2) outlining the critical characteristics of the facility and how they may potentially impact the surrounding environment. When the term community is used, it applies to the community at large, including both the local political entity with jurisdiction over the facility and the local non-user population. Input information on these issues is provided by several sources. One source is the Federal Aviation

Administration's Heliport Design Guide (38). This document presents information and criteria for the planning and development of heliports intended for both private as well as public transportation. It outlines the basic physical, technical, and public interest factors which should be considered in planning and establishing heliport sites. As this guide indicates, the heliport site selection involves four major considerations: (1) the desired location and physical layout; (2) operational safety; (3) the impact on navigable airspace; and (4) the effect on the surrounding community.

A second source of information are the Federal Aviation Regulations (FAR)(39), which are established by the Federal Aviation Administration and which relate to the operational safety of helicopter operations. Regulations important to helicopter operations include: FAR Part 77, which discusses objects affecting navigable airspace; FAR Parts 27 and 29, which set forth the airworthiness standards for the manufacture of helicopters; and FAR Part 91 which prescribes the general operating rules for all aircraft.

The establishment of a heliport typically requires prior approval, or the issuance of a license, from the appropriate state aeronautics commission or similar authority (38). A review of California's new heliport regulations (40) provides input to the heliport site location, community acceptance issues from the state planning and regulatory point of view. Information on the planning and operation of heliports at the local level is provided by the experiences of both past and present city heliports in this country as reported in references (41,42,43). These references discuss factors impacting the operation of heliports, such as noise, physical layout and design factors, approach and departure paths, both VFR and precision IFR operating procedures, obstacle clearances, and interface with ground transportation systems. All of these factors impact, to some degree, the successful operation and acceptance of helicopter technology.

A fourth source of information on community acceptance issues is provided by two studies (44,45) conducted to: (1) forecast the potential noise restrictions which may be imposed on civil helicopters in the next decade; and (2) develop guidelines for establishing helicopter noise levels which would be acceptable to the communities from which they operate and over which they fly. Appendix IV contains several figures which: (1) compare several current residential community noise regulations with forecasted VTOL noise criteria for the next decade; (2) propose community noise acceptability guidelines; (3) compare federal, state and local noise regulations with these proposed guidelines; and (4) present a summary plan to achieve future certification noise limits.

Further information on community acceptance issues is provided by the operator survey previously discussed. This survey contains several questions designed to: (1) solicit information on community reaction to helicopter operations and (2) relate this reaction to specific types of operation and helicopter equipment. Appendix III summarizes the information received from this survey.

4. Civil Helicopter Accident Analysis

One important requirement shared by passengers, and operators, as well as local communities, is the need for safe operations. To provide information on the safety aspects of helicopter operations in the civil sector, two tasks were accomplished. First, an analysis of civil helicopter accident statistics from 1968 to 1974 was conducted utilizing the National Transportation Safety Board's data tapes (46). As the figures and tables in Appendix V indicate, accident rates for civil helicopters are significantly higher than both single engine and multi-engine fixed-wing general aviation aircraft. The most predominant cause of the 1722 accidents during this period is pilot error, accounting for 51 percent of these accidents. Other major causes include power plant and rotor system failures, and accidents attributed to the terrain in which the operations are conducted. These statistics indicate that to achieve an improvement in helicopter safety, emphasis should be placed on improving the interface between the pilot and the helicopter.

Further information on the safety aspects of helicopters is provided by a study on the pilot-aircraft interface conducted by Hawkins and Griffin (47). This report describes information obtained from a questionnaire survey of a sample of 136 Army helicopter pilots. The impetus for this survey was the occurrence of accidents which involved rotary wing aircraft in collisions with wires and pylons. An initial analysis of the official records concerning the occurrence of helicopters striking wires, combined with the results of early field experiments, suggested that there was no single cause, such as a specific effect of vibration on visual acuity, which could adequately account for the wire strike problem. Thus the Hawkins and Griffin research evolved as a study of the broader aspects of vibration and vision as factors in the overall efficiency of operational helicopter pilots. The specific objectives of the study include the following (47):

(a) To provide the designer with the opinions of a large sample of pilots on the design and operational features of present helicopters.

(b) To help those research workers concerned with human factors problems of operational helicopter flying in the assessment of important subjective factors such as the pilot's conception of his task.

(c) To attempt a comparison between:

   (i) Pilots judgments of the way in which they order their visual time for specified flight.

   (ii) Direct observations of the visual behavior of pilots flying routine operations and of subjects during laboratory investigations of visual search efficiency.

A summary of the more pertinent results of this study is found in Appendix VI.

C. Definition of Research Objectives

The information discussed in the previous few sections provides the basis for the definition of the initial iteration of research objectives, shown in Appendix VII. This objectives tree begins with the most general objective and becomes more specific as one reads down the tree-like structure (50). The objectives are statements of things to be done rather than statements of the means by which they are accomplished.

The major or most general objective of this program is to increase the acceptance and utility of helicopters in civil applications. To achieve this objective, one must, among other things, improve the community, passenger, and operator acceptance of these vehicles. It is the third level of objectives that are utilized in the project selection model. To improve community acceptance, one must reduce exterior noise levels and engine emissions and increase the operational safety of these vehicles, among other things. To improve passenger acceptance one must, among other things, reduce travel time and costs, insure operational safety, increase air travel accessibility, and reduce the interior noise, vibration, and gust sensitivity of these vehicles. Finally, to improve operator acceptance one must lower vehicle acquisition and maintenance costs, increase vehicle performance, increase mission reliability, and reduce fuel consumption, among other things.

2. Definition of Research Project Alternatives

Previous research projects funded by NASA's Civil Helicopter Research Program as well as the input information and research objectives previously discussed provide a basis for defining future research project alternatives to achieve program objectives. Typically a research program receives proposals for research projects by initiating requests for proposals on tasks generated within the organization, as well as by accepting unsolicited proposals generated external to the organization. The project alternatives shown in Table 2 were generated by both means. To be included on this list, a project

Table 2 Research Project Objectives

PROJECT DESCRIPTOR	BRIEF PROJECT OBJECTIVE
HIGHER HARMONIC PITCH CONTROL	To investigate the feasibility of applying higher harmonic pitch control to reduce helicopter vibration.
REDUCE TRANSMISSION NOISE AT SOURCE	To develop and test methods for reducing transmission noise at the source.
EXTERIOR NOISE REDUCTION VERSUS COST	To identify the relationship between exterior noise reduction methods and vehicle acquisition and operating costs.
DOCUMENT RELIABILITY, MAINTAINABILITY DATA BASE	To document the reliability and maintainability data base of helicopters in civil operations, to identify problems peculiar to this environment.
QUANTIFY DESIGN/MANUFACTURING VARIABLE COSTS	To identify and evaluate the design and manufacturing variables that establish a vehicle's acquisition cost.
COST EFFECTIVENESS ANALYSIS OF EMERGENCY POWER SCHEMES	To evaluate the feasibility and cost effectiveness of emergency contingency power schemes for helicopters.
FEASIBILITY OF ENGINE EMISSION REDUCTION	To evaluate the technical feasibility of engine emission reduction and to identify penalties on vehicle performance and costs.
ESTABLISH TERMINAL AREA RIDE QUALITY LIMITS	To establish limits in procedures for helicopter operations in the terminal area so that the ride is acceptable to the passenger.
AIRFRAME/SKIN DAMPING TO REDUCE INTERIOR NOISE	To test a helicopter airframe scale model to establish guidelines for skin and airframe stiffness and damping to minimize cabin noise.
COST EFFECTIVENESS OF VIBRATION CONTROL METHODS	To evaluate the feasibility and cost effectiveness of helicopter vibration control methods.
EQUIPMENT AND OPERATIONAL REQUIREMENTS FOR URBAN HELIPORTS	To determine the equipment and operational requirements for helicopter operations from urban heliports.
EVALUATE CONTINGENCIES LEADING TO PILOT ERRORS	To identify and evaluate the contingencies leading to pilot errors that result in helicopter accidents.
COST EFFECTIVENESS OF AUTOMATIC INSPECTION, DIAGNOSTICS	To evaluate the costs and benefits of automatic inspection, diagnostic and prognostic systems for helicopters in the civil environment.
DYNAMIC AND ACOUSTIC PROPERTIES OF COMPOSITE MATERIALS	To identify and evaluate the dynamic and acoustical properties of advanced composite materials.
OPERATING PROCEDURES TO REDUCE EXTERIOR NOISE	To evaluate the feasibility and effectiveness of curved approaches, steep descents, and other operational techniques to minimize helicopter noise signatures.
COST EFFECTIVENESS OF INTERIOR NOISE REDUCTION METHODS	To evaluate the cost effectiveness of established interior noise reduction methods applicable to a broad spectrum of helicopter configurations.
COCKPIT LAYOUT AS IT IMPACTS PERFORMANCE, SAFETY	To evaluate cockpit instruments and their layout as they relate to pilot performance, workload and potential pilot errors.
ESTABLISH COMBINATIONS OF TECHNOLOGY/ OPERATING PROCEDURES TO MEET NOISE GOALS	To establish feasible combinations of technology and operating procedure improvements required to achieve proposed exterior noise levels.

had to meet at least one of the criteria defined by this program's research and technology operating plan (RTOP), discussed earlier in the program overview section of this chapter. These eighteen project alternatives by no means represent all the projects necessary and sufficient to satisfy the program objectives. However, they do represent an estimate of the usual number a project manager of this size program must normally evaluate each year. They range in scope from feasibility studies to experimental test and evaluation of hardware and they broadly cover the spectrum of program objectives. A brief statement of the objective of each project is presented in Table 2.

E. Application of Project Scoring Functions

Having defined the research objectives and eighteen project alternatives that require funding, one is now in a position to apply the project scoring functions for the evaluation of each project. In the paragraphs that follow, the discussion focuses on an evaluation of objective priorities, project benefits, benefit uncertainty and schedule priority.

1. Objective Priorities

To evaluate objective priorities, a three step process is employed. In the first step, each one of a three man evaluation team independently rated the interaction of each objective with other program objectives. A three point scale is used to rate these interactions as shown in Table 9, Appendix I: a value of 3 indicates little or no interaction between objectives, 4 means moderate interaction, and 5 indicates potentially heavy interaction between the two objectives. Only the relative intensity of the interaction of two objectives is evaluated; the fact that objective interactions may be either positive or negative does not affect the evaluation. These ratings were then compared, differences discussed, and general consensus achieved. Figure 21, Appendix VIII, lists this consensus of ratings. As an example, consider how the objective to reduce fuel consumption interacts with other program objectives. This objective moderately impacts the objective to increase vehicle applications, since reduced fuel consumption would make the helicopter more comparable with fixed-wing aircraft and thus would potentially increase their application to functions now performed by these types of aircraft. In addition, it interacts moderately with the objective to reduce travel costs, since fuel cost is a significant percentage (15-20 percent) of the helicopter's operating cost. Notice that the research objectives to reduce exterior noise and to increase mission reliability interact most frequently with the other objectives.

Next, the relative priority of each objective to each program client is estimated. These estimates are based on information from the literature, as well as surveys, questionnaires and direct dialogue with the client, as discussed in the previous sections of this chapter. Figure 22 in Appendix VIII presents the matrix which contains these priorities; a value of 7 represents the highest priority, while a value of 1 represents the lowest. The best agreement in priorities occurs among the military, helicopter manufacturers, and operators, while the greatest dichotomy of views occurs between the local communities and the other five clients.

Finally, a vector representing the relative importance of each client is obtained from program management. Using values of 1, meaning least important, to 7, meaning most important, Figure 6 presents the client priority vector.

Figure 6 Client Priority Vector

Passengers	6
Pilots	4
Communities	5
Military	2
Helicopter Industry	5
Operators	7

Matrix multiplication, as expressed in the functions developed and discussed in Chapter III, results in both direct and indirect objective priorities, presented in Figures 27 and 29 Appendix IX. The direct objective priority scores range from 1100 to 3400, with the objectives to increase operational safety and to increase mission reliability ranking high, while the objectives to reduce engine emissions and to reduce gust sensitivity ranking low. The scores of the indirect objective priorities range from 5100 to 5700, with the objective to increase mission reliability ranking highest and the objectives to increase performance, to lower maintenance costs and to increase vehicle applications ranking lowest. Figure 28 in Appendix IX compares the direct objective priorities obtained using management values of client weights with those obtained using equal weights for all clients. Some small changes in objective priorities can be noted; for example, the objective to increase air travel accessibility drops in priority when all clients are given equal weight.

2. Project Benefits

Once the objective priorities have been established, the potential benefits projected for each project are estimated. As in the method for determining objective priorities, the benefit scoring function also entails a three step procedure. In the first step, three evaluators independently rated the synergistic value of the output of project A to other proposed projects, using the 7-point scale shown in Table 12, Appendix I. These ratings are then compared, and where significant differences exist, discussion is held to achieve a general consensus of opinion. These evaluations are then recorded in the project interaction matrix, Figure 28, Appendix VIII. As an example of this type of evaluation, consider the value of the results of the project to evaluate operating procedures to reduce exterior noise. The results of this study will make a major contribution to the successful accomplishment of the project to establish combinations of technology and operating procedures necessary to meet projected noise limits. It will also contribute some to the project to define the cockpit instrument panel from a human factors standpoint, since pilot workload is a major factor in operating procedures of this type. This project also contributes indirectly to the projects to evaluate higher harmonic pitch control and to quantify design and manufacturing variable costs; it is remotely associated with the cost feasibility of exterior noise reduction and with the analysis of the cost effectiveness of emergency power schemes.

Next the same evaluation team scored the contribution of each project to each of the program objectives, using a four point scale, classifying contributions as major, moderate, minor, or little to none, corresponding to numerical values of 3,2,1 or 0, respectively. Once a consensus of opinion is achieved, these ratings are recorded in the contribution matrix, Figure 24, Appendix VIII. As an example of this type of evaluation, consider how the project to establish terminal area ride quality limits contributes to program objectives: it makes a moderate contribution to the objective to increase vehicle applications, since the vehicle's application as a passenger transport depends on improved passenger ride quality; moderate contribution to the objective to reduce vibration, since vibration levels tend to be highest in the terminal area, low speed regimes; and minor contribution to the objective to reduce exterior noise. Finally, using the objective priority vector, matrix multiplication is performed according to the expressions developed in Chapter III to derive both direct and indirect project benefit scores. These scores are then normalized to a value of 0 to 1 by subtracting the minimum project score of the group from each project and then dividing all resulting scores by that same minimal score. Figures 30 and 31, Appendix IX, present the project indirect and direct benefit coefficients.

Tables 19 and 20, Appendix IX, present a summary of changes in project direct and indirect benefit coefficients as a function of client priorities. Notice that indirect project benefit coefficients are insensitive to client priorities while direct project benefit coefficients are relatively sensitive, depending on the project under consideration. In other words, the importance one places on program clients does influence the evaluation of projects' direct benefits.

3. Benefit Uncertainty

The purpose of the project benefit uncertainty scoring function is to provide an evaluation of the uncertainty in achieving project benefits. In the initial step of the process, the evaluation team independently rated each project on each of the nine technical criteria discussed in Chapter III, using a three point scale. For the technical, schedule and cost uncertainty criteria, a value of 3 represents minimal uncertainty; 2, moderate uncertainty; and 1, high uncertainty. For the remaining criteria, a value of 3 represents excellent; 2, adequate; and 1, minimal. Only after all projects were rated for one criterion was the next criterion considered. This helped to enhance the independence of one criterion rating from the next and prevented a high or low rating for a particular project on a specific criterion from having an impact on all other criteria for that project (50). As in all the scoring function evaluations, the rating scales were thoroughly explained to the evaluators prior to the evaluation process in order to insure consistency.

Once general group consensus was achieved these ratings were recorded in the criteria matrix, Figure 25, Appendix VIII. As an example of this type of rating, consider the project to evaluate operating procedures used to reduce exterior noise signatures. This is an experimental project involving flight hardware and a flight schedule. There are several factors that could potentially prevent the completion of required tasks within the estimated cost and schedule, and which therefore increases the technical, schedule, as well as cost uncertainty of the project. Thus these criteria are rated low. Since this project has access to the best in acoustical equipment and several generic helicopter types, the research facilities are highly rated. The personnel who will conduct this research are capable of the task, and the project is adequately planned. The flexibility of the technical approach is rated low since no options for concurrent research tasks are planned (for example, this project could ideally be coordinated with some of the tasks of the terminal area ride quality project). The potential for technology spin-offs are rated average and since the topic of the research is of particular interest to the FAA, the intangible criterion is highly rated.

In the next step, the relative importance of the technical criteria to the overall uncertainty evaluation was established by means of discussion with program management of the Civil Helicopter Research Program. Using a 7-point scale, with 7 representing most important and 1 representing least important, these criteria weights are shown in Figure 7. These values relate the importance of each criterion in successfully achieving the potential benefits from proposed projects. For instance, in this program, management feels that meeting schedule deadlines is not as important as successfully achieving the project tasks. Therefore schedule uncertainty rates lower than cost or technical uncertainty. (It should be pointed out, however, that these ratings represent management values for this particular program.)

Using the expression developed in Chapter III, benefit uncertainty scores can now be computed. As in the benefit evaluation, these scores are normalized by subtracting the minimum score from each project total and then dividing by the same minimum score. The resulting project benefit uncertainty coefficients are presented in Figure 32, Appendix IX. These results indicate that the potential benefits of the projects to quantify the design and manufacturing variable costs and to evaluate contingencies leading to pilot errors are most certain of success.

Figure 7 Technical Criteria Weights

Technical Uncertainty	7
Schedule Uncertainty	5
Cost Uncertainty	7
Availability of Research Facilities	4
Availability of Technical Expertise	5
Quality of Technical Approach	6
Flexibility of Technical Approach	6
Technology Transfer	3
Intangible Factors	3

4. Schedule Priority

The objective of the project schedule priority scoring function is to identify the potential scheduling dependencies between projects and to measure their total relative value. To accomplish this objective, three engineers were given a project interaction matrix to independently evaluate. The element P_{ij} of this matrix represents the recommended schedule relationship between project i and project j. If the evaluator felt that project i should be completed prior to project j, he was to record a value of 1 in the P_{ij} element. If the converse was true then a value of -1 was required; no schedule relationship dictated a 0 value. These evaluations represent a first iteration analysis. As such, they represent initial estimates of project scheduling relationships. They are not prohibitive constraints on project scheduling plans, and overlapping schedule relationships are not considered.

Once completed, these three matrices were compared, checked for consistency of the transitivity condition and the results discussed with the evaluators so that a matrix representing a consensus of views could be constructed. This matrix is presented in Figure 26, Appendix VIII. The schedule priority scores for each project were then computed by summing across the row for each project and converted to normalized coefficients for use in the project utility function. Figure 33, Appendix IX, presents the results of this process. These results indicate that the projects to quantify design and manufacturing variable costs and to document the reliability and maintainability data base of civil operators rate highest relative to the other projects when considering which projects should take precedence solely from a scheduling point of view.

5. Summary of Project Utilities

In Chapter III it was stated that the payoff of a research program is achieved from the utility of each of its individual projects. It is assumed that each project has utility due to the benefits it provides, the certainty in achieving these benefits, and the priority it should be afforded as a result of scheduling considerations. Table 3 contains a summary of each project's utility coefficients. Since each component of this utility exists as a normalized coefficient with values in the range of 0-1, it is feasible to add these coefficients (thereby assuming the existence of an interval scale), in order to obtain a measure of a project's total utility (assuming each component is equally weighted). In this case, each project's measure of utility lies in the range of 0 to 4.0. Doing this, one finds that the projects can be divided into four distinct groups, as illustrated in Figure 8. In the first group, there is only one project, to quantify the design and manufacturing variable costs, with a utility of 3.6. In the second group, there are seven projects with a utility range of 2.3 to 3.0; in the third group, four projects with a utility range of 1.8 to 1.9; and in the fourth group, six projects with a utility range of 0.9 to 1.5. Figures 34 to 37 in Appendix X presents a graphical summary of these project utilities.

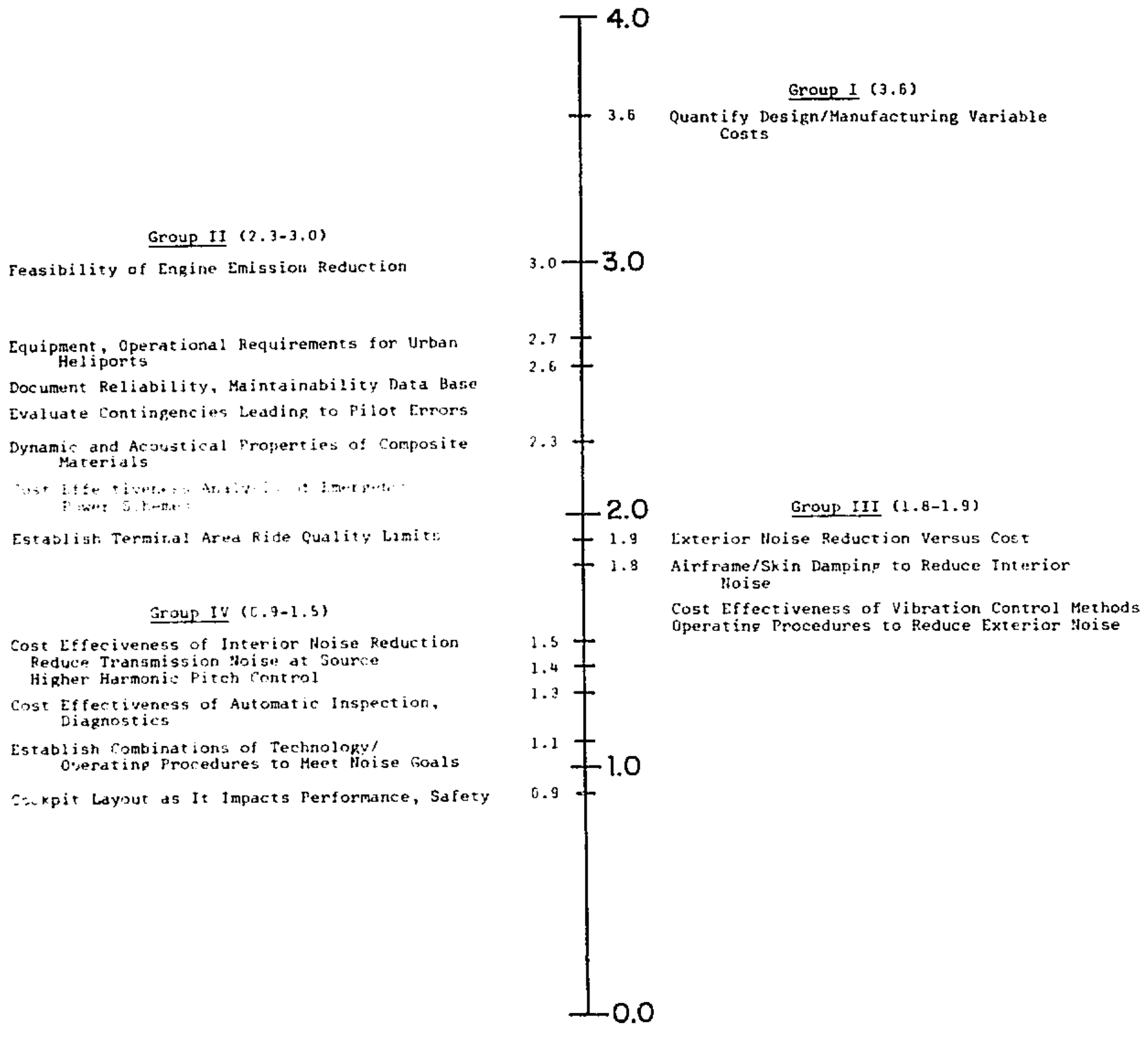


Figure 8 Summary of Project Utilities

Project ↓ / Sub-Strategy →	Direct Benefits	Indirect Benefits	Benefit Uncertainty	Schedule Priority
Higher Harmonic Pitch Control	0	0.4	0.3	0.7
Reduce Transmission Noise At Source	0.1	0.4	0.3	0.7
Exterior Noise Reduction Versus Cost	0.7	0.3	0.4	0.5
Document Reliability, Maintainability Data Base	0.3	0.9	0.5	0.9
Quantify Design/ Manufacturing Variable Costs	0.6	1.0	1.0	1.0
Cost Effectiveness Analysis of Emergency Power Schemes	0.6	0.8	0.2	0.7
Feasibility of Engine Emission Reduction	0.7	0.8	0.9	0.6
Establish Terminal Area Ride Quality Limits	0.1	1.0	0.5	0.7
Airframe/Skin Damping to Reduce Interior Noise	0.4	0.4	0.2	0.8
Cost Effectiveness of Vibration Control Methods	0.4	0.6	0.3	0.5
Equipment, Operational Requirements for Urban Heliports	1.0	0.3	0.6	0.8
Evaluate Contingencies Leading to Pilot Errors	0.3	0.6	1.0	0.7
Cost Effectiveness of Automatic Inspection Diagnostics	0.7	0	0	0.6
Dynamic and Acoustical Properties of Composite Materials	0.5	0.5	0.6	0.7
Operating Procedures to Reduce Exterior Noise	0.7	0.3	0.1	0.7
Cost Effectiveness of Interior Noise Reduction Methods	0.5	0.4	0.2	0.4
Cockpit Layout As It Impacts Performance Safety	0.4	0	0.2	0.3
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	0.8	0	0.4	

Table 3 Summary of Project Utility Coefficients

F. Sensitivity Analysis

To investigate the robustness of these utility coefficients, a sensitivity analysis was performed to test the potential effect of small changes in ratings and values. In each case, the sensitivity in these coefficients was evaluated as a function of independent, unit changes in matrix elements. The results of this analysis are discussed in the following paragraphs.

Changes in objective indirect priority weights as a function of changes in the elements of the objective interaction matrix vary from a minimum of 50 to a maximum of 170, depending on the matrix element changed. Since the range of objective indirect weights is narrow (5090 to 5670), a change of 170 can significantly affect the priority ranking. However, since total weighting scores are used in the evaluation of project indirect benefits, coefficients are not sensitive to changes of this magnitude. Similar results were found in evaluating the change in objective indirect priority weights due to changes in elements of the client objective priority matrix.

In the case of objective direct priorities, the priority weights were found to vary from a minimum of 40 to a maximum of 140 as a function of changes in elements of the client objective priority matrix. Since the range of objective direct priority weights is large (1100 to

Sub-Strategy → Project ↓	Direct Benefits	Indirect Benefits	Benefit Uncertainty	Schedule Priority
Higher Harmonic Pitch Control	0	0.4	0.3	0.7
Reduce Transmission Noise At Source	0.1	0.4	0.3	0.7
Exterior Noise Reduction Versus Cost	0.7	0.3	0.4	0.5
Document Reliability, Maintainability Data Base	0.3	0.9	0.5	0.9
Quantify Design/ Manufacturing Variable Costs	0.6	1.0	1.0	1.0
Cost Effectiveness Analysis of Emergency Power Schemes	0.6	0.9	0.2	0.7
Feasibility of Engine Emission Reduction	0.7	0.8	0.9	0.6
Establish Terminal Area Ride Quality Limits	0.1	1.0	0.5	0.7
Airframe/Skin Damping to Reduce Interior Noise	0.4	0.4	0.2	0.8
Cost Effectiveness of Vibration Control Methods	0.4	0.6	0.3	0.5
Equipment, Operational Requirements for Urban Heliports	1.0	0.3	0.6	0.8
Evaluate Contingencies Leading to Pilot Errors	0.3	0.6	1.0	0.7
Cost Effectiveness of Automatic Inspection Diagnostics	0.7	0	0	0.6
Dynamic and Acoustical Properties of Composite Materials	0.5	0.5	0.6	0.7
Operating Procedures to Reduce Exterior Noise	0.7	0.3	0.1	0.7
Cost Effectiveness of Interior Noise Reduction Methods	0.5	0.4	0.2	0.4
Cockpit Layout As It Impacts Performance Safety	0.4	0	0.2	0.3
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	0.8	0	0.3	0

Table 3 Summary of Project Utility Coefficients

3400), these changes typically have little effect on objective priority rankings and no impact on project direct benefit coefficients.

Changes in indirect benefit coefficients are more sensitive to variation in elements of the project interaction matrix than to variation in elements of the contribution matrix. Changes in elements of the project interaction matrix result in a variation in the indirect benefit coefficient values from 0.01 to 0.04 depending on the matrix element involved. Variations in these coefficients due to changes in elements of the contribution matrix are insignificant.

Both the maximum and minimum variances of the projects benefit; benefit uncertainty and schedule priority scores are shown as error flags on Figures 27 through 33 in Appendix IX. One concludes from this analysis that all of the scoring functions are effectively insensitive to single evaluation inputs. That is, there is no one single input that significantly affects the output of any one of these four scoring functions.

G. Application of Integer Programming Algorithm

Once the project utility component coefficients have been determined, they must be placed in order of priority and numerical weights assigned to reflect their relative importance. The weights are assumed to be additive. For instance, if one component is assigned a weight of 0.4, another a weight of 0.2 and another a weight of 0.2, the importance of the two latter ones taken together must equal the importance of the first one. Ten alternative sets of coefficient weights, reflecting different emphasis on each utility coefficient, are used to investigate how each project utility coefficient varies as a function of component priority values. Figure 9 presents the results of this analysis. The shaded coefficients in this figure represent variations from the equal weights or baseline case. Neglecting the first two columns, where zero weights are employed, one observes that one project utility coefficient is independent of the component priorities used, twelve coefficients vary either plus or minus 0.1 from the baseline, four coefficients vary ±0.1 (range of 0.2) from the baseline and one coefficient (for the project to establish terminal area ride quality limits) varies over a range of 0.3 (0.4 to 0.7). These last five projects are, of course, the most important from the point of view of studying selection tradeoffs as a function of management priorities.

The final type of information necessary before the integer program algorithm can be applied is project cost estimates. Where contractor proposal cost estimates

Figure 9 Project Utility Coefficients as a Function of Project Utility Component Weights

Project ↓ / Project Utility Component Weights* →	0.5,0.5, 0,0	0.33,0.33, 0.33,0	0.25,0.25, 0.25,0.25	0.2,0.2, 0.3,0.3	0.3,0.1, 0.3,0.3	0.4,0.1, 0.25,0.25	0.4,0.2, 0.2,0.2	0.2,0.4, 0.2,0.2	0.2,0.2, 0.4,0.2	0.2,0.2 0.2,0.4
Higher Harmonic Pitch Control	▨ 0.2	▨ 0.2	0.3	▨ 0.4	0.3	0.3	0.3	▨ 0.4	0.3	▨ 0.4
Reduce Transmission Noise At Source	▨ 0.3	▨ 0.3	0.4	0.4	0.4	▨ 0.3	▨ 0.3	0.4	0.4	▨ 0.5
Exterior Noise Reduction Versus Cost	0.5	0.5	0.5	0.5	0.5	0.5	0.5	▨ 0.4	0.5	0.5
Modument Reliability, Maintainability Data Base	0.6	0.6	0.6	▨ 0.7	0.6	0.6	0.6	▨ 0.7	0.6	▨ 0.7
Quantify Design/ Manufacturing Variable Costs	▨ 0.8	0.9	0.9	0.9	0.9	▨ 0.8	▨ 0.8	0.9	0.9	0.9
Cost Effectiveness Analysis of Emergency Power Schemes	▨ 0.7	▨ 0.5	0.6	▨ 0.5	▨ 0.5	▨ 0.5	0.6	0.6	▨ 0.5	0.6
Feasibility of Engine Emission Reudction	0.7	▨ 0.8	0.7	0.7	0.7	0.7	0.7	▨ 0.8	▨ 0.8	0.7
Establish Terminal Area Ride Quality Limits	▨ 0.5	▨ 0.5	0.6	0.6	▨ 0.5	▨ 0.4	▨ 0.5	▨ 0.7	0.6	0.6
Airframe/Skin Damping to Reduce Interior Noise	0.4	▨ 0.3	0.4	▨ 0.5	▨ 0.5	0.4	0.4	▨ 0.5	0.4	▨ 0.5
Cost Effectiveness of Vibration Control Methods	▨ 0.5	0.4	0.4	0.4	0.4	0.4	▨ 0.5	▨ 0.5	0.4	▨ 0.5
Equipment, Operational Requirements for Urban Heliports	▨ 0.6	▨ 0.6	0.7	0.7	0.7	▨ 0.8	0.7	▨ 0.6	0.7	0.7
Evaluate Contingencies Leading to Pilot Errors	▨ 0.4	0.6	0.6	▨ 0.7	▨ 0.7	0.6	0.6	0.6	▨ 0.7	▨ 0.7
Cost Effectiveness of Automatic Inspection, Diagnostics	0.3	▨ 0.2	0.3	0.3	▨ 0.4	▨ 0.4	▨ 0.4	0.3	0.3	▨ 0.4
Dynamic and Acoustical Properties of Composite Materials	▨ 0.5	▨ 0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Operating Procedures to Reduce Exterior Noise	▨ [illegible]	0.4	0.4	0.4	▨ 0.5	▨ 0.5	▨ 0.5	0.4	0.4	▨ 0.5
Cost Effectiveness of Interior Noise Reduciton Methods	▨ 0.5	0.4	0.4	0.4	0.4	▨ 0.5	0.4	0.4	▨ 0.3	0.4
Cockpit Layout As It Impacts Performance, Safety	0.2	0.2	0.2	0.2	▨ 0.3	▨ 0.3	▨ 0.3	0.2	0.2	0.2
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	▨ 0.4	▨ 0.4	0.3	▨ 0.2	0.3	▨ 0.4	▨ 0.4	▨ 0.2	0.3	▨ 0.2

*Presentation order of weights is direct benefits, indirect benefits, benefit uncertainty and schedule priority.

were available, they were used. Otherwise, several experts in the respective technological areas were presented proposals and asked to estimate what that project would cost to complete. In both instances, a conservative philosophy was adopted, and a rather wide range about the estimate was assumed. These project cost estimate ranges are listed in Table 4.

Because of the somewhat uncertain nature of project costs and because one needs information on how selection results depend on utility component priorities, an iterative approach to algorithm application was planned. Five case options of project costs were selected, as shown in Table 4. The first three cases represent high, low and moderate cost vectors, respectively. For example, in the first case option, the highest cost for each project was assumed. For each of these three cases of project cost estimates, six independent iterations of the integer programming algorithm were conducted, with each iteration utilizing a different project utility component weight vector and a program budget constraint of $500,000. These six vectors are presented in Table 5 and represent the full range of coefficients seen for each project, as previously identified. No technology balance constraints were used in these iterations, since the range of technology reflected in the eighteen project options was

Case → Project ↓	Project Costs (1000$)					
	Project Cost Estimate Range	Case 1	Case 2	Case 3	Case 4	Case 5
Higher Harmonic Pitch-Control	70-100	100	70	80	70	70
Reduce Transmission Noise at Source	75-105	105	75	90	75	75
Exterior Noise Reduction Versus Cost	60-95	95	60	70	70	85
Document Reliability, Maintainability Data Base	40-80	80	40	55	80	65
Quantify Design/Manufacturing Variable Costs	35-70	70	35	50	70	70
Cost Effectiveness Analysis of Emergency Power Schemes	30-70	70	30	50	70	65
Feasibility of Engine Emission Reduction	40-70	70	40	55	70	70
Establish Terminal Area Ride Quality Limits	75-90	90	75	80	85	75
Airframe/Skin Damping to Reduce Interior Noise	50-75	75	50	60	75	50
Cost Effectiveness of Vibration Control Methods	60-85	85	60	70	85	60
Equipment, Operational Requirements for Urban Heliports	60-95	95	60	80	80	75
Evaluate Contingencies Leading to Pilot Errors	40-75	75	40	55	70	60
Cost Effectiveness of Automatic Inspection, Diagnostics	35-60	60	35	50	55	50
Dynamic and Acoustical Properties of Composite Materials	70-85	80	75	75	80	70
Operating Procedures to Reduce Exterior Noise	60-90	90	60	80	60	65
Cost Effectiveness of Interior Noise Reduction Methods	45-75	75	45	55	75	55
Cockpit Layout as It Impacts Performance, Safety	50-80	80	50	60	55	50
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	70-90	90	70	80	75	70

Table 4 Project Cost Estimates by Model Case

Utility Vector Weights → Project ↓	0.25,0.25, 0.25,0.25	0.4,0.2 0.2,0.2	0.2,0.4, 0.2,0.2	0.2,0.2, 0.4,0.2	0.2,0.2, 0.2,0.4	0.4,0.1 0.25,0.25
Higher Harmonic Pitch Control						
Reduce Transmission Noise at Source						
Exterior Noise Reduction Versus Cost	S	S			S	
Document Reliability, Maintainability Data Base	S	S	S	S	S	S
Quantify Design/Manufacturing Variable Costs	S	S	S	S	S	S
Cost Effeciveness Analysis of Emergency Power Schemes	S	S	S	S	S	S
Feasibility of Engine Emission Reduction	S	S	S	S	S	S
Establish Terminal Area Ride Quality Limits			S	S		
Airframe/Skin Damping to Reduce Interior Noise	S		S		S	
Cost Effectiveness of Vibration Control Methods						
Equipment, Operational Requirements for Urban Heliports		S		S		S
Evaluate Contingencies Leading to Pilot Errors	S	S	S	S	S	S
Cost Effeciveness of Automatic Inspection, Diagnostics	S	S			S	
Dynamic and Acoustical Properties of Composite Materials				S		S
Operating Procedures to Reduce Exterior Noise						
Cost Effectiveness of Interior Noise Reduction Methods	S		S			S
Cockpit Layout As it Impacts Performance, Safety						
Establish Combinations of Technology/Operating Procedures To Meet Noise Goals						

Table 5 Case 3 Project Selections As a Function of Project Utility Vector Weights

felt to be diverse enough that they would not be needed.

Consider, for example, the results of case 3, as presented in Table 5, where the symbol S stands for a selected project for that particular iteration (each column represents a separate iteration). Notice that five projects are selected in every iteration, and therefore are independent of the utility component priority used. In addition, there are seven projects which may or may not be selected, depending on which component of project utility is emphasized, and six other projects that are selection omissions in every iteration. Table 6 summarizes the conclusions one draws from the iterations in this case. Obviously, priority should be given to the dominant selections. For the final few selections within the program budget, one must examine the tradeoff alternatives. For example, in the situation where priority is placed on direct benefits (utility vector weights 0.4, 0.2, 0.2, 0.2) one should fund the projects to investigate the costs of exterior noise reduction, to conduct a cost effectiveness analysis of automatic inspection and diagnostics systems, and to define the equipment and operational requirements for urban heliports. On the other hand, if priority is placed on the certainty in which the benefits can be expected as opposed to the direct benefits themselves (utility vector weights 0.2,

Table 6 Case 3 Model Results

DOMINANT SELECTIONS

Document reliability, maintainability data base.
Quantify design/manufacturing variable costs.
Cost Effectiveness analysis of emergency power schemes.
Feasibility of engine emission reduction.
Evaluate contingencies leading to pilot error.

BORDERLINE SELECTIONS

Exterior noise reduction versus cost.
Establish terminal area ride quality limits.
Airframe/skin damping to reduce interior noise.
Equipment, operational requirements for urban heliports.
Cost effectiveness of automatic inspection, diagnostics.
Dynamic and acoustical properties of composite materials.
Cost effectiveness of interior noise reduction methods.

NON-SELECTIONS

Higher harmonic pitch control.
Reduce transmission noise at source.
Cost effectiveness of vibration control methods.
Operating procedures to reduce exterior noise.
Cockpit layout as it impacts performance, safety
Establish combinations of technology/operating procedures to meet noise goals.

0.4, 0.2, 0.2), then one should fund the projects to study the airframe and skin damping to reduce interior noise, to establish terminal area ride quality limits. and to define the cost effectiveness of interior noise reduction methods in lieu of the previous three projects.

On the basis of the results from the first three project cost cases, two additional cases were derived. In these, the costs of the dominant project selections were increased to the maximum, while several of the borderline and non-selection projects were decreased to the minimum. One concludes from the results of cases four and five that, essentially, the dominant and non-selection projects are not sensitive to variations in project cost, within the estimated cost range. Table 7 presents a general summary of the model results on all five cases. In this table, borderline selections are listed by selection rank. That is, those projects at the top of this list were selected more frequently than those at the bottom of the list. Summaries of the results for each of the five cases are found in Tables 21 to 25 in Appendix XI.

In Chapter II it was stated that a project scoring model establishes an index of worth for each project and project alternatives are ranked by this index; the higher the index, the more desirable the project. Projects are

Table 7 Model Results Summary

DOMINANT SELECTIONS

Quantify design/manufacturing costs.
Feasibility of engine emission reduction.
Evaluate contingencies leading to pilot errors.
Document reliability, maintainability data base

BORDERLINE SELECTIONS

Cost effectiveness analysis of emergency power schemes.
Establish terminal area ride quality limits.
Equipment, operational requirements for urban heliports.
Dynamic and acoustical properties of composite materials.

Airframe/skin damping to reduce interior noise.
Cost effectiveness of interior noise reduction methods.

Exterior noise reduction versus cost.
Cost effectiveness of automatic inspection, diagnostics.
Operating procedures to reduce exterior noise.

NON-SELECTIONS

Higher harmonic pitch control.
Reduce transmission noise at source.
Cost effectiveness of vibration control methods.
Cockpit layout as it impacts performance, safety.
Establish combinations of technology/operating procedures to meet noise goal.

selected by their relative rank until the research budget has been consumed. A weakness in this approach is that the selection of projects from a ranked list offers no assurance of an optimal allocation. That is, the model provides no means to consider whether it would be better to select two lower-cost, lower-ranking projects instead of a higher-cost, higher-ranking one. The integer programming algorithm permits these types of comparisons to be made. To compare the selection priority ranking between the scoring model technique and the integer programming algorithm, a final analysis was performed. To obtain the rank of the projects selected for funding by the integer programming algorithm, the research budget constraint was reduced to $50,000 and then increased in increments of $50,000 for each iteration of the algorithm, with each iteration typically introducing a new project selection into the selection set, until the actual budget of $500,000 is reached. This approach was conducted on each of the five project cost cases using the baseline or equal utility component weights vector (0.25, 0.25, 0.25, 0.25). These results are compared with the baseline ranking (equal utility weights) of projects in Table 8. In this table, the projects are listed by their total utility score, from highest (at the top) to lowest. Selecting projects by the method of a typical

Table 8 Project Selection Rank versus Project Baseline Rank

Case → Project By Baseline Rank	Case 1	Case 2	Case 3	Case 4	Case 5
Quantify Design/Manufacturing Variable Costs	1	1	1	1	1
Feasibility of Engine Emission Reduction	2	3	2	2	2
Equipment, Operational Requirements for Urban Heliports		6	6	3	4
Document Reliability, Maintainability Data Base	6	5	5		6
Evaluate Contingencies Leading to Pilot Errors	4	4	4	4	3
Dynamic and Acoustical Properties of Composite Materials	5		7	6	7
Cost Effectiveness Analysis of Emergency Power Schemes	3	2	3	5	5
Establish Terminal Area Ride Quality Limits		10	8		8
Exterior Noise Reduction Versus Cost		9			
Airframe/Skin Damping To Reduce Interior Noise					
Cost Effectiveness of Vibration Control Methods					
Operating Procedures to Reduce Exterior Noise					
Cost Effectiveness of Interior Noise Reduction Methods		7			
Reduce Transmission Noise At Source					
Higher Harmonic Pitch Control					
Cost Effectiveness of Automatic Inspection, Diagnostics		8			
Establish Combinations of Technology/Operating Procedures To Meet Noise Goals					
Cockpit Layout as It Impacts Performance, Safety					

scoring model, one would simply go down this ranked list until the budget was consumed. One concludes from this comparison that the project selection priorities are significantly different in each of the five cases, as that which would have resulted from the scoring model method. In addition, program payoffs would be increased by funding those project selections recommended by the integer programming algorithm as opposed to the scoring model. The value of this algorithm increases further when additional constraints (such as technology balance constraints or manpower resource constraints, for example) must be considered. Although there are, of course, other means of selecting projects for funding not considered here, the integer programming algorithm is an effective and justifiable approach.

G. Discussion of Results

In considering a summary of the results of this analysis presented in Table 7, one notes some obvious or expected results as well as some less than obvious, or as is often the case, unexpected results. One project that was expected to be among those recommended for funding is the project to quantify design and manufacturing variables that establish a vehicle's acquisition cost. The results of this project will provide a great deal of very useful information to other project alternatives, simply because costs impact every research objective. Much of this information is important enough to delay other projects until it is in hand, and thus the schedule priority of the project is high. In addition, the project makes at least a minor contribution to a vast majority of program objectives. Two additional projects that are selected for funding, as expected, are the projects to evaluate the contingencies leading to pilot errors and to document the reliability and maintainability data base of civil operators.

Perhaps more important than the expected results are the less than obvious or unexpected ones. One project that ranks higher than anticipated is the project to evaluate the feasibility of engine emission reduction. On the surface it would appear that the results of this project would contribute little to the results of other projects or to the program objectives. In addition, the objective to reduce engine emission, to which this project is directly related, ranks low in priority among other program objectives. However, closer scrutiny reveals that the requirements for engine emission reduction have potentially negative impact on both vehicle acquisition and operating cost, system maintenance, emergency power requirements, urban heliport operations, and aircraft performance. Therefore it interacts with several projects and program objectives. Two unexpected non-selections are the projects to evaluate operating procedures to reduce exterior noise and to reduce aircraft transmission noise at the source. The exterior noise project does provide significant direct benefits. Reducing exterior noise signatures will increase vehicle applications, increase air travel accessibility, and decrease interior noise within the aircraft cabin. This project's impact on operational safety and vehicle acquisition cost also needs to be examined. However the project is experimental in nature and therefore considerable cost and schedule uncertainties are involved. In addition, the results for one type of aircraft (for example, single rotor systems) may not be transferable to other types of aircraft (twin rotor aircraft, for example). Therefore the certainty in achieving the potential benefits is low. The project's schedule priority is relatively low as are the project's indirect benefits. There are a few other projects in the program that could use the results of this project.

Although transmission noise is considered to be one of the most significant factors in passenger ride dissatisfaction, the fact is, this project makes little contribution to program objectives other than to reduce interior noise, and the priority of this objective is not great, considering all client values. In addition, the results of this project provide little gain to other projects of the Civil Helicopter Technology Program. Therefore, in reflecting back on the information analysis, the reasoning behind these results are sound.

Both the expected and unexpected results point out the importance of being able to track back through the model to establish the information and reasoning behind a particular result. As Helin and Souder (30) point out, it is not the analytical or decision optimizing properties of a model that are most significant or of more value. The greatest benefit provided by a project selection model is that in the process of using the model to achieve a solution and to examine the reasoning behind a solution, the use of information and communication channels is increased. Thus the process forces a more complete examination of project alternatives and decision premises. The documentation of information, data, and values is an important element in this process for two reasons. First, the documentation provides visibility for the decision process. Second, it permits further improvements in the information interface between the research staff and the technology users and non-users.

While the actual funding of research projects may occur on an annual basis, the selection process is not an annual one-shot affair. Obtaining information to provide the basis for establishing and prioritizing research objectives, evaluating research project options, and planning the long term nature of a research program is a continual, iterative process. Another iteration of this process is now underway in the Civil Helicopter Research Program. At the normative level, analysis of information obtained in previous iterations is being used to define areas where more specific details are required. The results of the operator survey are a good case in point. Specific points of question in individual questionnaires have been marked so that follow-up interviews with the operators can explore particular responses in greater detail. In addition, although technological problem areas were ranked as a result of this survey, little specific trade-off alternative information was obtained. Objective interaction analysis combined with the initial survey results provide an excellent basis for further survey or interview work to examine trade-off alternatives. As an example of such a trade-off, one would like to know how much performance loss operators would sacrifice for a reduction in exterior noise. Other trade-offs, such as improved performance versus additional life cycle cost and reduced operating cost versus additional initial vehicle cost also require investigation. This information would be most beneficial in constructing interval scales of client values.

At the descriptive level, complete results of the analysis are provided as feedback to the research evaluation team. This feedback provides an important dual purpose. First, the results raise certain questions which, to be answered, require the analysis process be conducted in reverse so that the reasoning and data underlying the result may be examined. Quite often this provides a detail or two overlooked in the initial information exchange between research personnel and the technology user or non-user. These added details often present different perspectives and thus permit a more accurate worth assessment to be derived. Second, the analysis highlights certain areas where further data are necessary for more accurate evaluations. Knowledge of these areas would be useful, for example, to more closely differentiate the trade-offs between the borderline selection alternatives. It would also be beneficial in a second iteration where additional projects are included and new selections are required.

A final type of information that is important in future iterations of a project selection model is the feedback between the normative and descriptive levels of the analysis. In evaluating project interactions, project to objective interactions and the like at the descriptive level, the research staff must have intimate knowledge of the use of the technology and the problems inherent in using it. This knowledge can only be provided by someone intimate in its operation. Likewise, to fully evaluate his own value structure concerning a technology and its use, the operator must understand what his values mean in terms of the effects on the technology. For example, if an operator places high priority on future equipment that will be less noisy and ride more comfortably, he should appreciate what those qualities are likely to cost in terms of vehicle cost, performance and the like. Knowing this information quite often can affect his value structure. Therefore the feedback of information between the normative and descriptive levels is an important part of an iterative analysis.

H. Summary

This chapter documents the application of the proposed project selection model to NASA's Civil Helicopter Technology Program. The application of this model is important for several reasons. First, the management of this program requires a list of research project priorities which reflect the needs of both helicopter users and those non-users who will be impacted by these vehicles. Second, this application provides the means to study the utility of this model in a real world environment. Finally, the model application provides an opportunity to develop more fully the components of the model.

After an overview of the Civil Helicopter Technology Program is presented, the sources and types of information from which the client values are derived, are discussed. This information provides a basis for identifying research objectives and project alternatives. Once research objectives have been prioritized and project alternatives identified, these project alternatives are evaluated using scoring functions for a project's potential benefits, certainty in achieving these benefits and schedule priority. Six iterations of an integer programming algorithm are conducted for each of five cases of project cost vectors, with each iteration utilizing a different set of utility component weights. The results of these iterations indicate a set of four dominant project selections and a set of five non-selections that are essentially independent of project utility priorities and project costs. The few remaining project selections within the program budget constraint depend on utility sub-strategy priorities and project cost estimates used.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

In recent commentary in "Transportation Research News," Kenneth Orski (48) discusses an essay entitled "On the Usefulness of Useless Research." This essay was written some 40 years ago by Abraham Flexner, a noted scholar and founder of the Institute of Advanced Studies at Princeton. As Orski writes, in that essay Flexner argued that scientific and technological progress develops as an autonomous process according to a logic of its own, largely uninfluenced by external events or considerations. He further contended that great advances in science and its application are commonly the result of accidental events, through the operation of the principle of serendipity, i.e., the discovery of facts that were unintended and not looked for. Flexner therefore concluded that it was unnecessary, indeed counterproductive, to plan and direct research efforts. Rather, Flexner contended, research should be allowed to follow a course of its own, relying on serendipity to bring about beneficial results.

In contrast to this laissez-faire approach, Orski introduces the concept of mission or application oriented research. This concept is grounded in the belief that research cannot be divorced from the larger purposes of human endeavor and, therefore, must be directed toward specific social objectives. The central theme in Orski's argument is that technology in itself has no social value except insofar as it serves, or facilitates achieving, larger societal purposes. Therefore, research should not begin with a desire to advance the state of the art, but rather with the consideration of user and community needs.

Orski's theme of application oriented research is a central one in this dissertation. That is, research and development not only can be, but should be, planned and formally directed; and the driving force in such a plan should be the application or mission for which the research "project" is to be ultimately used. The proposed project selection model developed in this study represents a first step in achieving the objective of formulating a complete model for planning research and development.

The purpose of this model is to provide a mechanism to integrate the necessary information so that research projects may be selected for funding. Its functional objective is to insure that: (a) all pertinent information is considered and (b) the projects are compared in a consistent and meaningful way with a minimum of bias.

The model uses an integer programming algorithm as the optimization method to select those projects that collectively maximize program payoff while achieving program resource and balance constraints. The program payoff comes from the utility of each of its individual projects, assuming each project's utility is due to the benefits it provides, the certainty in achieving these benefits, and its priority due to scheduling considerations. Each component of this utility is measured by its own scoring function, and the scores, once normalized, are assigned a priority weight and combined by means of a project utility function. The coefficients obtained from the project utility function provide the coefficients for the objective function of the integer program algorithm.

In an effort to evaluate the utility and effectiveness of this model in a real world environment, it was applied to NASA's Civil Helicopter Technology Program. The results of this exercise indicate several key points. First, the model is operational; that is, it is relatively easy to implement and simple to use. Second, it provides a technique for incorporating many individual views and expertise in a structured, systematic manner. This helps to insure the effective utilization of all the expertise available to the organization, which is especially important when the program spans a wide range of technical disciplines, as does the Civil Helicopter Technology Program. Finally, the model can be implemented at any point in the program, not just at program conception.

The model is particularly effective in assessing objective priorities with a minimum of bias, by focusing on the value structure of the research client, and by identifying the effects of, and the conflicts in, these objectives. Likewise, it aids the decision maker in ordering project priorities by indicating, for each project and for the program as a whole, their implications. With respect to the eighteen project alternatives considered in this application, four are recommended to receive high priority in selection decisions: to quantify the design and manufacturing variable costs, to evaluate the feasibility of engine emission reduction, to document the reliability and maintainability data base of civil operators, and to evaluate contingencies leading to pilot errors. These projects are dominant project selections, that is, they are selected independent of project costs and utility component priorities used in the model algorithm iterations. A second group of projects are identified as borderline selections. Several of this group are typically selected for a particular model iteration; the specific ones are dependent on the utility component priorities and project costs used. Finally, five project options are recommended to receive low priority in selection decisions. On the basis of the iterative runs of the model, these projects failed to be selected on any iteration, regardless of utility component priority or project costs.

On the basis of this analysis, management is given wide latitude in the selection decision; the model does not make the decisions. Rather, it simply recommends decision options on the basis of management values and on the consequences these options are likely to have. These consequences are identified in terms of:

1. objective priorities, reflecting client values;
2. direct project benefits, relating projects to program objectives and then to objective priorities;
3. indirect project benefits, relating project contributions to other projects;
4. uncertainty in achieving project benefits;
5. the schedule priority relationship of the project alternatives.

These consequences are easily abstracted from the documentation by simply tracking back through the model logic to examine the reasoning inherent in the analysis.

The benefits of model information documentation are in management's ability to analyze the model results and then to investigate the details and reasoning inherent in these results. It is difficult to overestimate the value of the ability to track back through the model. This capability improves the information interface between the research staff and the technology users by providing feedback data to act as a guide to increase future information exchange. In addition, since the model partitions the subjective and objective facets of the problem, this process is very effective in illustrating the impact of value judgments on decisions at all levels of the analysis.

Perhaps the most important asset of this model is that it promotes improved communication and information seeking behavior of program participants. In using the model, and analyzing its results, they become aware of the need to increase their use of existing communication channels and to develop new ones to obtain additional data. Therefore the effect of the introduction of the model on the increased availability and content of information flow to the decision maker is a key asset. The insights exchanged between the research staff and research clients in developing this information may be more important than the output provided by the model algorithm.

The proposed model is not intended as a panacea for all research and development project selection problems. However, the approach is predicted on the realities and practicalities of today's research environment and is suggested as an improvement on previous models in two basic areas. First, it provides a value structure framework for using the subjective judgments of program clients in evaluating research objective priorities. These priorities can then be used to evaluate the potential benefits expected from each project. Second, it incorporates resource allocation, project benefit evaluation, benefit uncertainty estimation, and project scheduling information into the selection decision framework so that tradeoff alternatives may be studied.

The model, although operational at this point, is not without certain deficiencies that could be improved through further research. One area where further study is required is in the definition of specific information requirements needed to develop the evaluations required in the model's scoring functions. In the initial application of this type of model, it is wise to leave wide latitude for evaluators to identify their own reasons for their evaluation. However, in later iterations, these initial inputs can be used to develop a check list of data needs to serve as a basis for further refinement of evaluations. The more specific the information requirements, the more consistent the evaluations can be, especially in the area of subjective value judgments.

Further study is also required to determine the relationship between the expenditure of research funds and the probability of success and the expected benefits from potential projects. One would also like to know the relationship between project benefits and the length of time for project completion as well as the optimal rate of expenditure. Once these relationships are established, then the model could employ a linear programming algorithm in place of an integer programming algorithm; so that partial funding of project alternatives could be studied. This capability would give added flexibility to the decision-making process.

Project selection decisions are made continually during a research program and thus this type of model will be in constant use. The concept of information flows generated in the selection process is an essential one in the use of this model, as previously discussed. Therefore one approach to handling this requirement for information is to provide a real-time information system to work in conjunction with the model. Further study is needed to define the requirements and to assess the utility of such a system. Finally, more work is also required to relate the short-term selection decision process with: 1) the processes of project control and progress evaluation so that management can better define when a project should be discontinued and 2) the long-term program plans, so that the impact of short-term selection decisions on long-term payoffs can be assessed.

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APPENDIX I Definition of Scales Utilized in Scoring Functions

Table 9 Scale Definition - Objective Interaction Matrix

Table 10 Scale Definition - Client Objective Priority Matrix

Table 11 Scale Definition - Contribution Matrix

Table 12 Scale Definition - Project Interaction Matrix

Table 9

SCALE DEFINITION - OBJECTIVE INTERACTION MATRIX

5 = <u>Major Influence</u>

achieving objective i will have a major influence on objective j (either in a positive or negative sense)

4 = <u>Minor Influence</u>

achieving objective i will have a minor influence on objective j (either in a positive or negative sense)

3 = <u>No Influence</u>

Table 10

SCALE DEFINITION - CLIENT OBJECTIVE PRIORITY MATRIX

7 = <u>Highest Priority</u>

6

5

4

3

2

1 = <u>Lowest Priority</u>

Table 11

SCALE DEFINITION - CONTRIBUTION MATRIX

3 = <u>Major Contribution</u>

successful attainment of project i will provide a major contribution to the successful achievement of objective j.

2 = <u>Some Contribution</u>

1 = <u>Minor Contribution</u>

0 = <u>Little Or No Contribution</u>

Table 12

SCALE DEFINITION - PROJECT INTERACTION MATRIX

6 = Absolutely Essential

The success of project i depends directly on the results of project j.

5 = Major Contribution

The results of project i will provide a major contribution to project j.

4 = Some Contribution

3 = Minor Contribution

2 = Indirect Contribution

1 = Remote Association

projects j and i are remotely associated, although no cross contributions can be identified.

0 = No Contribution

APPENDIX II Summary of Ride Quality Flight Research Results

Table 13 Experiment Noise and Vibration Levels

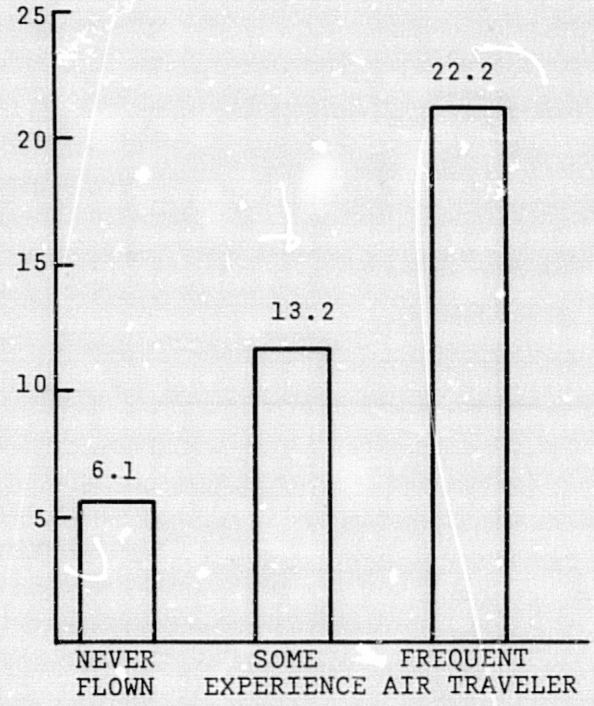
	VIBRATION (G rms)		NOISE (dBA)
	A_z (VERTICAL)	A_y (LATERAL)	
HIGH	0.14-0.18	0.09-0.11	88-92
LOW	0.08-0.12	0.06-0.08	83-95

Table 14 Perceived Importance of Environmental Factors Affecting Subjects Ride Satisfaction

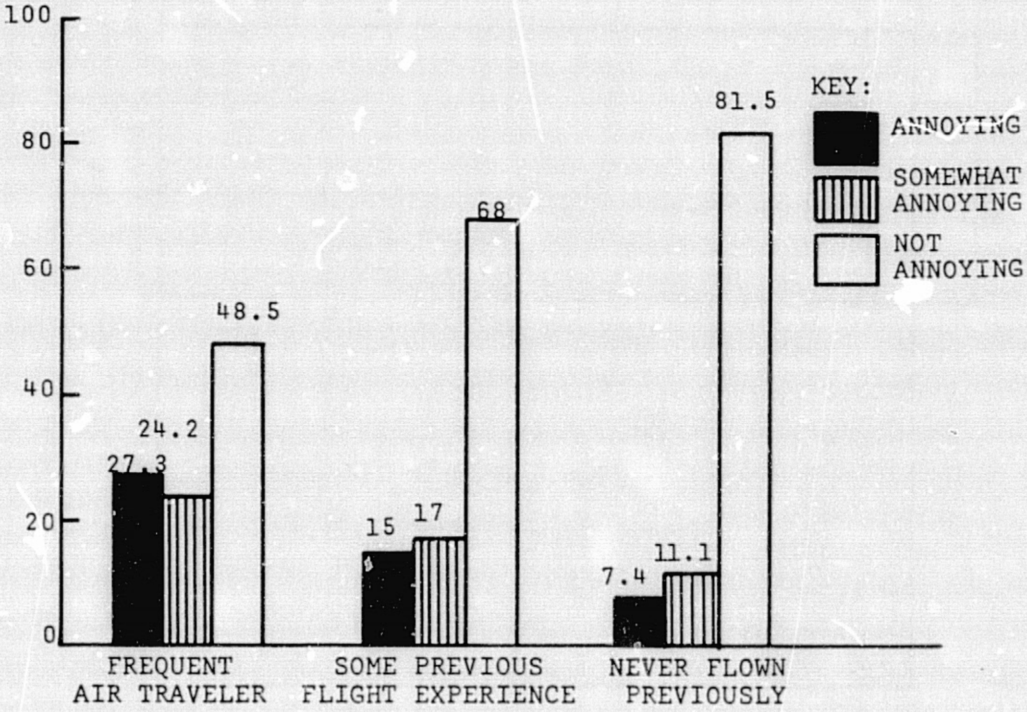
FACTOR	ALL SUBJECTS	SUBJECTS WHO HAD NEVER FLOWN PREVIOUSLY
NOISE	1	4
ABILITY TO SEE OUT OF WINDOW	2	1
VIBRATION	3	5
SEAT COMFORT	4	2
GENERAL MOTION	5	6
TEMPERATURE	6	3
PRESSURE CHANGE	7	7
SUDDEN JOLTS	8	9
SEATING SPACE	9	8

1=Most Important

9-Least Important



PERCENT NOT SATISFIED



FEELINGS ABOUT NOISE

Figure 10 Importance of Previous Flight Experience on Ride Satisfaction

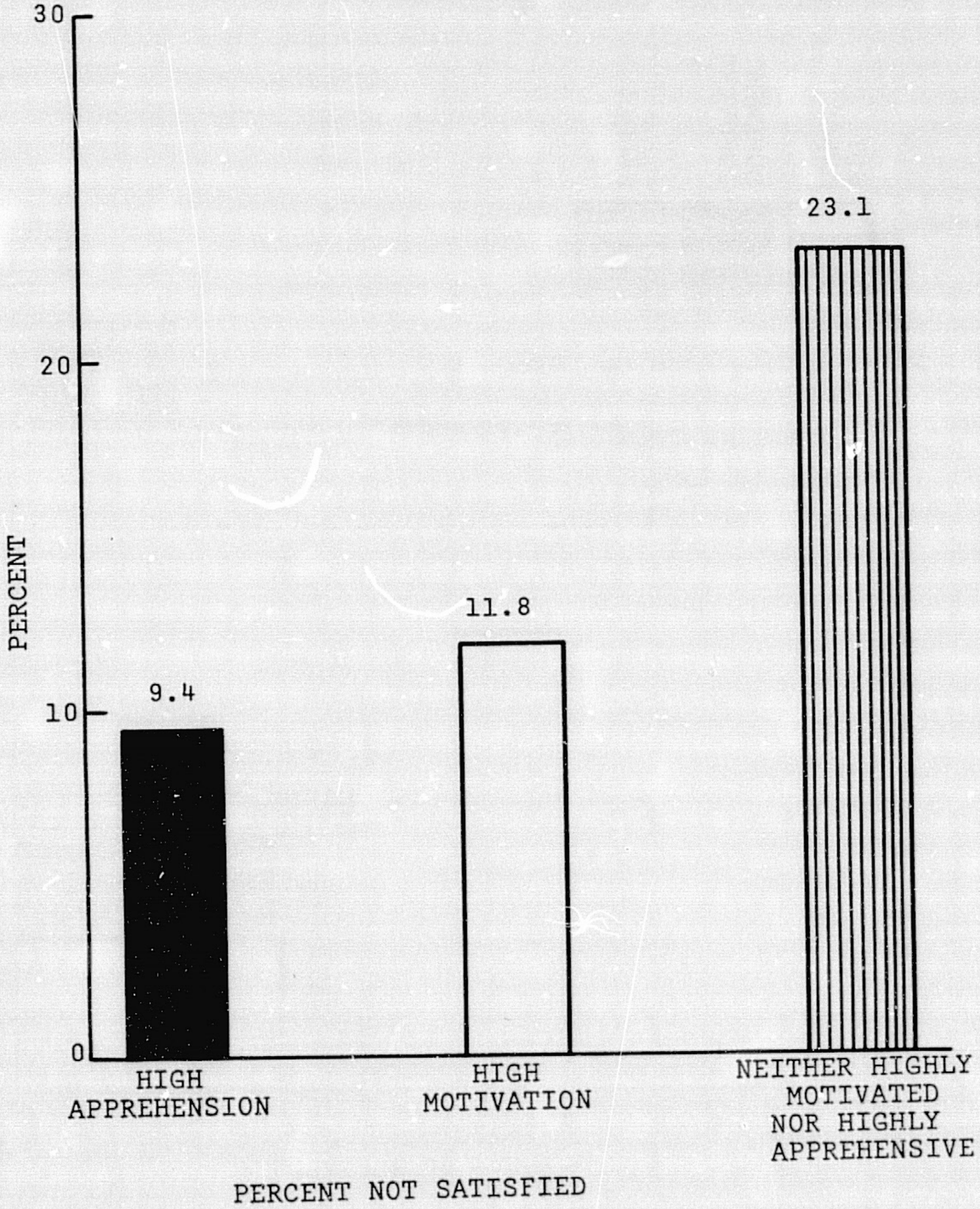


Figure 11 Importance of Anxiety, Motivation and Passenger Satisfaction

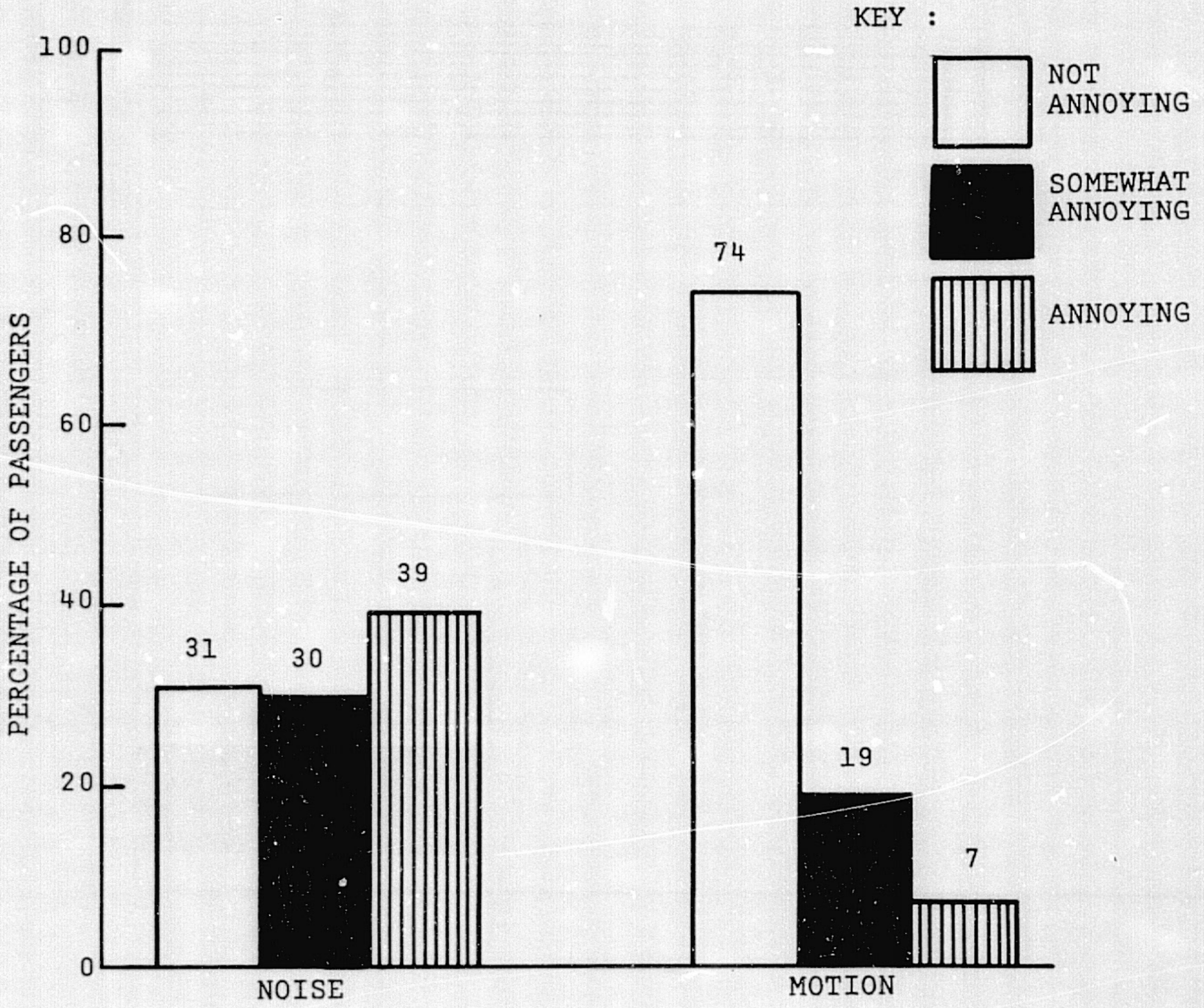
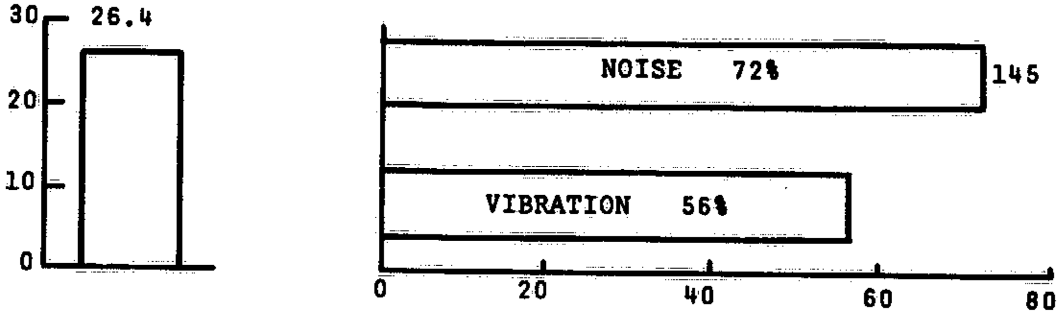
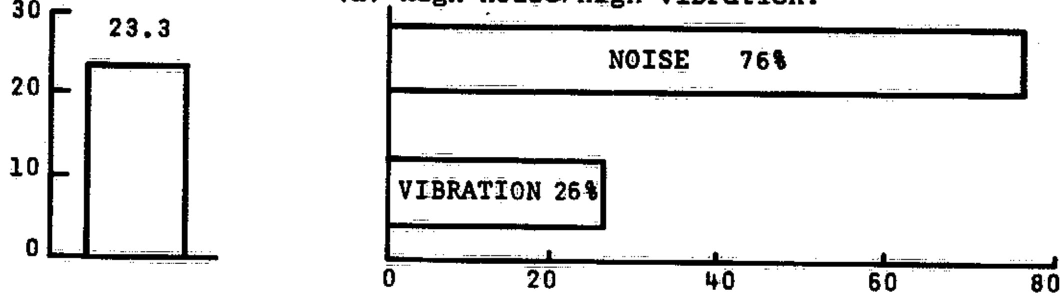


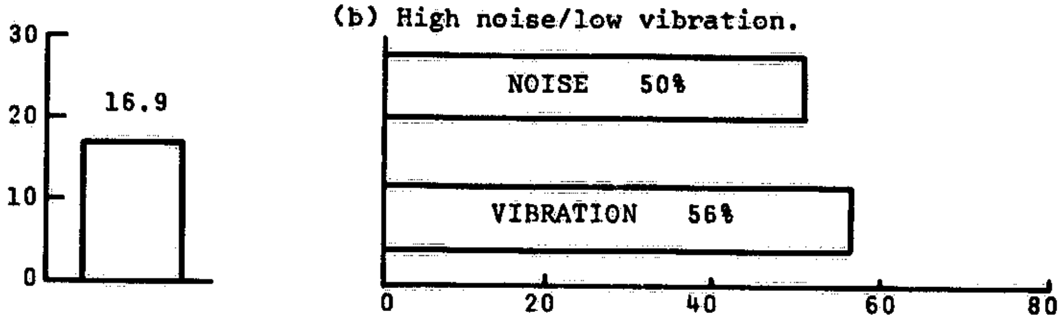
Figure 12 Passenger Feelings About Noise and Motion



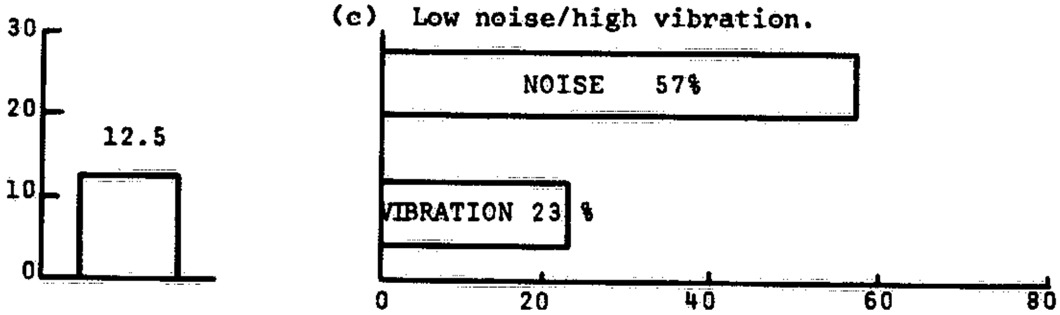
(a) High noise/high vibration.



(b) High noise/low vibration.



(c) Low noise/high vibration.



(d) Low noise/low vibration.

Figure 13 Importance of Noise, Vibration Reductions

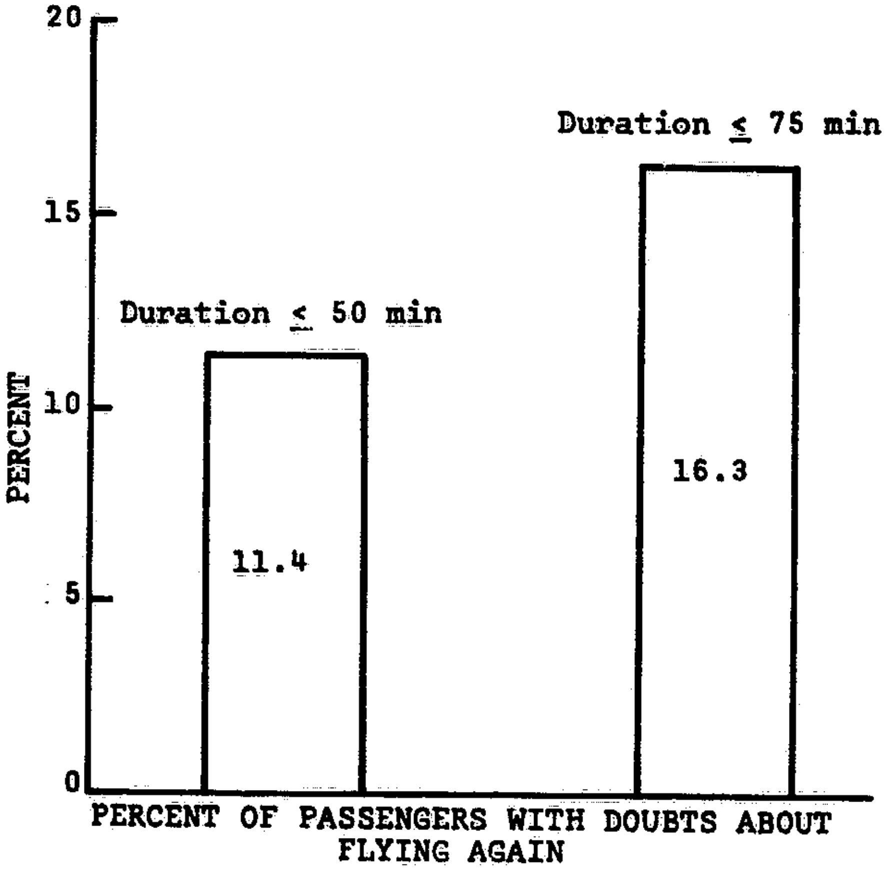


Figure 14 Influence of Flight Duration on Willingness to Fly Again

APPENDIX III Summary of Civil Helicopter Operator Survey Results

Results Statified by Type of Operator

(1) Commercial

(2) Corporate

(3) Civil Government

COMMERCIAL OPERATORS

61 Responses

HELICOPTER OPERATOR QUESTIONNAIRE

1. Below are listed several possible uses of helicopters today. Please estimate the percentage of your operating time that is utilized in each of the following operations:

Agriculture, forestry, herding 13.2%

Resource exploration 7.6%

Patrol, photo, pollution detection monitoring 14%

Air taxi, charter, passenger transport 26%

Construction 8%

Bank, paper transportation 3%

Logging < 1%

Other (please specify) 13%

Fire control, support 6.6%

2. How long has your organization been operating helicopters? MEAN = 10.2
MODE = 3

3. How many aircraft do you currently operate?
Helicopters MEAN = 6.4 MODE = 2
Fixed-Wing ____

Helicopter type	No. of aircraft	Average number of annual flight hours/aircraft
Bell 206	34%	MEAN = 767 MODE = 400
Bell 47	18%	
Hughes 300	8%	

4. How many operating bases do you employ? MEAN = 1.8

5. Where are the majority of your operations based?

NO RESPONSE 7%

44% Airport

44% Private heliport, separate from airport

5% Public heliport, separate from airport

6. Have your operations encountered any difficulty in obtaining a permit to operate a heliport?

43% No

15% Yes, a great deal

33% Yes, some

10% Not applicable

7. If yes, what was the major problem(s) you encountered? NO RESPONSE 48%

27% Community reaction

1% Availability of suitable site

7% Zoning regulations

17% Other (please specify) ____

8. Do your operations employ the use of any public use heliports or helistops?

20% Yes, often
26% Yes, occasionally
15% Rarely
15% No
7% No, they are not available

NO RESPONSE 3%

9. Would you utilize public use heliports if they were available?

64% Yes, they would be an asset
26% Yes, possibly
7% No, not at this time

NO RESPONSE 3%

10. Do you receive complaints from the community regarding your operations?

5% Yes, frequently
21% Yes, occasionally
48% Rarely
23% Not at all

NO RESPONSE 3%

11. Please rate the potential importance of the following operating procedures to minimize the impact of helicopter operations on the surrounding community.

RESPONSES IN PERCENT	Not Feasible	1 Not Important	2	3	4	5	6	7 Very Important
Fly at the highest practical altitude	11	13	7	11	15	16	3	20
Avoid airspeeds which produce significant blade slap	11	13	11	5	11	7	5	30
Select route over least populated areas	8	3	3	3	15	13	3	48
Select approach/departure route to follow major thoroughfares, railroads, rivers	7	3	5	0	15	10	8	49

Other procedures: please elaborate

12. What percent of your total maintenance is--

Scheduled MEAN = 79.5%

Unscheduled MEAN = 20.4%

13. What percent of your total maintenance is related to--

Engines MEAN = 26.4%
Airframe 18.4%
Drive system 21.0%
Avionics 10.0%
Rotors 11.9%
Other

14. To what do you attribute most unscheduled maintenance?

Vibration 57%
Operating environment 36%
Hard landings 3%
Vehicle design 49%
Engine failures 18%
Other (please specify) 18%
Avionics < 1%

15. Which factor(s) are most significant in your aircraft availability?

46% Weather
5% Other (please specify)
33% Maintenance

16. How much of your normal operating time is lost due to bad weather?

MEAN = 8.1%

17. How many of your aircraft are equipped for IFR flight?

0 = 85% 1 = 10% 2 = 5%

18. Do you foresee the need of this capability in the future?

19. If yes, for what type of operation would this capability be used most often?

In the following sections, many factors relevant to civil helicopters are listed. We would like to solicit your opinions on where the most emphasis should be placed in future research efforts, relative to your own operational experience. Your answers should reflect the relative priority you attach to these factors. For each factor, please check one box indicating how much emphasis that item should receive. The boxes are numbered from 1 to 7, with 1 meaning little emphasis and 7 meaning major emphasis.

20. Community Acceptance

	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce noise impact on community	7	7	11	16	13	10	30
Improve safety of operation	3	0	3	13	25	5	43
Reduce pollution	36	18	11	10	2	0	8
Other (please specify)	☐	☐	☐	☐	☐	☐	☐

RESPONSE IN PERCENT

21. **Performance Considerations**

	1	2	3	4	5	6	7
Greater range	13	11	16	18	10	8	20
Increased maneuverability	31	10	20	13	8	8	0
More payload	0	2	8	13		8	46
More efficient power plant	3	0	3	13	25	8	41
Increased speed	5	2	7	18	10	18	38
Reduced fuel consumption	5	8	16	23	13	11	28
Other (please specify) ____________							

22. **Passenger Acceptance**

	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce vibration	2	2	5	11	18	13	46
Reduce noise	0	2	5	3	18	3	66
Costs more competitive with other air systems	3	2	7	8	13	10	54
Increased system safety	5	2	11	18	15	10	36
Other (please specify) ____________							

23. Please indicate the relative value of the following factors impacting your operation. Place a 1 by the factor where technological improvements could most aid your operation, a 2 by the second most important factor, a 3 by the third most important factor, and so forth. A number or rank may be used more than once and you may supplement the list with your own factors if you so desire.

Factor	Rank	
Aircraft performance	MEAN = 2.6	MODE = 1.0
Direct operating costs	MEAN = 2.0	MODE = 1.0
Passenger acceptance	MEAN = 3.6	MODE = 3.0
Improved IFR capability	MEAN = 4.9	MODE = 8.0
Aircraft initial costs	MEAN = 2.6	MODE = 2.0
Community acceptance	MEAN = 4.5	MODE = 6.0
Aircraft safety	MEAN = 3.1	MODE = 3.0
Reduced fuel consumption	MEAN = 4.4	MODE = 4.0

24. If you think that this questionnaire omitted any important items, please tell us what they are.

CORPORATE OPERATORS

59 RESPONSES

HELICOPTER OPERATOR QUESTIONNAIRE

1. Below are listed several possible uses of helicopters today. Please estimate the percentage of your operating time that is utilized in each of the following operations:

Passenger transportation 63%

Construction 4%

Cargo transportation 6%

Private (Personal) 8%

Other (please specify) Photo 7% Other 10%

2. How long has your organization been operating helicopters? MEAN 8 Years
MODE 2 Years

3. How many aircraft do you currently operate?

Helicopters MEAN 2
MODE 1

Helicopter type	No. of aircraft	Average number of annual flight hours/aircraft
Bell 206	49%	MEAN = 571 MODE = 300
Bell 47	10%	
Bo 105	8%	

4. How many operating bases do you employ? MEAN = 1.6

5. Where are the majority of your operations based?

[31%] Airport

[58%] Private heliport, separate from airport

[3%] Public heliport, separate from airport

NO RESPONSE 8%

6. Have your operations encountered any difficulty in obtaining a permit to operate a heliport?

[29%] No

[8%] Yes, a great deal

[19%] Yes, some

[10%] Not applicable

7. If yes, what was the major problem(s) you encountered? NO RESPONSE 59%

[7%] Community reaction

[2%] Availability of suitable site

[14%] Zoning regulations

[19%] Other (please specify)

8. Do your operations employ the use of any public use heliports or helistops?

19% Yes, often

32% Yes, occasionally

20% Rarely

19% No

10% No, they are not available

9. Would you utilize public use heliports if they were available?

71% Yes, they would be an asset

15% Yes, possibly

12% No, not at this time

NO RESPONSE 2%

10. Do you receive complaints from the community regarding your operations?

2% Yes, frequently

10% Yes, occasionally

41% Rarely

46% Not at all

NO RESPONSE 2%

11. Please rate the potential importance of the following operating procedures to minimize the impact of helicopter operations on the surrounding community.

RESPONSES IN PERCENT	Not Feasible	1 Not Important	2	3	4	5	6	7 Very Important
Fly at the highest practical altitude	5	9	0	12	17	19	7	25
Avoid airspeeds which produce significant blade slap	8	15	3	7	10	10	10	34
Select route over least populated areas	14	3	2	14	10	14	2	42
Select approach/departure route to follow major thoroughfares, railroads, rivers	10	5	5	5	8	8	17	39

Other procedures: please elaborate

12. What percent of your total maintenance is--

Scheduled MEAN = 79.6%

Unscheduled MEAN = 15.3%

13. What percent of your total maintenance is related to--

Engines MEAN = 25.4%
Airframe MEAN = 20.5%
Drive system 18.9%
Avionics 8.3%
Rotors 12.2%
Other 4.9%

14. To what do you attribute most unscheduled maintenance?

Vibration MEAN = 41%
Operating environment 29%
Hard landings 2%
Vehicle design 54%
Engine failures 14%
Other (please specify) 20%
Avionics 7%

15. Which factor(s) are most significant in your aircraft availability?

61% Weather
19% Maintenance
16% Other (please specify) ____________

16. How much of your normal operating time is lost due to bad weather?

MEAN = 13.7%

17. How many of your aircraft are equipped for IFR flight?

0 = 81%   1 = 15%   2 = 2%

18. Do you foresee the need of this capability in the future? ____________

19. If yes, for what type of operation would this capability be used most often?

____

In the following sections, many factors relevant to civil helicopters are listed. We would like to solicit your opinions on where the most emphasis should be placed in future research efforts, relative to your own operational experience. Your answers should reflect the relative priority you attach to these factors. For each factor, please check one box indicating how much emphasis that item should receive. The boxes are numbered from 1 to 7, with 1 meaning little emphasis and 7 meaning major emphasis.

20. Community Acceptance

RESPONSES IN PERCENT	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce noise impact on community	7	5	14	19	17	8	31
Improve safety of operation	2	0	8	19	8	7	54
Reduce pollution	27	27	17	19	7	0	2
Other (please specify)____________	☐	☐	☐	☐	☐	☐	☐

Responses in Percent

21. **Performance Considerations**

	1	2	3	4	5	6	7
Greater range	7	7	14	12	14	27	19
Increased maneuverability	27	17	15	15	8	8	3
More payload	3	5	5	19	25	17	24
More efficient power plant	3	2	7	12	12	19	44
Increased speed	2	0	5	7	24	24	39
Reduced fuel consumption	2	5	7	22	10	22	31
Other (please specify)							
______________________							

22. **Passenger Acceptance**

Responses in Percent

	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce vibration	2	5	3	8	15	19	46
Reduce noise	0	0	3	8	7	29	53
Costs more competitive with other air systems	2	0	3	10	17	19	46
Increased system safety	5	2	3	15	15	14	44
Other (please specify)							
______________________							

23. Please indicate the relative value of the following factors impacting your operation. Place a 1 by the factor where technological improvements could most aid your operation, a 2 by the second most important factor, a 3 by the third most important factor, and so forth. A number or rank may be used more than once and you may supplement the list with your own factors if you so desire.

Factor	Rank
Aircraft performance	MEAN = 2.2 MODE = 1.0
Direct operating costs	MEAN = 2.6 MODE = 1.0
Passenger acceptance	MEAN = 3.3 MODE = 4.0
Improved IFR capability	MEAN = 4.2 MODE = 1.0
Aircraft initial costs	MEAN = 2.8 MODE = 3.0
Community acceptance	MEAN = 4.2 MODE = 3.0
Aircraft safety	MEAN = 2.4 MODE = 1.0
Reduced fuel consumption	MEAN = 3.9 MODE = 2.0

24. If you think that this questionnaire omitted any important items, please tell us what they are.

CIVIL GOVERNMENT OPERATIONS

43 RESPONSES

160

HELICOPTER OPERATOR QUESTIONNAIRE

1. Below are listed several possible uses of helicopters today. Please estimate the percentage of your operating time that is utilized in each of the following operations:

Patrol 60.6%

Fire control/support 5.6%

Pollution detection/monitoring 2.0%

Passenger transportation 6.0%

Search and rescue 6.2%

Ambulance/emergency rescue 6%

Other (please specify) 10%

2. How long has your organization been operating helicopters? MEAN = 8 Years

3. How many aircraft do you currently operate?

Helicopters MEAN = 4.3

Helicopter type	No. of aircraft	Average number of annual flight hours/aircraft
Bell 47	23%	MEAN = 985 MODE = 600
Hughes 300	19%	
Bell 206	16%	

4. How many operating bases do you employ? MEAN = 1.4

5. Where are the majority of your operations based?

NO RESPONSE = 2%

- 65% Airport
- 30% Private heliport, separate from airport
- 2% Public heliport, separate from airport

6. Have your operations encountered any difficulty in obtaining a permit to operate a heliport?

- 60% No
- 7% Yes, a great deal
- 2% Yes, some
- 30% Not applicable

7. If yes, what was the major problem(s) you encountered? NO RESPONSE 84%

- 5% Community reaction
- 2% Availability of suitable site
- 2% Zoning regulations
- 7% Other (please specify)

8. Do your operations employ the use of any public use heliports or helistops?

21% Yes, often

9% Yes, occasionally

21% Rarely

40% No

2% No, they are not available

NO RESPONSE 7%

9. Would you utilize public use heliports if they were available?

44% Yes, they would be an asset

33% Yes, possibly

14% No, not at this time

NO RESPONSE 7%

10. Do you receive complaints from the community regarding your operations?

5% Yes, frequently

26% Yes, occasionally

51% Rarely

16% Not at all

NO RESPONSE 2%

11. Please rate the potential importance of the following operating procedures to minimize the impact of helicopter operations on the surrounding community.

Responses in percent	Not Feasible	1 Not Important	2	3	4	5	6	7 Very Important
Fly at the highest practical altitude	30	2	5	5	16	2	2	37
Avoid airspeeds which produce significant blade slap	12	9	7	12	21	2	7	28
Select route over least populated areas	40	0	2	5	12	9	9	23
Select approach/departure route to follow major thoroughfares, railroads, rivers	14	12	0	5	12	9	23	26

Other procedures: please elaborate

12. What percent of your total maintenance is--

Scheduled MEAN = 75%

Unscheduled MEAN = 20%

13. What percent of your total maintenance is related to--

Engines MEAN = 30%

Drive system 16%

Rotors 17%

Airframe MEAN = 16%

Avionics 9%

Other

14. To what do you attribute most unscheduled maintenance?

Vibration 42%

Hard landings 5%

Engine failures 23%

Operating environment 44%

Vehicle design 26%

Other (please specify) 28%

15. Which factor(s) are most significant in your aircraft availability?

37% Weather

44% Maintenance

14% Other (please specify)

NO RESPONSE = 5%

16. How much of your normal operating time is lost due to bad weather?

MEAN = 9.4% MODE = 5%

17. How many of your aircraft are equipped for IFR flight?

0 = 93% 1 = 5% 2 = 2%

18. Do you foresee the need of this capability in the future?

19. If yes, for what type of operation would this capability be used most often?

In the following sections, many factors relevant to civil helicopters are listed. We would like to solicit your opinions on where the most emphasis should be placed in future research efforts, relative to your own operational experience. Your answers should reflect the relative priority you attach to these factors. For each factor, please check one box indicating how much emphasis that item should receive. The boxes are numbered from 1 to 7, with 1 meaning little emphasis and 7 meaning major emphasis.

20. Community Acceptance

Responses in percent	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce noise impact on community	0	9	12	9	9	14	47
Improve safety of operation	0	5	7	16	16	16	40
Reduce pollution	30	23	7	14	7	2	9
Other (please specify)	☐	☐	☐	☐	☐	☐	☐

Responses in percent

21. **Performance Considerations**

	1	2	3	4	5	6	7
Greater range	7	7	2	30	14	21	16
Increased maneuverability	19	19	7	23	16	4	2
More payload	2	5	2	9	21	23	37
More efficient power plant	0	2	0	7	12	33	47
Increased speed	0	5	0	14	14	33	33
Reduced fuel consumption	0	5	9	16	23	9	35
Other (please specify)							
____________________							

22. **Passenger Acceptance**

Responses in percent

	1 Little Emphasis	2	3	4	5	6	7 Major Emphasis
Reduce vibration	0	2	5	27	21	19	26
Reduce noise	0	0	2	9	12	23	49
Costs more competitive with other air systems	2	2	0	2	12	12	60
Increased system safety	0	0	9	7	16	16	44
Other (please specify)							
____________________							

23. Please indicate the relative value of the following factors impacting your operation. Place a 1 by the factor where technological improvements could most aid your operation, a 2 by the second most important factor, a 3 by the third most important factor, and so forth. A number or rank may be used more than once and you may supplement the list with your own factors if you so desire.

Factor	Rank
Aircraft performance	MEAN = 3.0 MODE = 1
Direct operating costs	MEAN = 2.4 MODE = 2
Passenger acceptance	MEAN = 4.8 MODE = 7
Improved IFR capability	MEAN = 5.7 MODE = 8
Aircraft initial costs	MEAN = 2.2 MODE = 1
Community acceptance	MEAN = 4.3 MODE = 6
Aircraft safety	MEAN = 2.4 MODE = 1
Reduced fuel consumption	MEAN = 3.9 MODE = 2

24. If you think that this questionnaire omitted any important items, please tell us what they are.

APPENDIX IV Recommended Helicopter Exterior Noise Guidelines

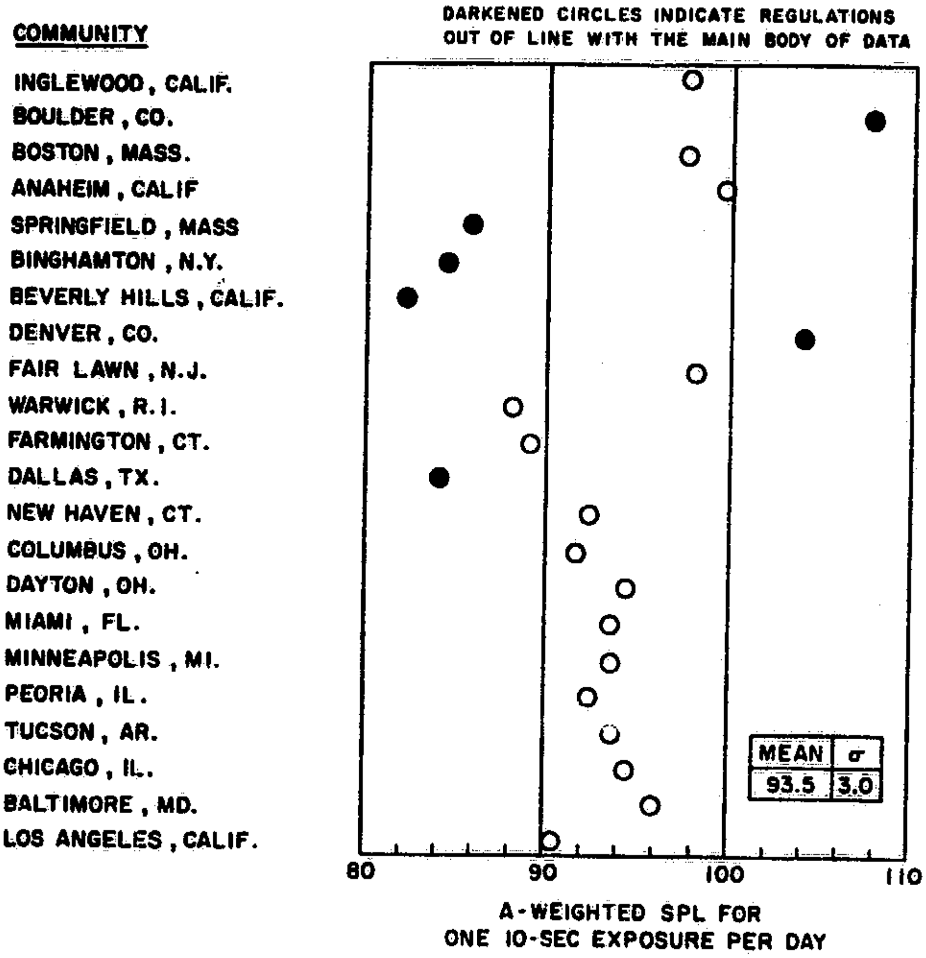


Figure 15 Comparison of Residential Community Noise Regulations (Reference 44).

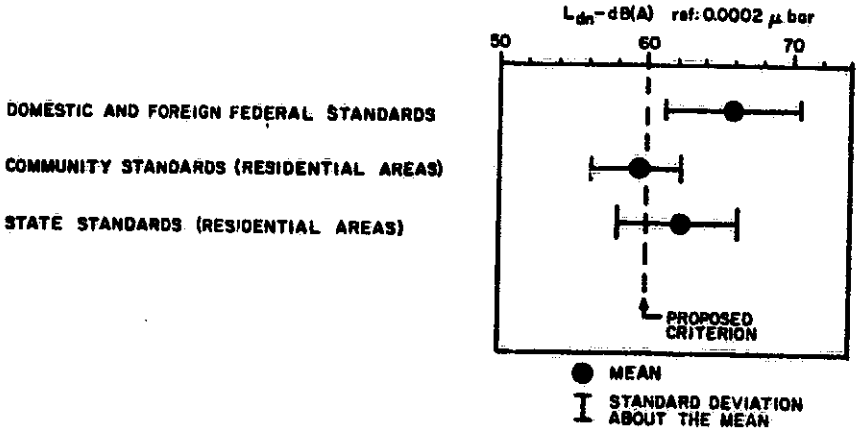


Figure 16 Comparison of Federal, State and Local Noise Regulations and Guidelines with the Proposed Community Acceptance Criteria (Reference 44).

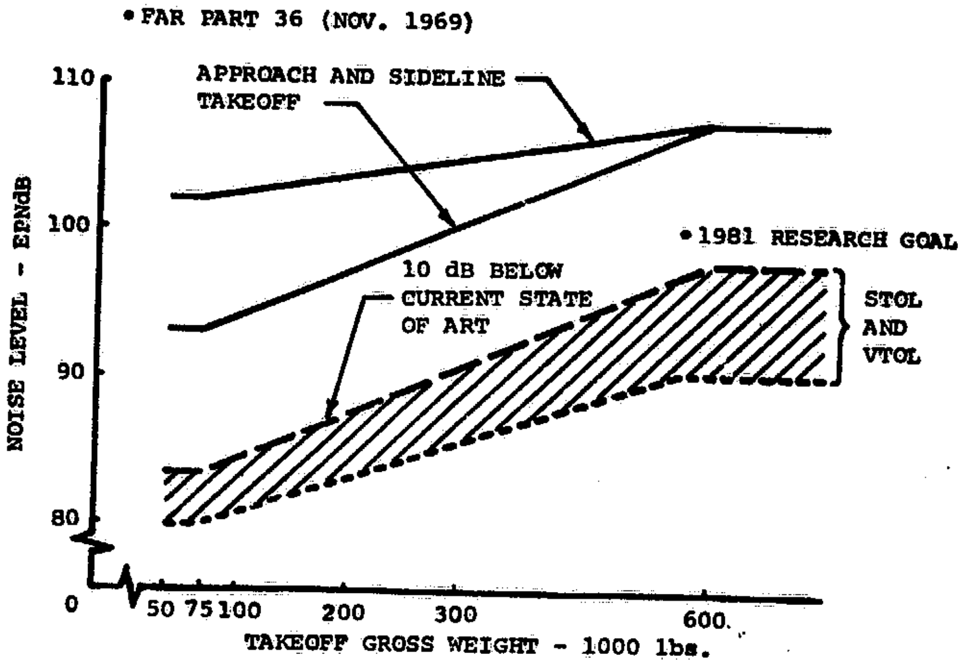


Figure 17 Aircraft Noise Criteria (Reference 45).

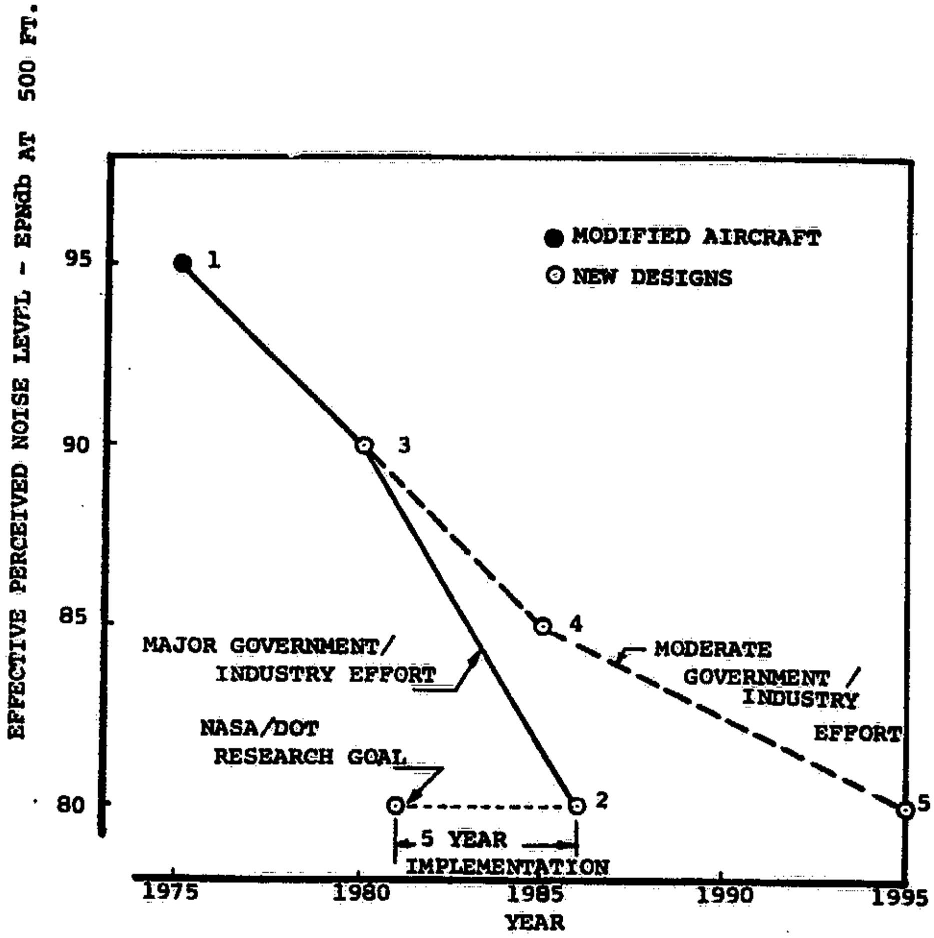


Figure 18 Plan for Future Certification Noise Limits (Reference 45).

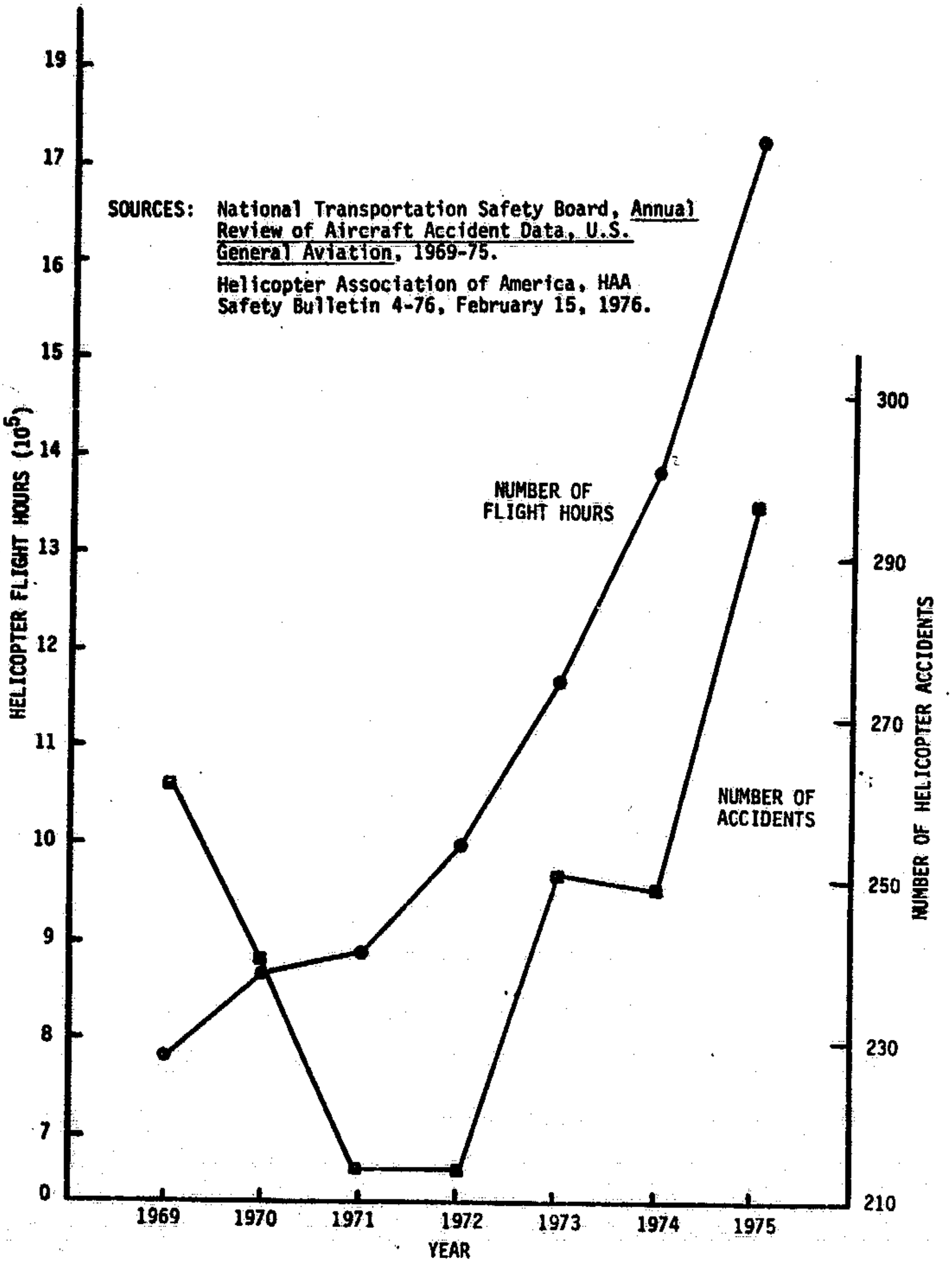
APPENDIX V Civil Helicopter Accident Statistics

Figure 18	Civil Helicopter Accident Statistics
Figure 19	Accident Rate Comparison 1969-1974
Table 15	Ten Most Frequent Types of Accidents for Helicopters in Civil Sector 1968-1974
Table 16	Most Frequent Causes of Accidents for Helicopters in Civil Sector 1968-1974
Table 17	Civil Helicopter Accidents by Phase of Operation 1968-1974
Table 18	Civil Helicopter Accidents by Kind of Flying 1968-1974

Sources of Information:

National Transportation Safety Board, Annual Review of Aircraft Accident Data, U. S. General Aviation, 1969-1975.

Helicopter Association of America, HAA Safety Bulletin 4-76, February 15, 1976.



SOURCES: National Transportation Safety Board, Annual Review of Aircraft Accident Data, U.S. General Aviation, 1969-75.

Helicopter Association of America, HAA Safety Bulletin 4-76, February 15, 1976.

Figure 19 Civil Helicopter Accident Statistics.

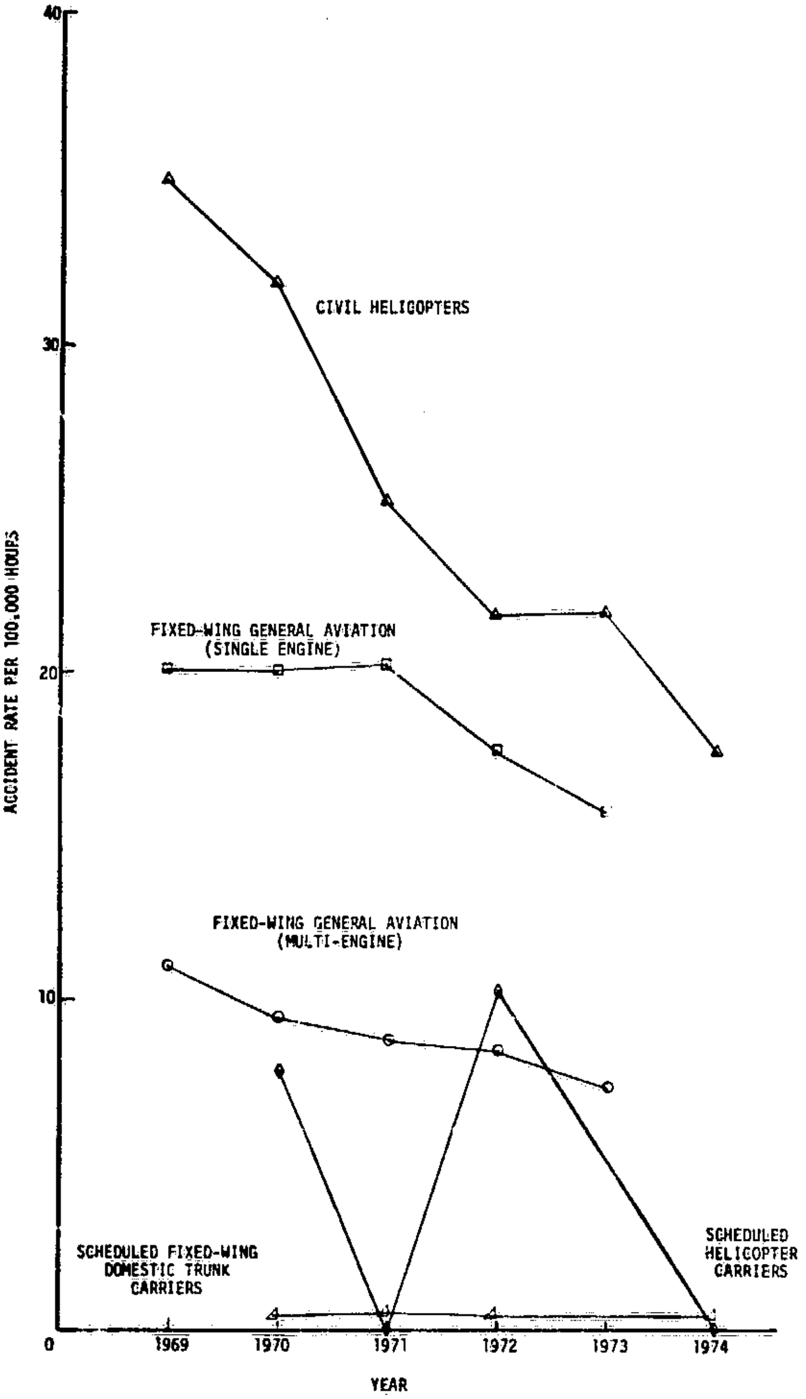


Figure 20 Accident Rate Comparison 1969-1974

Table 15 Ten Most Frequent Types of Accidents for Helicopters in Civil Sector 1968 - 1974

Total Accidents - 1722

Type of Accident	Frequency	Percent of Total
Engine failure or malfunction	493	28.6
Collision with wires/poles	171	9.9
Hard landing	163	9.5
Collision with ground/water, uncontrolled	153	8.9
Collision with miscellaneous objects	118	6.9
Collision with ground/water, controlled	99	5.8
Tail rotor failure	78	4.5
Roll over	75	4.4
Collision with trees	62	3.6
Main rotor failure	31	1.8

Table 16 Most Frequent Causes of Accidents for Helicopters in Civil Sector 1968-1974

Total Accidents -- 1722

Total Causes Cited for Accidents -- 2430*

Cause of Accident	Frequency	Percent of Total
Pilot, human factor	1237	51
Power Plant	313	13
Terrain	241	10
Rotor System	197	8
Personnel	189	8
Weather	66	3
Undetermined	43	2

*For statistical purposes, where two or more causes exist in an accident, each is recorded and no attempt is made to establish a primary cause.

Table 17 Civil Helicopter Accidents by Phase of Operation 1968-1974

Total Accidents -- 1722

Phase of Operation	Frequency	Percent of Total
Inflight	923	53.6
Landing	399	23.2
Takeoff	278	16.1
Static	62	3.6
Taxi	51	3.0

Table 18 Civil Helicopter Accidents by Kind of Flying 1968-1974

Total Accidents -- 1722

Kind of Flying	Frequency	Percent of Total
Commercial	908	52.7
Non-Commercial	342	20.0
Miscellaneous	294	17.0
Instructional	178	10.3

APPENDIX VI Summary of Hawkins and Griffin Pilot Survey Results

Source: Reference 47

Question: If you were an instructor, what specific skills would you look for in your trainee pilots in order that you might consider them able to fly a helicopter proficiently?

397 responses were obtained from 93 pilots. There were 77 separate types of response, classified into 12 distinct types of ability, as shown in the following table:

CLASSES OF RESPONSE +3 Most Frequent Individual Responses (excluding single responses)	NO. OF RESPONSES (PILOTS)	% OF TOTAL RESPONSES
1. JUDGEMENT - PERCEPTUAL ABILITIES e.g. judgement of distance (12), judgement of speed (10), height judgement (7)	53	13.1%
2. CONTROL - MANUAL ABILITIES e.g. smoothness in control movements (15), simultaneous control co-ordination (10) quick reactions (9)	41	10.3%
3. ABSTRACT - SOCIAL ABILITIES e.g. self confidence (9) common sense (8), determination (4)	37	9.4%
4. MENTAL - COGNITIVE ABILITIES e.g. concentration (12) thinking ahead (6), making correct deductions (4)	36	9.1%
5. DEALING WITH DIFFICULT SITUATIONS e.g. calmness in a crisis (10), decision making under stress (8), react in emergency (5)	29	7.3%
6. ABSTRACT - PHYSICAL ABILITIES e.g. anticipation (12), alertness (8), relaxation (6)	29	7.3%
7. TECHNICAL APTITUDES e.g. technical aptitudes (15) knowledge of aircrafts limitations (5)	21	5.3%

8.	VISUAL ABILITIES e.g. scanning of instruments (12) quick assimilation of instrument information (5), observation (3)	21	5.3%
9.	ABILITY TO LEARN e.g. respond to direct instruction (6), assimilation of new skills (5) open to criticism (3)	20	5.0%
10.	GENERAL FLYING SKILLS e.g. airmanship (5), captaincy (3), desire to want to fly (2)	13	3.3%
11.	SPECIFIC FLYING SKILLS e.g. map read and navigate (8), radio operations (2)	11	2.8%
12.	SPECIFIC PSYCHOLOGICAL ATTRIBUTES e.g. memory (2)	4	1.0%
	CO-ORDINATION - (82) ***	82	20.6%

Question: Select one particular operation which you consider to be both typical and a necessary part of the pilot's overall task. The operation that you choose should only last a few minutes. It should involve a high level of specialist skill, such that it would illustrate differences between relatively experienced and inexperienced pilots.

The following table comprises an ordered list of the six operations most frequently mentioned by the 103 pilots who answered this question.

OPERATIONS	NUMBER OF PILOTS	PERCENTAGE FREQUENCY
Entering a confined area	31	30.1%
Engine off landing	15	14.6%
Approach	10	9.7%
Carriage of underslung load	8	7.8%
Hover	8	7.8%
Lift Off	6	5.8%

Question: One feature of pilot performance in which we are particularly interested is the manner in which the pilot orders his time spent in various visual activities such as reading maps and observing necessary dials. We would like you to describe how you consider that your visual time is ordered by completing the table shown below.

The table was subdivided such that in the first section they were required to judge how they normally arranged their visual time, while in the second section they were asked to respond in terms of how their visual time ought to be ordered. For analysis purposes the distinction was thus made between actual and theoretical judgments.

The table below provides details of the means and standard deviations (in parentheses) for the percentage of all the 129 pilots who answered this question.

(See Next Page)

FLIGHT CONDITION		INSTRUMENTS AND DIALS	FLIGHT PLANS AND MAPS	OUTSIDE THE HELICOPTER
ACTUAL VISUAL TIME				
KNOWN TERRAIN	Forward flight, 1000ft.	13.1% (6.6)	9.0% (6.6)	78.2% (10.9)
	Forward flight, 100ft.	8.6% (4.6)	6.8% (5.3)	85.7% (8.2)
UNKNOWN TERRAIN	Forward flight, 1000ft.	11.2% (5.3)	17.5% (7.6)	71.6% (10.2)
	Forward flight, 100ft.	7.4% (3.9)	14.6% (9.4)	79.4% (10.3)
AIRFIELD	Takeoff, climb to 700ft.	20.0% (12.2)	0.7% (2.1)	80.2% (11.6)
	Approach and Landing.	17.3% (10.5)	0.5% (1.6)	82.6% (10.8)
CLEARING	Takeoff, climb to 700ft.	16.9% (11.3)	0.7% (2.1)	83.6% (10.4)
	Approach and Landing.	14.7% (9.4)	0.5% (1.8)	85.9% (10.0)
THEORETICAL VISUAL TIME				
KNOWN TERRAIN	Forward flight, 1000ft.	11.8% (7.3)	7.3% (5.6)	81.0% (9.9)
	Forward flight, 100ft.	7.8% (5.1)	5.5% (4.6)	87.3% (8.6)
AIRFIELD	Takeoff, climb to 700ft.	15.8% (10.8)	0.7% (2.3)	83.3% (10.8)
	Approach and Landing.	13.4% (9.7)	0.6% (2.0)	86.0% (9.9)

The authors were able to draw several very general conclusions from consideration of the mean percentage

1. The majority of the pilots visual time, irrespective of flight condition, is considered to be spent outside the helicopter; on average 82% of the total time.

2. The manner in which the remaining visual time (approximately 20%) is allocated to maps and instruments seems to be highly dependent upon the particular flight condition.

3. Airfield and clearing flight conditions require more instrument time and this seems to reduce the amount of visual time available for consulting maps and flight plans.

4. On the average, the pilot sample considered that it 'ought to' allocate more visual time outside the helicopter at the expense of instrument and map time than was normally the case.

Question: On the basis of your knowledge of present-day helicopters, are there any design features of these helicopters which you consider could be usefully changed to help the pilot operate with greater tactical efficiency, more safely and in greater comfort?

Table A is a ranked list of the most frequent individual responses while Table B is a ranked list of classes of responses, each showing responses as a function of type of helicopter the pilot most frequently operated.

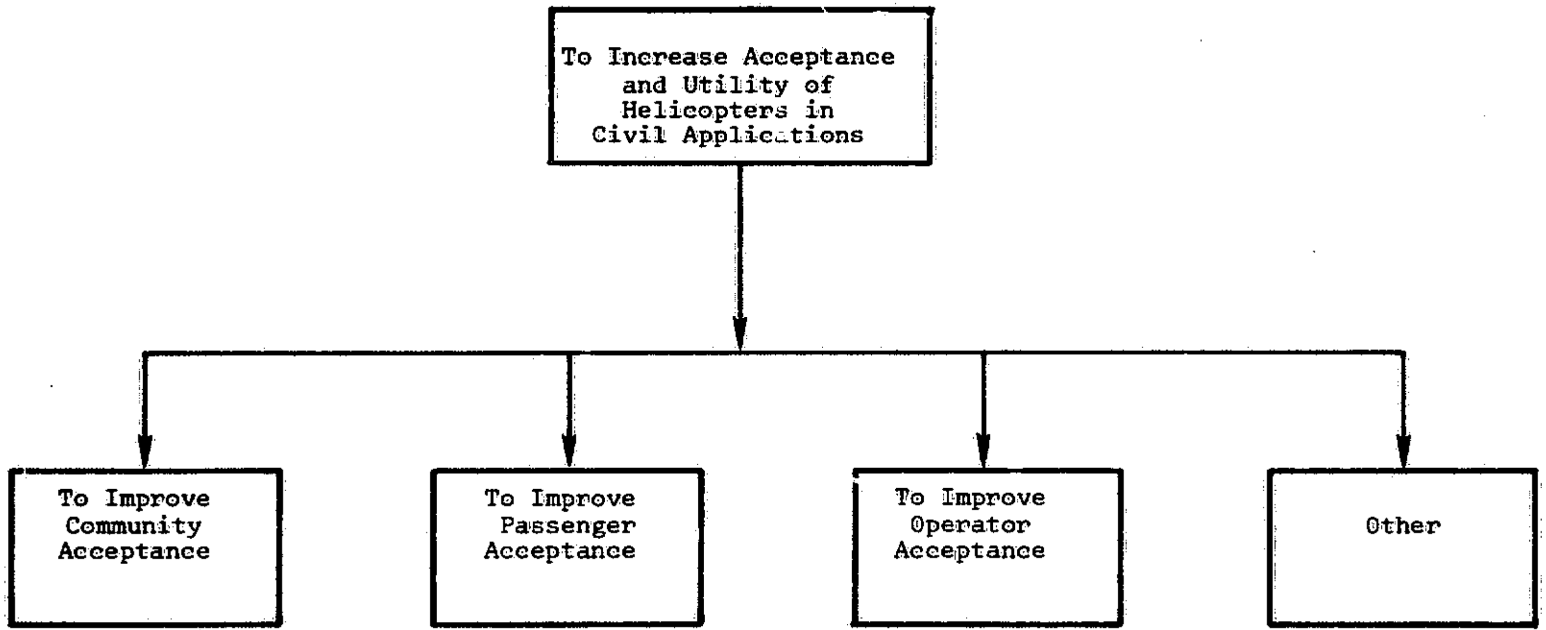
RANK	RESPONSE	SIOUX	SCOUT	ALOUETTE	TOTAL
1.	Better Seats	56	15	1	72
2.	Improve instrument layout and position	21	8	2	31
3.	More effective heating and cooling system needed	19	5	5	29
4.	De-mister	24	0	4	28
5.	Improve windscreen wipers	17	7	3	27
6.	Adjustable seats	16	6	4	26
7.	Draughts/leaks from doors	15	2	0	17
8.	Roller map display unit	10	5	1	16
	Improve visibility	2	13	1	16
	Control console obscures vision	14	2	0	16
11.	Storage space for maps	12	2	0	14
12.	All needles in one direction for 'normal' setting	8	4	1	13
13.	Head-up display	7	3	2	12
14.	Visual and audio signals for emergencies	8	3	0	11
	Navigation aids needed	4	5	2	11
16.	Sliding doors	3	5	2	10
	Inaccurate fuel gauges	9	1	0	10
	Adjustable controls	10	0	0	10

CLASSES OF RESPONSE	SIOUX	SCOUT	ALOUETTE	TOTAL
1. Seating 2.	94 (75%)	23 (18%)	8 (6%)	125
2. Visual environment	82 (71%)	25 (22%)	9 (7%)	116
3. Instruments in general-design and type	47 (69%)	16 (24%)	5 (7%)	68
4. Controls	53 (84%)	8 (13%)	2 (3%)	63
5. Instruments in general-layout and position	40 (69%)	12 (17%)	6 (14%)	58
6. Doors	38 (74%)	10 (20%)	3 (6%)	51
7. Maps & Navigation	29 (66%)	12 (27%)	3 (7%)	44
8. Heating & cooling	24 (56%)	13 (30%)	6 (14%)	43
9. Radios	23 (54%)	11 (31%)	2 (5%)	36
10. Safety devices	21 (64%)	10 (30%)	2 (6%)	33
11. Particular instruments-design and type	23 (96%)	1 (4%)	0	24
12. Helicopter capability	23 (85%)	4 (15%)	0	27
13. Helicopter design	16 (94%)	1 (6%)	0	17

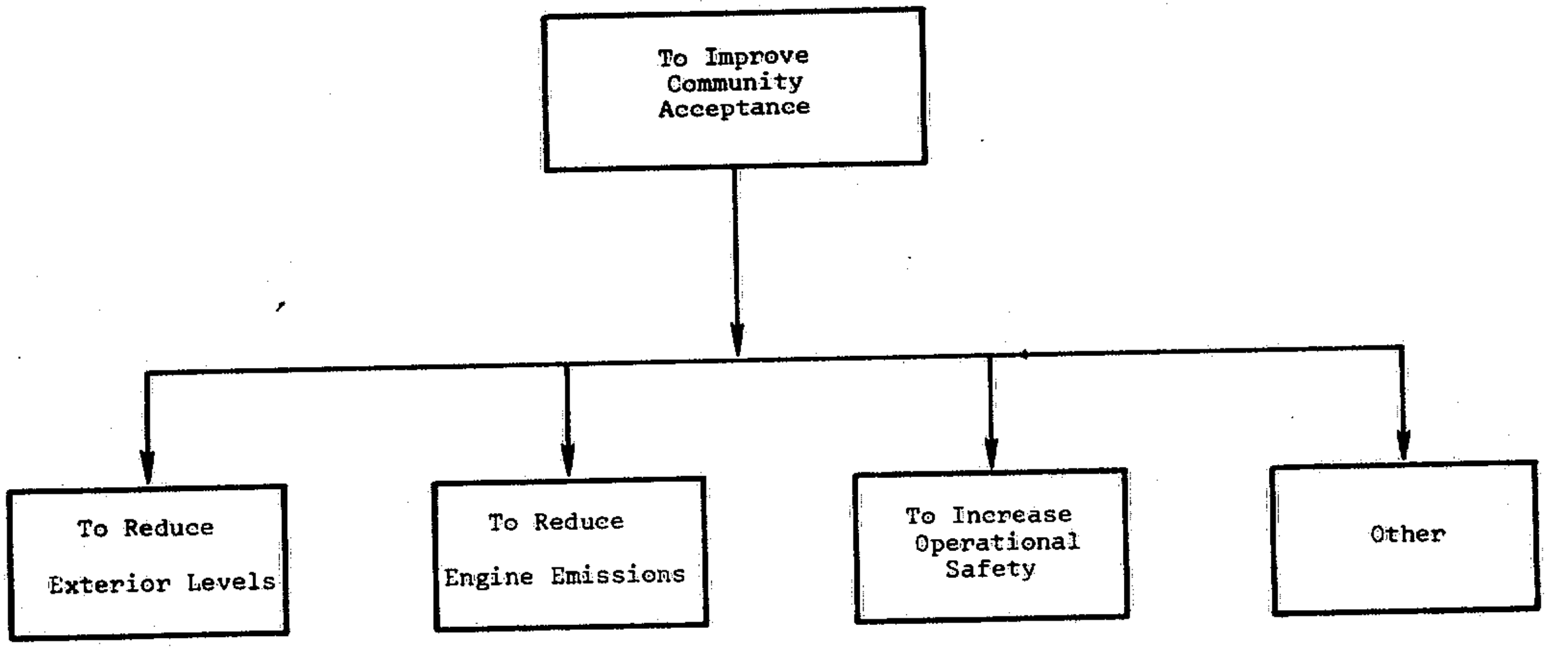
14. Physical features of the cockpit	8 (73%)	3 (27%)	0	11
TOTAL	521 (72%)	149 (21%)	47 (7%)	718 (100%)

APPENDIX VII Research Objectives

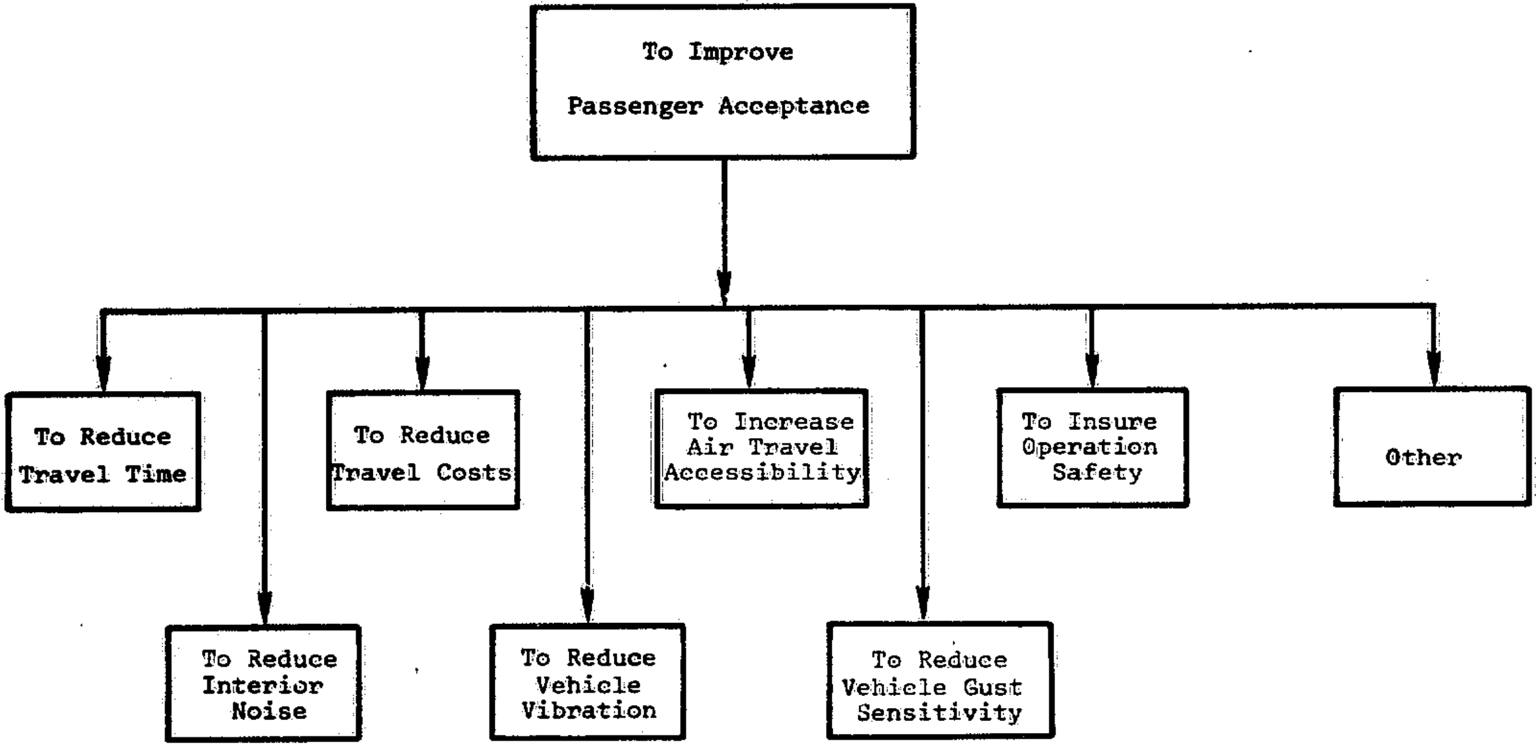
Research Objectives Tree



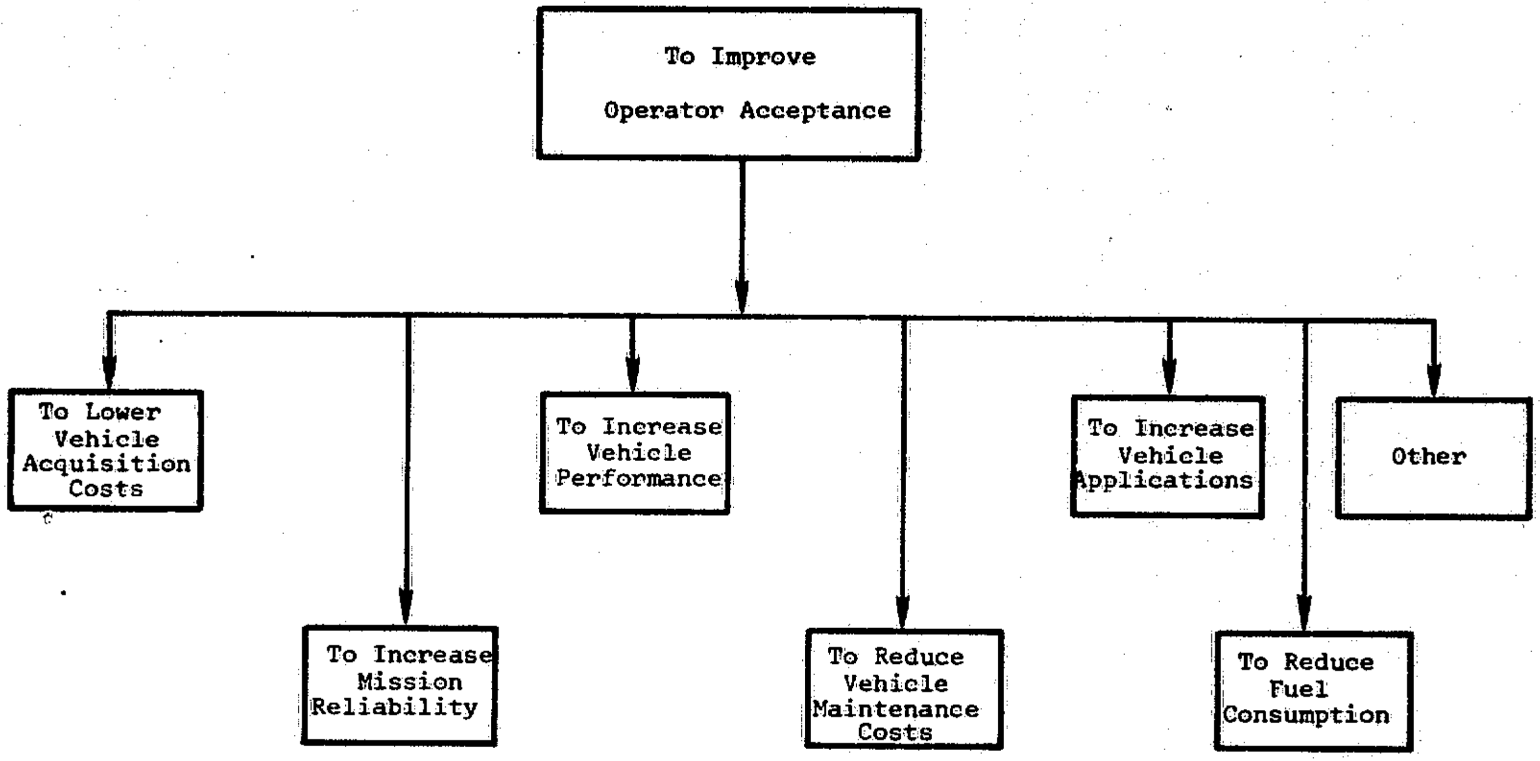
Research Objectives Tree (cont.)



Research Objectives Tree (cont.)



Research Objectives Tree (cont.)



APPENDIX VIII Summary of Evaluations Utilized in Scoring Function

Figure 20 Objective Interaction Matrix
Figure 21 Client Objective Priority Matrix
Figure 22 Project Interaction Matrix
Figure 23 Contribution Matrix
Figure 24 Criteria Matrix
Figure 25 Schedule Priority Matrix

Figure 21 Objective Interaction Matrix

Objective J → Objective i ↓	Increase Vehicle Applications	Reduce Exterior Noise	Reduce Fuel Consumption	Increase Operational Safety	Reduce Engine Emissions	Lower Maintenance Costs	Reduce Travel Time	Reduce Vehicle Gust Sensitivity	Reduce Vibration	Increase Air Travel Accessibility	Increase Mission Reliability	Reduce Interior Noise	Reduce Travel Costs	Increase Vehicle Performance	Lower Vehicle Initial Costs
Increase Vehicle Applications	5	3	3	3	3	3	3	3	3	3	3	3	3	3	4
Reduce Exterior Noise	5	5	3	3	3	3	3	3	3	5	3	5	3	3	2
Reduce Fuel Consumption	4	3	5	3	3	3	3	3	3	3	3	3	4	3	3
Increase Operational Safety	4	3	3	5	3	3	3	3	3	4	5	3	3	3	3
Reduce Engine Emissions	4	3	3	3	5	3	3	3	3	4	3	3	3	3	2
Lower Maintenance Costs	4	3	3	3	3	5	3	3	3	3	3	3	4	3	3
Reduce Travel Time	4	3	3	3	3	3	5	3	3	4	3	3	4	3	3
Reduce Vehicle Gust Sensitivity	4	3	3	3	3	3	3	5	4	4	3	3	3	3	3
Reduce Vibration	4	3	3	3	3	4	3	3	5	4	4	3	3	3	2
Increase Air Travel Accessibility	5	3	3	3	3	3	4	3	3	5	3	3	3	3	3
Increase Mission Reliability	4	3	3	5	3	4	3	3	3	5	5	3	3	3	3
Reduce Interior Noise	4	4	3	3	3	3	3	3	3	4	3	5	3	3	2
Reduce Travel Costs	5	3	3	3	3	3	3	3	3	3	3	3	5	3	3
Increase Vehicle Performance	4	3	3	3	3	3	3	3	3	4	3	3	4	5	2
Lower Vehicle Initial Costs	5	3	3	3	3	3	3	3	3	4	3	3	4	3	5

Figure 22 Client Objective Priority (COP) Matrix

Objective ↓ / Client →	Passengers (Users)	Pilots	Communities	Military	Helicopter Industry	Operators
Increase Vehicle Applications	1	4	1	5	5	7
Reduce Exterior Noise	3	3	7	4	6	4
Reduce Fuel Consumption	2	3	4	3	3	4
Increase Operational Safety	4	7	7	5	6	6
Reduce Engine Emissions	1	1	5	1	2	1
Lower Maintenance Costs	3	5	1	7	6	7
Reduce Travel Time	5	4	3	4	5	4
Reduce Vehicle Gust Sensitivity	4	2	1	3	3	2
Reduce Vibration	5	4	1	5	6	4
Increase Air Travel Accessibility	6	3	3	1	4	5
Increase Mission Reliability	6	6	2	6	6	6
Reduce Interior Noise	6	5	1	4	5	3
Reduce Travel Costs	7	3	2	1	5	5
Increase Vehicle Performance	2	7	1	7	7	6
Lower Vehicle Initial Costs	2	5	1	4	5	6

Figure 23 Project Interaction Matrix

Project J → Project i ↓	Higher Harmonic Pitch Control	Reduce Transmission Noise At Source	Exterior Noise Reduction Versus Cost	Document Reliability, Maintainability Data Base	Quantify Designed Manufacturers Variable Costs	Cost Effectiveness Analysis of Emergency Power Schemes	Feasibility of Engine Emission Reduction	Establish Terminal Area Ride Quality Limits	Airframe/Skin Damping to Reduce Interior Noise	Cost Effectiveness of Vibration Control Methods	Equipment, Operational Requirements for Urban Heliports	Evaluate Contingent Leading to Pilot Errors	Cost Effectiveness of Automatic Inspection/Diagnostics	Dynamic and Acoustical Properties of Composite Materials	Operating Procedures to Reduce Exterior Noise	Cost Effectiveness of Interior Noise Reduction Methods	Cockpit Layout As It Impacts Performance, Safety	Establish Combinations of Tech/Operating Procedures to Meet Noise Goals
Higher Harmonic Pitch Control	6	1	2	2	1	0	0	1	1	3	0	0	1	0	3	2	0	3
Reduce Transmission Noise At Source	0	6	3	2	3	1	0	2	0	4	0	1	1	0	0	5	0	1
Exterior Noise Reduction Versus Cost	0	1	6	0	2	0	2	2	1	2	1	0	1	0	1	2	0	2
Document Reliability Maintainability Data Base	2	3	3	6	2	2	3	0	0	5	3	0	4	0	2	3	2	3
Quantify Design/Manufacturing Variable Costs	3	2	5	2	6	1	2	0	1	5	3	0	4	0	2	5	2	3
Cost Effectiveness Analysis of Emergency Power Schemes	1	2	3	2	2	6	2	3	0	1	2	2	1	0	4	4	3	4
Feasibility of Engine Emission Reduction	2	2	3	2	3	3	6	2	0	3	3	0	1	0	2	2	3	4
Establish Terminal Area Ride Quality Limits	2	2	3	0	3	3	1	6	0	4	4	0	2	0	5	2	2	4
Airframe/Skin Damping to Reduce Interior Noise	0	0	2	0	3	0	0	2	6	3	0	0	0	1	0	5	0	3
Cost Effeciveness of Vibration Control Methods	2	4	3	2	3	0	0	2	3	6	0	2	3	3	1	4	0	1
Equipment, Operational Requirements for Urban Heliports	0	0	1	0	1	1	0	0	0	0	6	3	1	0	3	0	5	3
Evaluate Contingencies Leading to Pilot Errors	0	0	0	2	0	1	0	2	0	0	5	6	3	0	4	0	5	3
Cost Effectiveness of Automatic Inspection Diagnostics	0	2	0	0	2	0	0	0	0	1	0	0	6	0	0	0	2	1
Dynamic and Acoustical Properties of Composite Materials	1	3	1	0	2	0	0	0	4	3	0	0	1	6	2	4	0	4
Operating Procedures to Reduce Exterior Noise	2	0	1	0	2	1	0	0	0	0	0	0	0	0	6	0	4	5
Cost Effectiveness of Interior Noise Reduction Methods	0	3	1	2	1	0	0	2	3	4	0	0	2	1	2	6	0	2
Cockpit Layour As It Impacts Performance Safety	0	0	1	0	0	0	0	0	0	0	2	4	1	0	0	0	6	0
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	1	1	6

Figure 24 Contribution Matrix

Project ↓ / Objective →	Increase Vehicle Applications	Reduce Exterior Noise	Reduce Fuel Consumption	Increase Operational Safety	Reduce Engine Emissions	Lower Maintenance Costs	Reduce Travel Time	Reduce Vehicle Gust Sensitivity	Reduce Vibration	Increase Air Travel Accessibility	Increase Mission Reliability	Reduce Interior Noise	Reduce Travel Costs	Increase Vehicle Performance	Lower Vehicle Initial Costs
Higher Harmonic Pitch Control	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Reduce Transmission Noise At Source	0	1	0	1	0	0	0	0	0	0	0	3	0	0	0
Exterior Noise Reduction versus Cost	2	3	2	0	2	2	0	1	1	0	0	3	2	0	2
Document Reliability, Maintainability Data Base	0	0	0	2	1	2	0	1	1	0	2	0	0	0	0
Quantify Design/ Manufacturing Variable Costs	2	1	1	0	1	1	0	1	2	0	1	1	2	1	3
Cost Effectiveness Analysis of Emergency Power Schemes	2	3	2	2	0	1	1	1	1	2	0	2	0	0	0
Feasibility of Engine Emission Reduction	3	0	2	0	3	2	0	0	1	3	1	0	2	1	3
Establish Terminal Area Ride Quality Limits	2	1	0	0	0	0	0	0	2	0	0	0	0	0	0
Airframe/Skin Damping to Reduce Interior Noise	2	0	0	0	0	1	0	1	2	0	0	2	1	0	3
Cost Effectiveness of Vibration Control Methods	2	0	0	0	0	2	0	2	3	0	0	0	2	0	2
Equipment, Operational Requirements for Urban Heliports	3	2	1	3	0	0	2	0	0	3	3	0	2	1	3
Evaluate Contingencies Leading to Pilot Errors	0	0	0	3	0	0	0	0	1	0	2	0	0	1	0
Cost Effectiveness of Automatic Inspection, Diagnostics	1	0	0	1	0	3	0	0	3	0	2	0	2	1	3
Dynamic and Acoustical Properties of Composite Materials	0	0	0	1	0	2	0	0	2	0	2	2	1	0	2
Operating Procedures to Reduce Exterior Noise	3	3	0	2	2	0	0	0	0	3	0	3	0	0	3
Cost Effectiveness of Interior Noise Reduction Methods	2	2	2	0	0	1	0	0	2	0	0	3	0	0	2
Cockpit Layout As It Impacts Performance, Safety	2	0	0	3	0	0	0	0	0	2	2	0	0	0	2
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	3	3	0	0	0	2	0	0	2	3	1	3	1	0	3

Technical Criteria → Project ↓	Technical Uncertainty	Schedule Uncertainty	Cost Uncertainty	Availability of Necessary Research Facilities	Availability of Necessary Technical Expertise	Quality of Technical Approach	Flexibility of Technical Approach	Technical Transfer	Intangibles
Higher Harmonic Pitch Control	3	1	1	3	2	2	2	1	3
Reduce Transmission Noise At Source	2	1	1	3	3	2	2	2	3
Exterior Noise Reduction Versus Cost	2	2	2	2	2	2	2	2	3
Document Reliability, Maintainability Data Base	3	3	3	3	3	3	1	2	1
Quantify Design/ Manufacturing Variable Costs	2	2	2	3	3	3	1	2	1
Cost Effectiveness Analysis of Emergency Power Schemes	2	2	2	3	2	2	2	1	2
Feasibility of Engine Emission Reduction	3	2	3	2	2	2	3	2	2
Establish Terminal Area Ride Quality Limits	2	1	2	2	3	3	2	3	2
Airframe/Skin Damping to Reduce Interior Noise	2	1	1	3	3	3	1	3	1
Cost Effectiveness of Vibration Control Methods	2	2	2	3	3	2	1	2	1
Equipment, Operational Requirements for Urban Heliports	2	2	3	2	2	2	2	2	3
Evaluate Contingencies Leading to Pilot Errors	3	3	3	2	2	2	2	3	3
Cost Effectiveness of Automatic Inspection, Diagnostics	1	2	2	3	2	2	2	2	2
Dynamic and Acoustical Properties of Composite Materials	3	1	2	3	3	3	1	3	1
Operating Procedures to Reduce Exterior Noise	1	1	1	3	2	2	1	2	3
Cost Effectivenss of Interior Noise Reduction Methods	1	1	1	3	3	2	2	3	2
Cockpit Layout As It Impacts Performance, Safety	2	1	2	2	2	2	2	2	3
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	2	1	2	3	2	2	2	2	2

Figure 25 Criteria (CR) Matrix

Project j → Project i ↓	High Harmonic Pitch Control	Reduce Transmission Noise At Source	Exterior Noise Reduction Versus Cost	Document Reliability, Maintainability Data Base	Quantify Design/ Manufacturing Variable Costs	Cost Effectiveness Analysis of Emergency Power Schemes	Feasibility of Engine Emission Reduction	Establish Terminal Area Ride Quality Limits	Airframe/Skin Damping to Reduce Interior Noise	Cost Effectiveness of Vibration Control Methods	Equipment, Operational Requirements for Urban Heliports	Evaluate Contingencies Leading to Pilot Errors	Cost Effectiveness of Automatic Inspection, Diagnostics	Dynamic and Acoustical Properties of Composite Materials	Operating Procedures to Reduce Exterior Noise	Cost Effectiveness of Interior Noise Reduction Methods	Cockpit Layout As It Impacts Performance, Safety	Establish Combinations of Technology/Operating Procedures to Meet Noise Goals
Higher Harmonic Pitch Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Reduce Transmission Noise At Source	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Exterior Noise Reduction Versus Cost	0	0	0	-1	-1	0	0	-1	0	0	0	-1	0	0	-1	0	0	1
Document Reliability, Maintainability Data Base	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1
Quantify Design/ Manufacturing Variable Costs	0	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1
Cost Effectiveness Analysis of Emergency Power Schemes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Feasibility of Engine Emission Reduction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Establish Terminal Area Ride Quality Limits	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	1	0	1	1
Airframe/Skin Damping to Reduce Interior Noise	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1
Cost Effectiveness of Vibration Control Methods	0	0	0	-1	-1	0	0	0	-1	0	0	0	0	0	0	0	0	0
Equipment, Operational Requirements for Urban Heliports	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1
Evaluate Contingencies Leading to Pilot Errors	0	0	1	0	0	0	0	0	0	0	-1	0	0	0	1	0	1	1
Cost Effectiveness of Automatic Inspection, Diagnostics	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	1	0
Dynamic and Acoustical Properties of Composite Materials	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	1	0	1
Operating Procedures to Reduce Exterior Noise	0	0	1	0	-1	0	0	-1	0	0	-1	-1	0	0	0	0	1	1
Cost Effectiveness of Interior Noise Reduction Methods	0	-1	0	0	-1	0	0	0	-1	0	0	0	0	-1	0	0	0	0
Cockpit Layour As It Impacts Performance Safety	0	0	0	-1	-1	0	0	-1	0	0	-1	-1	-1	0	-1	0	0	0
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	-1	-1	-1	-1	-1	-1	0	-1	-1	0	-1	-1	1	-1	-1	0	0	0

Figure 26 Schedule Priority (SP) Matrix

APPENDIX IX Summary of Scoring Functions Results

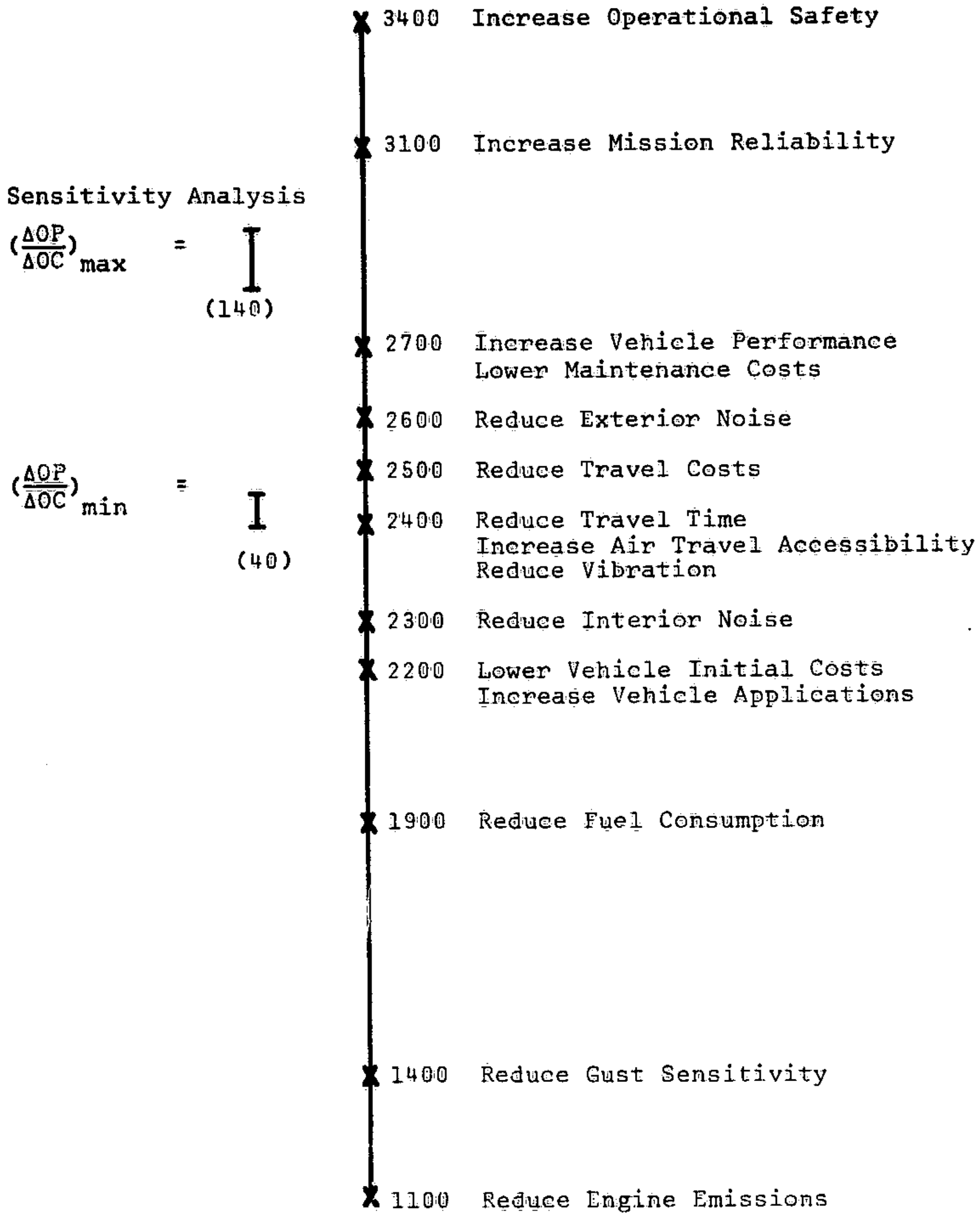


Figure 27 Direct Objective Priorities

MANAGEMENT CLIENTS' WEIGHTS

3400	Increase Operational Safety
3100	Increase Mission Reliability
2700	Increase Vehicle Performance Lower Maintenance Costs
2600	Reduce Exterior Noise
2500	Reduce Travel Costs
2400	Reduce Travel Time Increase Air Travel Accessibility Reduce Vibration
2300	Reduce Interior Noise
2200	Lower Vehicle Initial Costs Increase Vehicle Applications
1900	Reduce Fuel Consumption
1400	Reduce Gust Sensitivity
1100	Reduce Engine Emissions

EQUAL CLIENTS' WEIGHTS

700	Increase Operational Safety
600	Increase Mission Reliability Increase Vehicle Performance Lower Maintenance Costs
500	Reduce Exterior Noise Reduce Vibration Reduce Travel Time Reduce Interior Noise Lower Vehicle Initial Costs Reduce Travel Costs Increase Vehicle Applications
400	Increase Air Travel Accessibility Reduce Fuel Consumption
300	Reduce Gust Sensitivity
200	Reduce Engine Emissions

Figure 28 Direct Objective Priorities

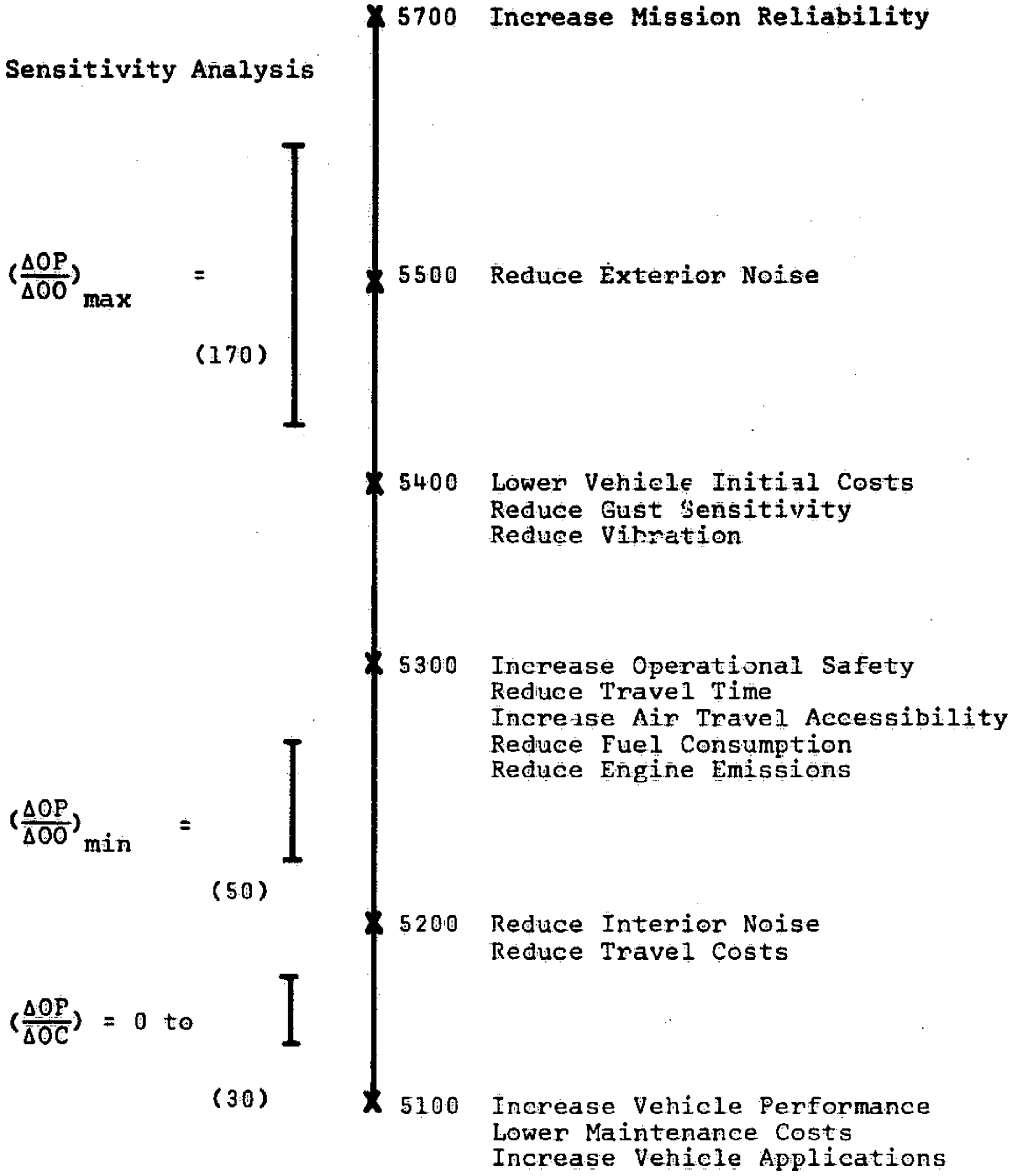


Figure 29 Indirect Objective Priorities

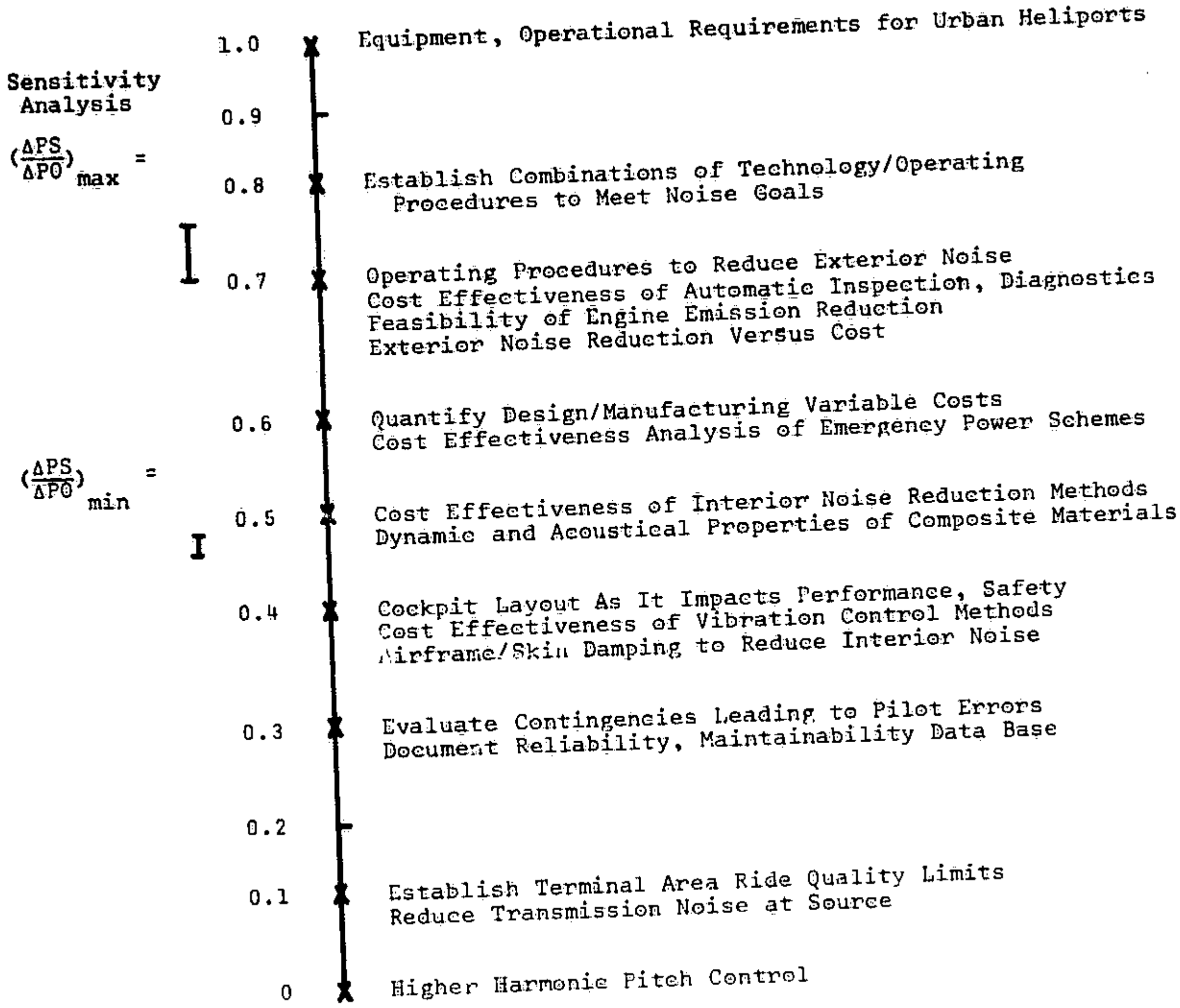


Figure 30 Project Direct Benefit Coefficients

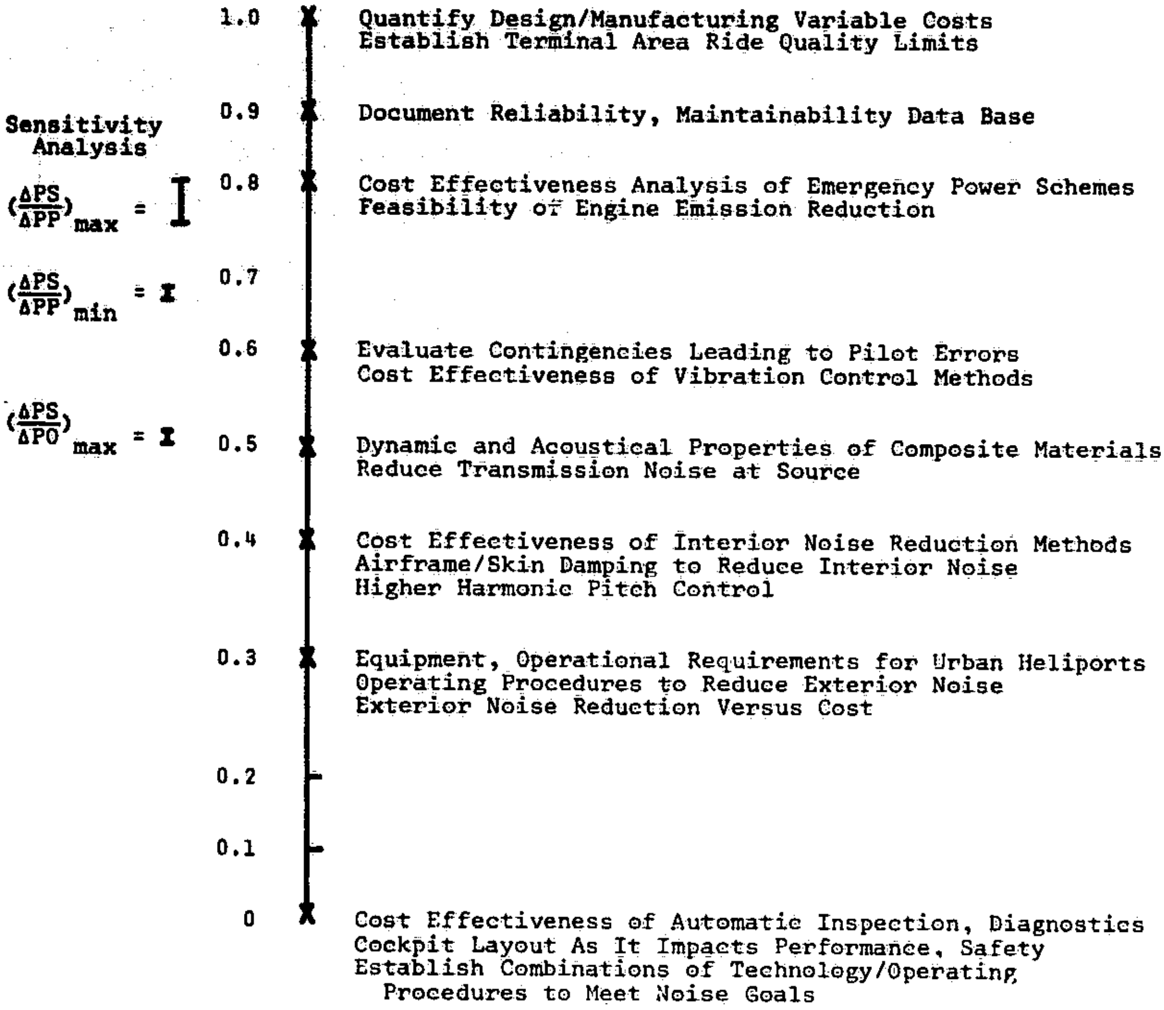


Figure 31 Project Indirect Benefit Coefficients

Client Weights → / Project ↓	Management 6,4,5,2,5,7	All Equal 1,1,1,1,1,1	Passenger Values 1,0,0,0,0,0	Pilot Values 0,1,0,0,0,0	Community Values 0,0,1,0,0,0	Military Values 0,0,0,1,0,0	Industry Values 0,0,0,0,1,0	Operator Values 0,0,0,0,0,1
Higher Harmonic Pitch Control	0	0	0	0	0	0	0	0
Reduce Transmission Noise At Source	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Exterior Noise Reduction Versus Cost	0.7	0.7	0.7	0.6	0.7	0.8	0.7	0.7
Document Reliability, Maintainability Data Base	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3
Quantify Design/ Manufacturing Variable Costs	0.6	0.6	0.6	0.6	0.4	0.7	0.7	0.6
Cost Effectiveness Analysis of Emergency Power Schemes	0.6	0.6	0.6	0.6	0.3	0.7	0.6	0.6
Feasibility of Engine Emission Reduction	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.8
Establish Terminal Area Ride Quality Limits	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1
Airframe/Skin Damping to Reduce Interior Noise	0.4	0.4	0.4	0.4	0.1	0.5	0.4	0.4
Cost Effectiveness of Vibration Control Methods	0.4	0.4	0.4	0.4	0.2	0.5	0.5	0.5
Equipment, Operational Requirements for Urban Heliports	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Evaluate Contingencies Leading to Pilot Errors	0.3	0.3	0.2	0.3	0.3	0.3	0.2	0.2
Cost Effectiveness of Automatic Inspection, Diagnostics	0.6	0.7	0.6	0.7	0.3	0.8	0.7	0.7
Dynamic and Acoustical Properties of Composite Materials	0.5	0.5	0.5	0.5	0.3	0.6	0.5	0.4
Operating Procedures to Reduce Exterior Noise	0.7	0.7	0.6	0.7	0.9	0.7	0.7	0.7
Cost Effectiveness of Interior Noise Reduction Methods	0.5	0.5	0.4	0.5	0.4	0.6	0.5	0.5
Cockpit Layout As It Impacts Performance, Safety	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.5
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	0.8	0.8	0.6	0.8	0.6	0.9	0.9	0.8

Table 19 Project Direct Benefit Coefficients As a Function of Client Weights

Project ↓ / Client Weights →	Management 6,4,5,2,5,7	All Equal 1,1,1,1,1,1	Passenger Values 1,0,0,0,0,0	Pilot Values 0,1,0,0,0,0	Community Values 0,0,1,0,0,0	Military Values 0,0,0,1,0,0	Industry Values 0,0,0,0,1,0	Operator Values 0,0,0,0,0,1
Higher Harmonic Pitch Control	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Reduce Transmission Noise At Source	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Exterior Noise Reduction Versus Cost	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Document Reliability, Maintainability Data Base	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Quantify Design/ Manufacturing Variable Costs	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Cost Effectiveness Analysis of Emergency Power Schemes	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9
Feasibility of Engine Emission Reduction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Establish Terminal Area Ride Quality Limits	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Airframe/Skin Dampint to Reduce Interior Noise	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cost Effectiveness of Vibration Control Methods	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Equipment, Operational Requirements for Urban Heliports	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Evaluate Contingencies Leading to Pilot Errors	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Cost Effectiveness of Automatic Inspection, Diagnostics	0	0	0	0	0	0	0	0
Dynamic and Acoustical Properties of Composite Materials	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Operating Procedures to Reduce Exterior Noise	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Cost Effectiveness of Interior Noise Reduction Methods	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cockpit Layout As It Impacts Performance, Safety	0	0	0	0	0	0	0	0
Establish Combinations of Technology/Operating Procedures to Meet Noise Goals	0	0	0	0	0	0	0	0

Table 20 Project Indirect Benefit Coefficients As a Function of Client Weights

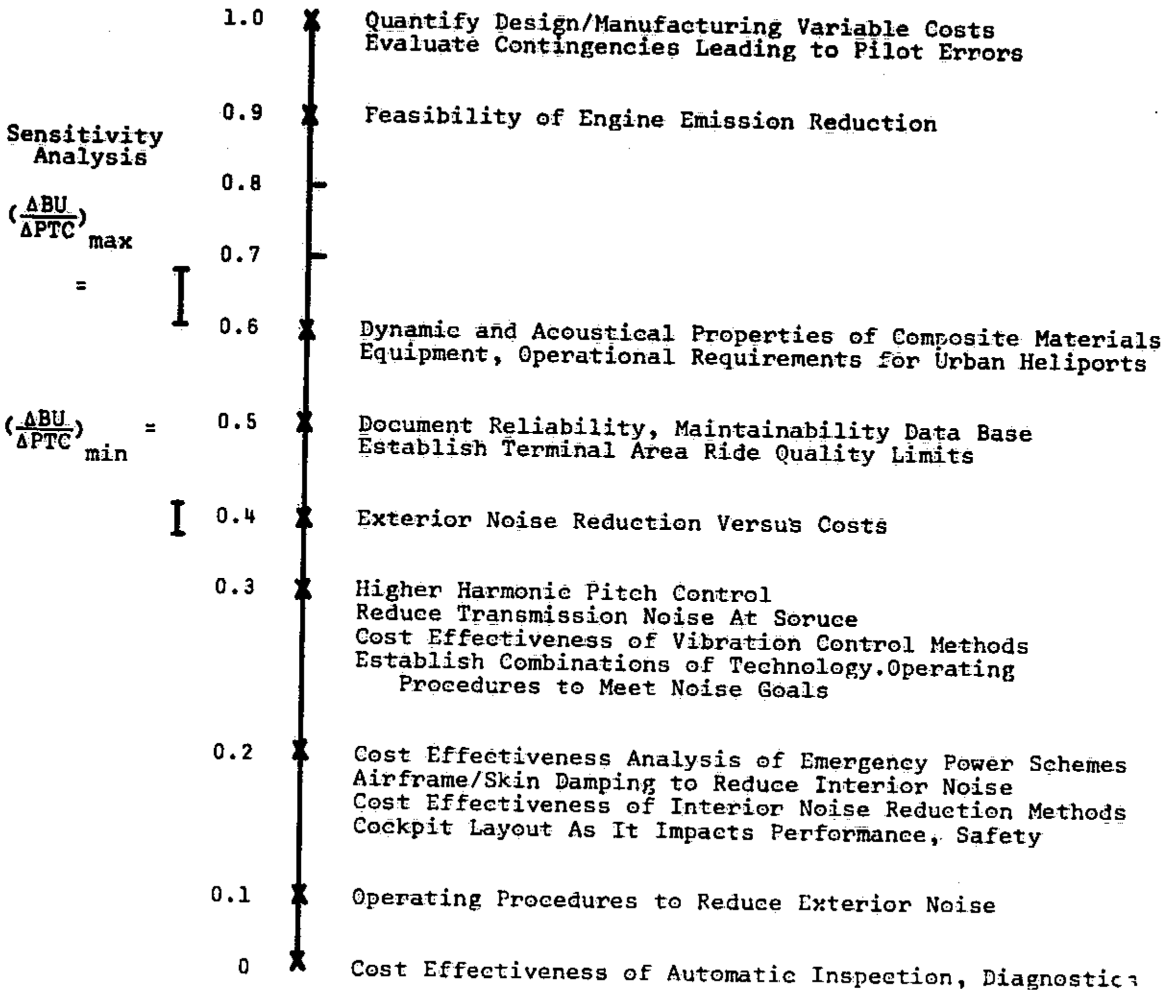


Figure 32 Project Benefit Uncertainty Coefficients

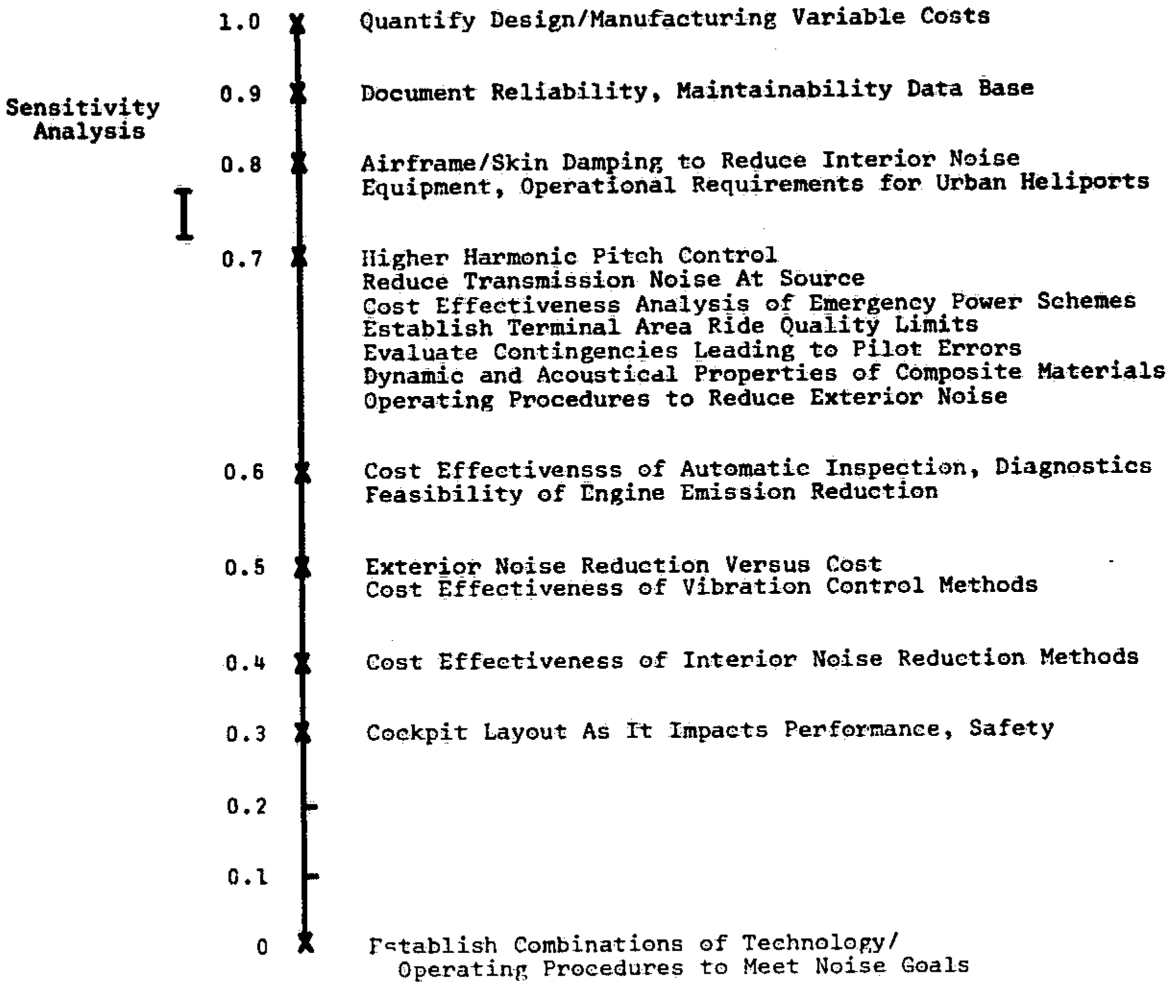


Figure 33 Project Schedule Priority Coefficients

APPENDIX X Graphical Summary of Project Utility Coefficients

Figure 33 Group I Project

Figure 34 Group II Projects

Figure 35 Group III Projects

Figure 36 Group IV Projects

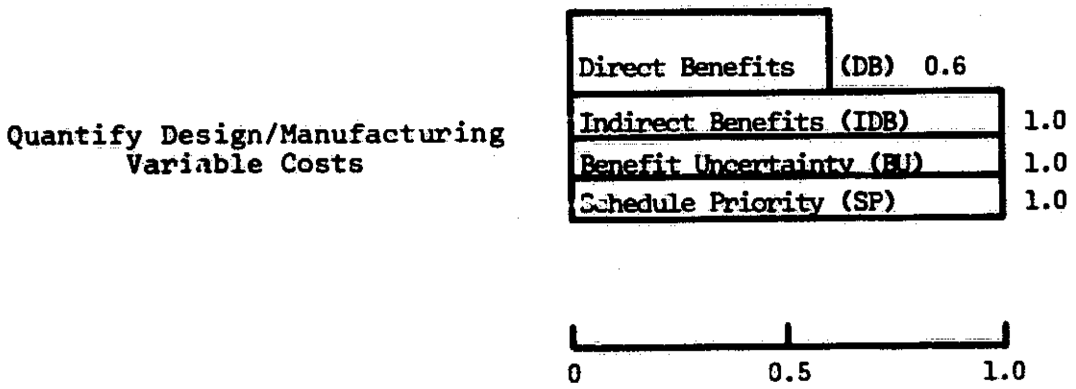


Figure 34 Group I Project

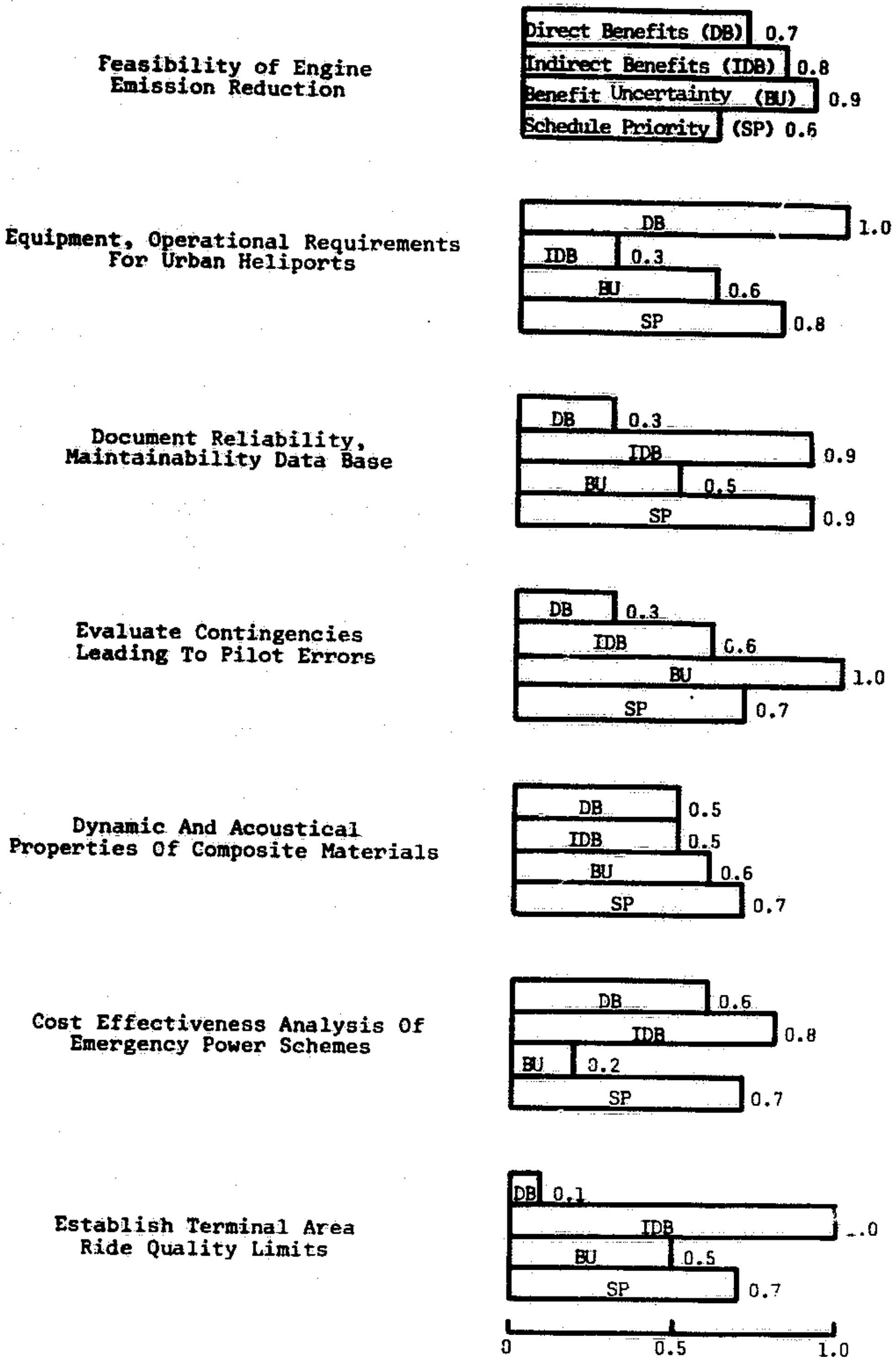


Figure 35 Group II Projects

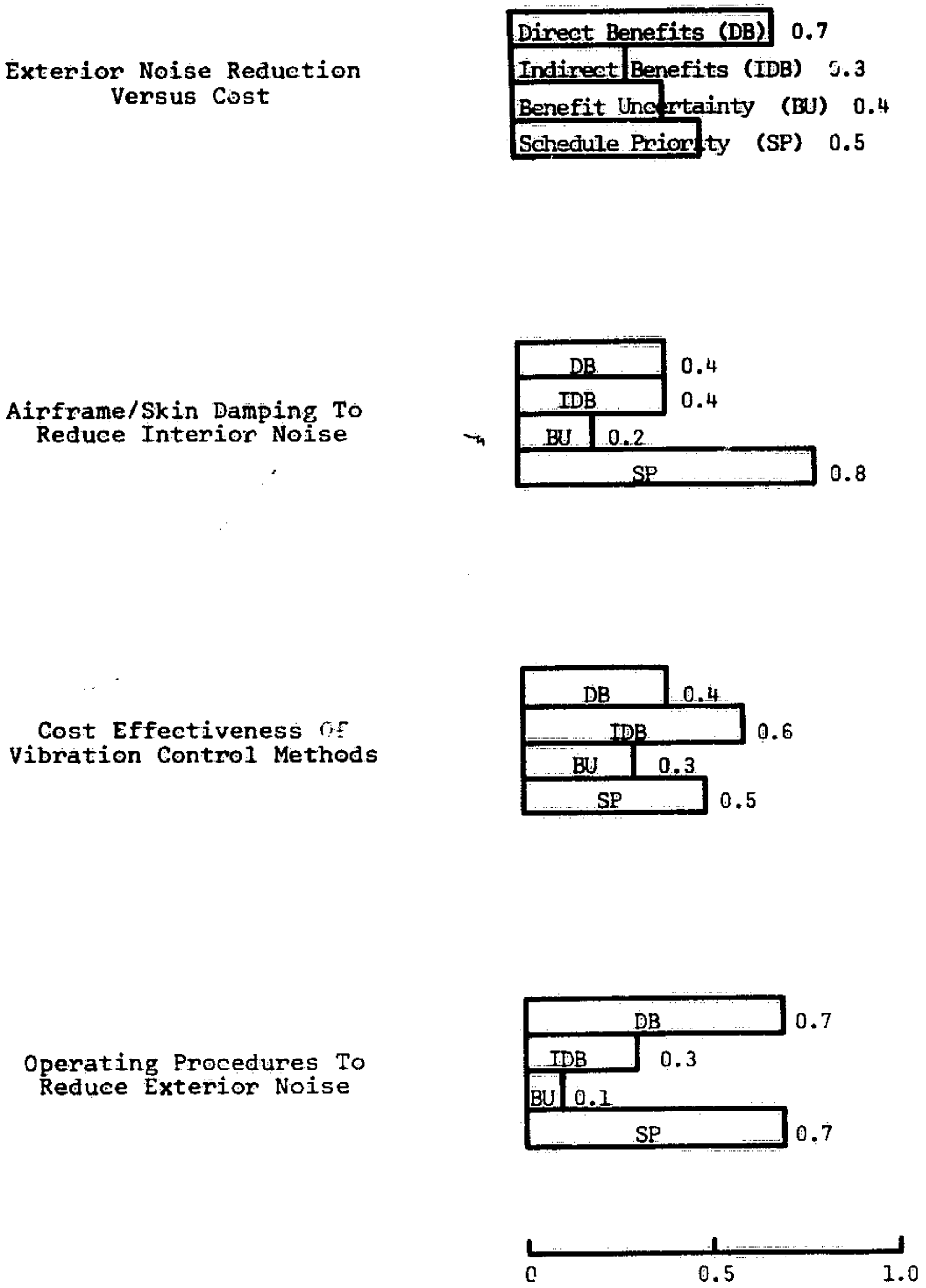


Figure 36 Group III Projects

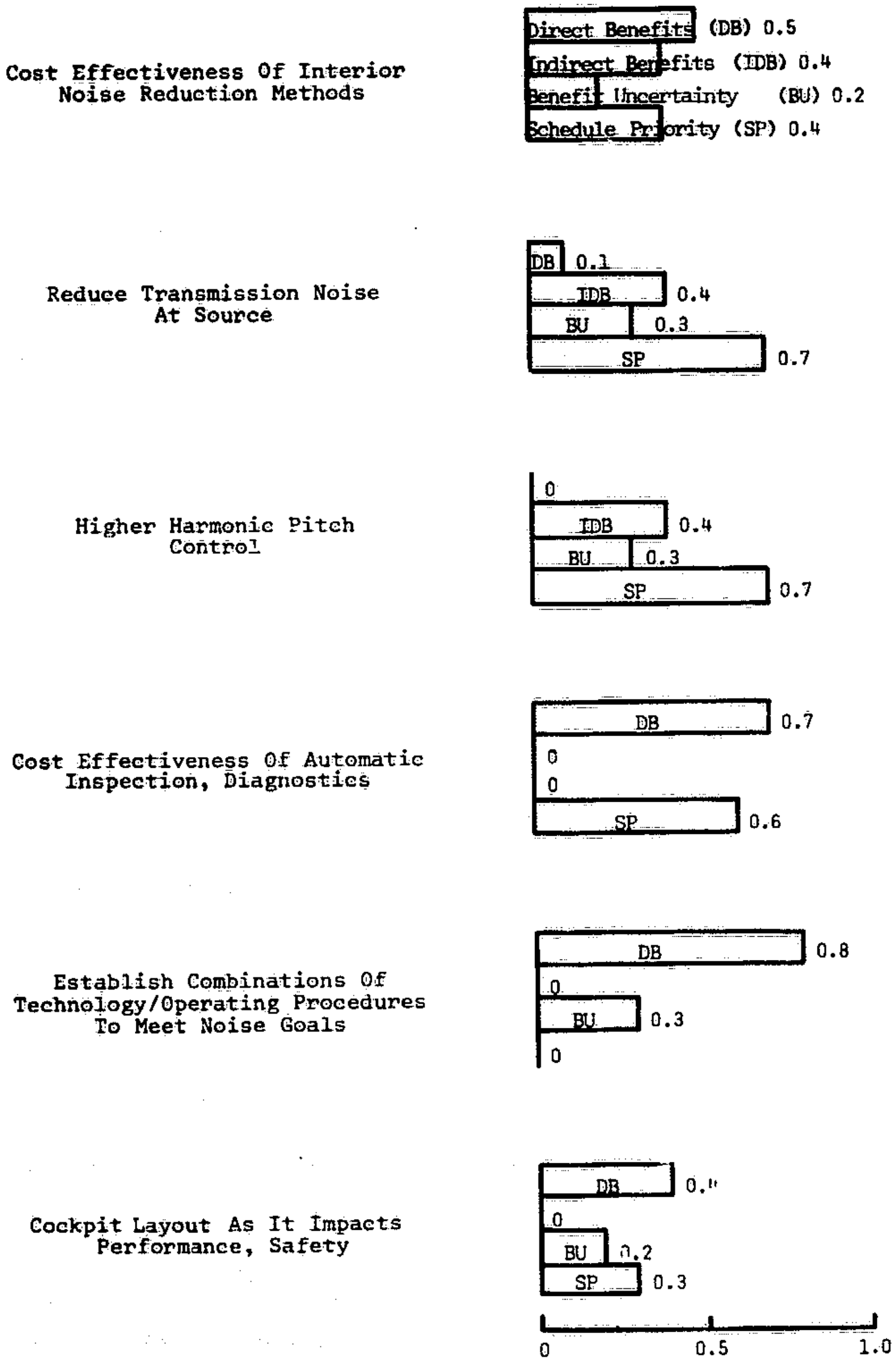


Figure 37 Group IV Projects

APPENDIX XI Summaries of Model Results by Case

Table 21 Case 1 Model Results

Dominant Selections:

- Document reliability, maintainability data base.
- Quantify Design/manufacturing variable costs.
- Cost effectiveness analysis of emergency power schemes.
- Feasibility of engine emission reduction.
- Evaluate contingencies leading to pilot error.

Borderline Selections:

- Equipment, operational requirements for urban heliports.
- Dynamic and acoustical properties of composite materials.
- Establish terminal area ride quality limits.
- Operating procedures to reduce exterior noise.

Non-selections:

- Higher harmonic pitch control.
- Reduce transmission noise at source.
- Exterior noise reduction versus cost.
- Airframe/skin damping to reduce interior noise.
- Cost effectiveness of vibration control methods.
- Cost effectiveness of automatic inspection, diagnostics.
- Cockpit layout as it impacts performance, safety.
- Cost effectiveness of interior noise reduction methods.
- Establish combinations of technology, operating procedures to meet noise goals.

Table 22 Case 2 Model Results

Dominant Selections:

Document reliability, maintainability data base.
Quantify design/manufacturing variable costs.
Cost effectiveness analysis of emergency power schemes.
Feasibility of engine emission reduction.
Evaluate contingencies leading to pilot error.
Equipment, operational requirements for urban heliports.
Cost effectiveness of automatic inspection, diagnostics.

Borderline Selections:

Exterior noise reduction versus cost.
Establish terminal area ride quality limits.
Cost effectiveness of vibration control methods.
Airframe/skin damping to reduce interior noise.
Dynamic and acoustical properties of composite materials.
Operating procedures to reduce exterior noise.
Cost effectiveness of interior noise reduction methods.

Non-Selections:

Higher harmonic pitch control.
Reduce transmission noise at source.
Cockpit layout as it impacts performance, safety.
Establish combinations of technology/operating procedures to meet noise goals.

Table 23 Case 3 Model Results

Dominant Selections:

- Document reliability, maintainability data base.
- Quantify design/manufacturing variable costs.
- Cost effectiveness analysis of emergency power schemes.
- Feasibility of engine emission reduction.
- Evaluate contingencies leading to pilot error.

Borderline Selections:

- Exterior noise reduction versus cost.
- Establish terminal area ride quality limits.
- Airframe/skin damping to reduce interior noise.
- Equipment, operational requirements for urban heliports.
- Cost effectiveness of automatic inspection, diagnostics.
- Dynamic and acoustical properties of composite materials.
- Cost effectiveness of interior noise reduction methods.

Non-Selections:

- Higher harmonic pitch control.
- Reduce transmission noise at source.
- Cost effectiveness of vibration control methods.
- Operating procedures to reduce exterior noise.
- Cockpit layout as it impacts performance, safety.
- Establish combinations of technology/operating procedures to meet noise goals.

Table 24 Case 4 Model Results

Dominant Selections:

- Quantify design/manufacturing variable costs.
- Feasibility of engine emission reduction.
- Evaluate contingencies leading to pilot errors.

Borderline Selections:

- Document reliability, maintainability data base.
- Cost effectiveness analysis of emergency power schemes.
- Establish terminal area ride quality limits.
- Equipment, operational requirements for urban heliports.
- Dynamic and acoustical properties of composite materials.
- Operating procedures to reduce noise.

Non-Selections:

- Higher harmonic pitch control.
- Reduce transmission noise at source.
- Exterior noise reduction versus cost.
- Airframe/skin damping to reduce interior noise.
- Cost effectiveness of vibration control methods.
- Cost effectiveness of automatic inspection, diagnostics.
- Operating procedures to reduce exterior noise.
- Cockpit layout as it impacts performance, safety.
- Establish combinations of technology, operating procedures to meet noise goals.

Table 25 Case 5 Model Results

Dominant Selections:

Document reliability, maintainability data base.
Quantify design/manufacturing variable costs.
Feasibility of engine emission reduction.
Evaluate contingencies leading to pilot errors.

Borderline Selections:

Cost effectiveness analysis of emergency power schemes.
Establish terminal area ride quality limits.
Airframe/skin damping to reduce interior noise.
Dynamic and acoustical properties of composite materials.
Cost effectiveness of interior noise reduction methods.

Non-Selections:

Higher harmonic pitch control.
Reduce transmission noise at source.
Exterior noise reduction versus cost.
Cost effectiveness of vibration control methods.
Cost effectiveness of automatic imspection, diagnostics.
Operating procedures to reduce exterior noise.
Cockpit layout as it impacts performance, safety.
Establish combinations of technology/operating procedures to meet noise goals.