APPLIED SYSTEMS ANALYSIS

Engineering Planning and Technology Management

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PROBLEMS

8.1. *Personal Objectives*
Imagine that you are in the market for a car. Consult the automobiles for sale section of a major newspaper. Select a popular model for which many offers are available. Plot these alternatives in terms of their mileage and cost. In terms of these objectives alone, which are the dominated, excluded, extreme, and compromise solutions?

8.2. *The Curve*
NIS Consultants has evaluated proposed sites for a municipal sewage facility along two objectives: entire fecal fumigation (EFF) and environmental quality improvement (EQUI). The optimal performance of each site is given by the following (EFF, EQUI) pairs:

A	(20, 135)	B	(75, 120)	C	(90, 100)	D	(35, 1050)
E	(82, 250)	F	(60, −50)	G	(60, 550)	H	(78, 500)
I	(70, 620)	J	(10, 500)	K	(40, 350)	L	(30, 800)
M	(95, −200)	N	(55, 220)	O	(40, −80)	P	(30, 500)
Q	(30, 900)	R	(60, 950)	S	(80, −150)	T	(45, 550)
U	(25, 1080)	V	(70, 800)	W	(63, 450)		

(*a*) Identify the dominated, excluded, and noninferior solutions.
(*b*) Which do you classify as extreme and compromise solutions? Discuss your answer.

8.3. *Optimizing*
Identify the noninferior solutions of Problem 8.2 by
(*a*) Maximizing EFF subject to EQUI $\geq b$ where $b = 200, 400, 600, 800$, and 1000 in turn.
(*b*) The weighting method, assigning relative values to (EFF, EQUI) of (20, 8), (40, 6), (60, 4), and (80, 2).

8.4. *Another Computer Run*
See Problem 6.12. Assume that the customer really thinks in terms of two objectives, minimization not only of cost, but also of impurities. Trace the noninferior solutions for these two objectives by
(*a*) The constraint method.
(*b*) The weighting method.

8.5. *Analysis*
Assuming that the set of noninferior solutions for the objectives X and Y can be described by the function: $Y = 50 - X^2$; describe the noninferior solutions by
(*a*) Maximizing Y subject to $X \geq 1, 2, 3, 4$, and 5
(*b*) Maximizing $Z = w_x X + w_y Y$

CHAPTER
9

SYSTEMS OPTIMIZATION PROCEDURE

9.1 THE PROBLEM

No single procedure can deal completely with all aspects of a system. Any single method must, in order to perform, make some assumptions about the real problem, must simplify it to some degree. It is thus likely to leave out some considerations that may be important overall.

As systems analysts, having the responsibility for a careful investigation of the entire situation, we must incorporate all the important elements. The question is, how can this be done efficiently? This chapter presents a procedure for using all the elements of optimization to achieve a best design.

9.2 DESIGN PROCEDURE

The recommended procedure for systems design consists of four main steps. These are each explained in detail in what follows. They are:

1. *Screening* of the feasible solutions to obtain a small set of noninferior solutions.
2. *Sensitivity Analysis* of these best solutions, to determine their performance in realistic situations.
3. *Dynamic Analysis* to establish the optimal pattern of development over time.
4. *Presentation*, the organization of the final result in a way that makes sense to the client.

Screening. Efficiency, economy of effort, must be the first consideration in organizing the overall analysis. The total number of feasible solutions to any realistic problem may be astronomical (see Section 7.1). It is essential to reduce this set as rapidly as possible to a manageable number.

The reduction of the alternatives to a small number is called *screening*, by analogy to sorting things with a sieve. The methods used to do this are commonly called *screening models*. These are usually linear programs, since these are ideally suited for handling very large problems, with thousands of variables and constraints—once the proper simplifying assumptions have been made.

The result of the screening process is one or more "optimum" or noninferior solutions (see Section 8.2). Any of these is optimal only in the sense that it optimizes the simplified mathematical description of the problem used for the optimization. Being solutions to approximations, they are at best approximations themselves.

The screening process in effect defines *regions of optimality*. The results are best interpreted as first-order estimates of the nature of the actual best designs for a system. These regions need to be examined in detail.

Sensitivity analysis. This explores the region of optimality in two ways. The first is by the organized methods described in Chapter 6. The second is by detailed engineering analysis of the system.

In the formal process, a specification sensitivity analysis (see Section 6.2) should be conducted to determine how the optimum would change if the problem were formulated differently. Similarly, the opportunity costs (see Section 6.3) should be examined to see if the optimum design is likely to change, given the known or anticipated changes in the parameters of the objective function.

Detailed engineering analysis is equally important. These should examine the problem in all its complexity, without the assumptions (such as linearity) which are the basis of the screening models. These may be entirely analytic, as through production functions (see Section 2.6); may be computer simulations; or may use complex physical models. In any event, this kind of full analysis is, of course, both time-consuming and expensive: only a few of them can be done.

With regard to the detailed engineering analysis, the screening process in effect provides an experimental design. It provides a sound basis for deciding what kind of detailed analysis to perform. It is an analytic substitute for the intuitive processes that otherwise lead designers to explore alternatives.

Overall, the sensitivity analyses generally reveal many ways in which the "optimum" answers of the screening process can be improved. They can demonstrate that some designs perform better over a wide range of the likely conditions. They may also indicate the importance of factors otherwise assumed away.

Dynamic analysis. The factor that is most typically assumed away in the initial analyses concerns staging of development over time. Typically, the screening models and engineering analyses look at a situation, a pattern of loads for a single period. The reason for this is simple: when the number of combinations is exponential in the number of periods (see Section 7.1) it is impractical to look at all combinations in the feasible region over many periods. The optimal pattern of development of time should eventually be incorporated.

This dynamic analysis can be done reasonably easily after the screening and sensitivity analyses. The number of plausible designs has by then been reduced to a handful for any period.

Dynamic programming is typically best suited for this analysis. As illustrated in Section 7.4, it deals effectively with nonconvex feasible regions such as those generated by exponential growth and economies of scale.

Presentation. A system design will only be implemented if it is approved by the clients. A major system must be endorsed by a company, a governmental agency, or a political process. With few exceptions, these executives, company directors, or politicians are not systems analysts. These individuals must be persuaded of the benefits of the design, if the systems analysis is to come to a successful conclusion.

Every effort should thus be made to ensure that the results can be understood. It is not enough to be right, one must be seen to be right. The client needs to see why the proposed plan is preferable to alternatives, to appreciate that the trade-offs between objectives are reasonable. Simple yet clear ways to present results, such as those illustrated in Section 8.5, become most valuable. In practice, the success of many of the most important projects has depended on the clarity and apparent reasonableness of the final presentation to the clients and the public. The site selection for the Second Sydney Airport (see Section 16.9) is a good example of this fact.

9.3 APPLICATION

The systems analysis for the development of the Delaware River Basin provides an excellent example of the recommended design procedure. It both illustrates the process well and clearly demonstrates its value.

The Delaware River Basin is a large, complex system of tributaries, facilities, and governmental boundaries and interests. It contains over 25 million people and a major segment of U.S. industry. It also supplies water to about 15 million more people around New York City. For most countries, it is at a national scale.

The issue of how best to channel and use the river has been carefully studied for many years. For the better part of the century, the U.S. Army Corps of Engineers developed plans for additional projects in the river. Their mathematical analyses were backed by large physical models of the basin which could be exercised to explore alternatives and validate the numerical studies. Their work represented the forefront of detailed engineering studies.

The systems analysis looked at a series of projects that included 35 reservoirs, 21 hydroelectric plants, and 4 major cities that require water. Assuming only two possible sizes for each facility, and ignoring the constraints on water quality and capacity of the facilities, there were over 500 million alternatives. Only a few thousand of them could, at very best, be examined in any detail by engineering studies.

Screening. The analysis team selected linear programming for the preliminary screening, primarily because of its efficiency compared to alternatives. Nonlinear functions were made piecewise linear. Nonconvex feasible regions were linearized as a preliminary approximation.

The program was formulated very much like that for Salt Lake City (see Section 5.11). The difference was that the analysts paid more attention to the detailed operating characteristics of the system. For example, they incorporated the monthly variations in stream flows. The reference by Jacoby and Loucks gives details.

The screening process resulted in a range of optimal designs. This is because the analysts recognized that there are wide variations in rainfall, and thus in patterns of water supply. They ran the linear program with a variety of flows and amounts of water in the reservoir, thus obtaining a range of optimal designs. This kind of solution is typical.

Sensitivity analysis. Each of these solutions was subjected to sensitivity analyses. They also defined starting points for detailed engineering analyses, which would modify the more approximate solutions of the linear program, and would look for others that would perform better.

Dynamic analysis. Once the static screening and detailed engineering simulation analyses were complete, the optimal scheduling of the projects could be determined by a relatively simple model.

The analysis divided the period from 1980 to 2010 in five-year stages. It was assumed that any project was either operational or nonexistent at that time. Further, it was also assumed that the benefits of each project were independent of each other; although this would not normally be true for a river, it was a reasonable assumption here since the projects were separated by existing, older facilities. These assumptions made it possible to create a recurrence formula and execute dynamic programming.

Presentation. To gain acceptance of their final results, the analysts were careful to validate each of the plans generated by the screening process with standard engineering simulations. They were always prepared to show their clients that their results were equivalent in every major detail to those that were known to be at the forefront of the field. Their analyses were thus credible.

Secondly, the analysis led to a design that was very significantly better than the previous best solutions. The linear program led the designers to locate design concepts that had escaped the intuitions of even the most experienced engineers responsible for the project systems analysis. This was, of course, most convincing.

Note that the detailed engineering analyses were not absolutely necessary to develop the design that emerged from the systems analysis. Yet if the engineering simulations had not been performed, the results would have been suspect, and the systems analysis might not have been accepted. When validated by the detailed analyses, however, the proposed design was absolutely convincing.

9.4 RESULTS

Systems analyses typically lead to major improvements in design, at very little cost compared to the benefits. For the Delaware River Basin, for example, the net benefits of the plan developed by systems analysis were 37% better than those estimated for the best design generated by usual procedures. The annual benefits alone were several times greater than the cost of the analyses; the total benefits were thus about 100 times the costs. Similarly, the analysis of the Third Water Tunnel for New York City (see Section 4.6) cost only $50,000 but led to savings of hundreds of millions of dollars.

These kinds of excellent results, obtained at modest cost, are the main motivation and real justification for applied systems analysis. Naturally these results are not guaranteed, but the opportunities are there.

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