CHAPTER 9

Sensitivity tests

Alternative situations that the findings in the foregoing chapter had suggested might have a bearing on the optimum programme are described in some detail. Two variations were introduced—one varying the size of the total budget for tuberculosis control and the proportion of this budget allocated to supplies, and the other varying the time-horizon for future effects of the current programme. Further, two basic assumptions in the model as applied to tuberculosis control in the Republic of Korea were varied within a wide range to test the sensitivity of the model to erroneous (or changing) estimated parameters. Both the rate used to discount future economic gain and the estimated preventive effectiveness (E) assigned to chemotherapy and BCG vaccination in the various age groups were varied. The resource allocation model as a planning tool and its use by the public health administrator in decision-making through the examination of possible alternatives are discussed.

GENERAL CONSIDERATIONS

The linear programming problem presented and solved in the foregoing chapters has been formulated on the basis of various data of different types. Some of the data are estimates and the programme planner needs to know how sensitive the optimum programme is to variations in the estimates (whether occasioned by error, progress, or political exigency). The essential worth of the resource allocation model as a public health tool is not only that it produces an optimum solution but also that each solution suggests possible alternative formulations to increase the output. Its use, through sensitivity tests, as a means of evaluating alternatives could be a very effective instrument in the hands of the health planner. The various types of data that call for such testing are briefly outlined in the following pages.

The ceilings on the use of certain resources and on the population coverages are set by financial, administrative, and operational considerations. The solutions have previously been shown to be highly sensitive to the constraints. It is possible to vary some or all of the constraints and thus to compare the corresponding variations in the outputs. The shadow prices afford useful clues as to the points at which such variations should be made.

Preventive services have a long-range effect. In order to assess the benefits to the community accruing from such services, the entire period over which the effect is expected to be felt is taken into consideration in applying the model. In the case study reported here, the assumption was made that the effects of preventive services would be felt over a period of 75 years on the basis of an epidemiological model. It should be pointed out that the establishment of a time-horizon for the effects of a preventive service is not synonymous with the formulation of a programme plan for that length of time. Thus the optimum programmes outlined in Chapter 8 are one-year programmes whose benefits are expected to extend over 75 years.

Other time-horizons could be fixed on administrative, operational, or financial grounds. An optimum programme could be selected on the basis of immediate benefits, realizable, say, within 15 years. In this case, ostensibly only activities with immediate effects would be selected. Between the two ends of the scale—i.e., from a complete disregard of future effects to a consideration of all effects as far into the future as they are expected to be felt—one could choose different time limits and compute benefits accordingly. It is of concern to see whether the content of a control programme would vary if different limits were put on the length of time during which the effects were expected to be felt, and, if so, how grossly. Further, as growth of output is a function of time it is useful to see how the output increases.

Finally, the computation of the benefits is based on a number of economic, sociological, and epidemiological parameters. *Estimates* of these parameters have been used. Some of these estimates are less precise than others, but all of them are associated with some degree of imprecision, and all of them affect the planning process in some way or other. It is therefore critical to investigate how the content of an optimum programme changes with variations in these estimates.

Other variables could also be suggested for sensitivity testing. For example, estimates of resource requirements for activities (supplies, doctor-minutes, bed-days, etc.) were based on national averages and could be tested for sensitivity to variation. The sensitivity tests presented in this chapter are intended as examples of what can be studied through the model.

Four sensitivity tests have been done on the model for tuberculosis control and are presented in the following sections. In these tests, the optimum programme for a single benefit—the reduction of economic loss—has been chosen for simplicity of presentation. The calculations of loss of optimality reported in Chapter 8 showed that, in fact, as regards the standard optimum subprogrammes the selection of any one subprogramme would hardly affect the optimality of any of the others. All the data presented in this chapter are based on material adjusted for interdependence of activities (cf. Table 15, page 91).

VARIATION OF BUDGET RESOURCE LEVELS

It was seen in Chapter 8 that the optimum subprogrammes suggested by the linear programming solution consumed the entire budget and the entire amount allocated for supplies, but used the other resources only to a limited extent. It may be remarked that the model does not visualize a separate allotment for supplies. The constraint on this resource merely stipulates that the amount to be spent on supplies should not exceed a certain proportion (25%) of the total budget. It was seen that the shadow price for a unit of this resource was very high, which indicates that, if the resource constraints can be revised, it may be worth while to reconsider first of all this budgetary stipulation. As an aid to judgement it would be instructive to investigate how the output improves with different appropriations for supplies.

A series of solutions was obtained using different (hypothetical) appropriations for supplies. Starting from 22% of the total budget, the appropriation was increased gradually, by 4% stages, up to a maximum of 42%. There were thus 6 situations, with no changes in the constraints except the one on supplies. The trend of the changes in the outputs with each increase in the provision for supplies is given in Table 19 and illustrated graphically in Fig. 6.

It is seen that at a level of about 38% of the total budget, supplies cease to be a binding constraint, as evidenced by the shadow price of zero for the next input increment.

The effect of doubling the budget was also studied together with similar variations in the provision for supplies (see again Table 19 and Fig. 6).

What emerges from these sensitivity tests is that on the average there is an increase of 0.36% (or US$ 273 000) in the outputs, corresponding to a 1% increase in the provision for supplies. If the total budget is doubled, the corresponding increase is on the average 0.45% (or US$ 372 000). The output continues to increase until the supplies provision reaches 42% of the total budget. At this point the shadow price indicates that there would be no further increase.

Hence, if other conditions permit, it would seem to be rational in the tuberculosis control situation in the Republic of Korea as reflected in the model to allocate as much as 40% of the total budget for expenditure on supplies.

VARIATION OF TIME-HORIZON LEVELS

Earlier in this chapter attention was drawn to the fact that a time limit could be fixed up to which long-term benefits of preventive action could be evaluated. This limit is referred to as the time-horizon. It is accepted that certain public health preventive actions, because of their cumulative or epidemiological effect, may have no impact on the community until a very considerable period of time has elapsed.

When preventive services are included among the possible activities, the setting of such time limits may have an important bearing on the composition of optimum programmes. It would be instructive to study whether the optimum programmes would change if benefits were computed up to different points of time, and if so in what way. (It might be argued that a time-horizon could also have been

Table 19. Optimum activity levels [a] (%) for the objective of reducing economic loss at various levels of total budget and budget for supplies

Activity				Budget for supplies as % of:											
				Original total budget (US$515 000)						Double total budget (US$1 030 000)					
Code number	Stratum	Age group (years)	Content	22	26	30	34	38	42	22	26	30	34	38	42
1	urban	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100	100	100	100	100
5	urban	15–44	primary case-finding + domiciliary treatment	100											
6	urban	15–44	primary case-finding + ambulatory treatment		100	100	100	100	100	100	100	100	100	100	100
15	urban	15–44	mass case-finding + domiciliary treatment					1.8	1.8					67.7	99.0
17	urban	15–44	mass case-finding + institutional and domiciliary treatment							15.7	35.3	54.8	74.3	26.0	
20	urban	45–64	primary case-finding + domiciliary treatment	87.9	100	100	100	100	100	100	100	100	100	100	100
40	urban	⩾65	referral case-finding + domiciliary treatment						100						100
51	rural	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100	100	100	100	100
55	rural	15–44	primary case-finding + domiciliary treatment	100	89.7	48.7	7.8								
56	rural	15–44	primary case-finding + ambulatory treatment		2.9	46.2	89.5	100	100						
58	rural	15–44	primary case-finding + institutional and ambulatory treatment		7.4	5.1	2.7								
70	rural	45–64	primary case-finding + domiciliary treatment	100	100	100	100	100	100	100	100	100	100	100	100
total output (millions of US$)				76.00	77.32	78.43	79.55	80.36	80.36	82.48	84.12	85.75	87.39	89.02	89.91
shadow price [b] (US$) of US$100 total budget				0	112	112	112	1 848	1 848	154	154	154	154	168	1 848
shadow price [b] (US$) of US$100 budget for supplies				11 550	5 432	5 432	5 432	0	0	3 976	3 976	3 976	3 976	3 948	0

[a] Activity level is expressed as the percentage of the number of eligible individuals in the population subgroup (cf. page 46, constraints m_7 to m_{30}).
[b] Marginal output per unit of input when the objective function has its optimum value.

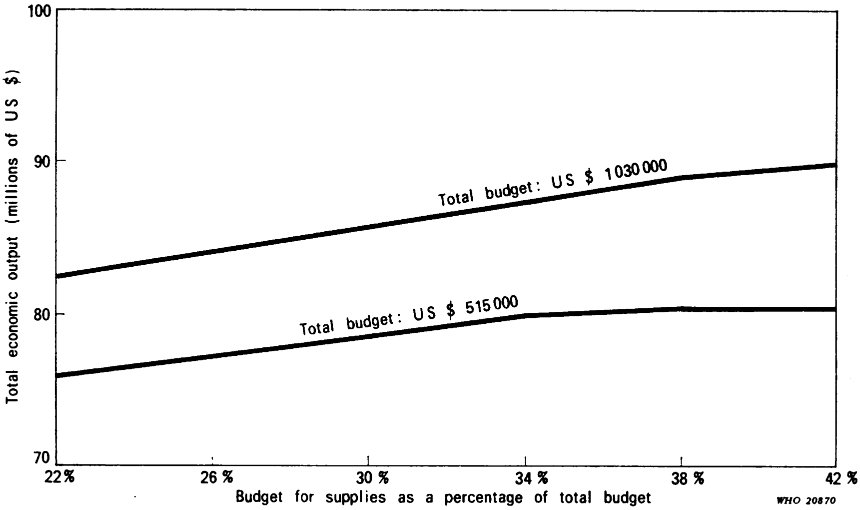

Fig. 6. Economic output corresponding to various levels of the budget for supplies.

set by using a high rate to discount future benefits. It is true that a high discount rate would practically obliterate benefits accruing in the distant future, but it would also have the effect of changing the relative values of benefits expected in the near future.)

In the case study under consideration, the epidemiological models predicted that the impact of present preventive action would, in some cases, be felt up to a period of 75 years. The full effects of such services have been taken into account when computing benefits (see Chapter 4). In the sensitivity tests, time limits of 15, 30, 45, 60, and 75 years were set for benefit computations. The five resulting optimum programmes are given in Table 20.

The table shows the optimum content of tuberculosis control programmes if the programme for the (current) year is planned on the assumption that the preventive effects of activities implemented now will be felt for 15, 30, 45, 60, or 75 years respectively. The subprogrammes do vary in content, but not markedly so. There are shifts in emphasis in the activities of diagnosis and treatment in the age group 15–44 years in both urban and rural areas.

Fig. 7 shows the output in millions of US dollars obtained with each optimum subprogramme. It shows that, although output is a function of the time-horizon, the rate of increase varies with the horizon: it is higher in the shorter horizons and then levels off. The importance of the curve is perhaps best understood if it is seen as one of a battery of such curves, each expressing for a specific disease entity the outputs as a function of the time-horizon of benefits. The public health planner, if presented with such a battery, could begin to visualize the maximum outputs of a total health programme—that is, one consisting of competing specific health programmes—if a shorter time-horizon of, say, 15 years is chosen in preference to a horizon of, for example, 45 or 75 years. Officials concerned with the economic sector, and often those responsible for political affairs, will usually try to lower the time-horizon, while disease control officers will generally want to raise it. Different diseases will array themselves differently: the preventive technologies available for some diseases, such as, for example, yaws, give a totally different pattern from those available for other conditions, such as sclerosis. The use of the resource allocation model provides the health administrator with information to facilitate his decision-making.

SENSITIVITY OF THE OPTIMUM PROGRAMMES TO VARIATION IN ESTIMATES

In spite of advances in medical research, the natural history of many diseases is not known with any great degree of precision. The estimates of prevalence and incidence, the case-fatality rate, the efficacy of medical technology in combating the

Table 20. Optimum activity levels [a] (%) for the objective of reducing economic loss using various time-horizons

Activity				Time-horizon (years)				
Code number	Stratum	Age group (years)	Content	15	30	45	60	75 [b]
1	urban	0–14	Direct BCG vaccination	100	100	100	100	100
5	urban	15–44	Primary case-finding + domiciliary treatment	63.6	63.6	100		24.4
6	urban	15–44	primary case-finding + ambulatory treatment				63.6	75.6
8	urban	15–44	primary case-finding + institutional and ambulatory treatment	36.4	36.4		36.4	
20	urban	45–64	Primary case-finding + domiciliary treatment	100	100	100	100	100
51	rural	0–14	direct BCG vaccination	100	100	100	100	100
55	rural	15–44	primary case-finding + domiciliary treatment	83.6	83.6	75.7	97.4	92.1
56	rural	15–44	primary case-finding + ambulatory treatment	16.4	16.4	16.4	2.6	
58	rural	15–44	primary case-finding + institutional and ambulatory treatment			7.9		7.9
70	rural	45–64	primary case-finding + domiciliary treatment	100	100	100	100	100
total output (millions of US$)				16.84	47.01	69.02	75.21	77.10

[a] Activity level is expressed as the percentage of the number of eligible individuals in the population subgroup (cf. p. 46, constraints m_7 to m_{20}).
[b] Used in the standard programme.

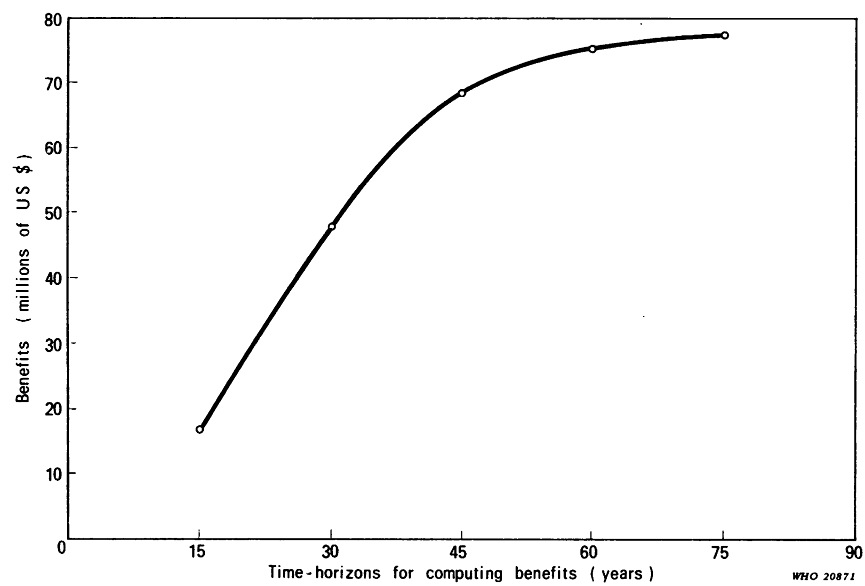

Fig. 7. Economic output corresponding to various time-horizons.

diseases in question, etc., are uncertain. Alternative methods of control cannot be compared without a knowledge of these epidemiological characteristics. The question arises of how precise this knowledge should be before an attempt is made to evolve a rational public health programme by such means as an allocation model of the kind reported here. The availability of an electronic computer makes it possible to assume estimates for these variables over a wide range of values. Critical levels, where drastic changes in optimum programmes occur, would indicate the tolerance margins within which a model may " safely " be used to assist decision-making.

Again as an illustration, two areas in which there was a high degree of uncertainty were taken for the case study of tuberculosis. These are: (1) the rate at which future benefits are discounted, and (2) the relative preventive efficacy of treatment and vaccination.

The rate of discount

In this study, future economic benefits have been discounted at the market rate of 5%, and the optimum programme arrived at in this way is described in Chapter 8. For the sake of simplicity that programme will be referred to as " the standard programme ". Arguments could be advanced, on the basis of economic theory, advocating one discount rate or another, all with some justification. A planner could perhaps select any one rate and arrive at an optimum programme. He would, however, wish to know what would be the extent of output loss if some other rate of discount were, in fact, more appropriate. Such a calculation has been made for the case study. The rate of discount has been varied from 3% to 16%. This is roughly equivalent to varying the present value of US$ 100 gained 25 years later from US$ 47.00 to US$ 2.50. The different optimum programmes obtained in this way are given in Table 21.

Table 21. Optimum activity levels [a] (%) for the objective of reducing economic loss using various discount rates

Activity				Discount rate							
Code number	Stratum	Age group (years)	Content	3 %	4 %	5 %[b]	6 %	7 %	8 %	10 %	16 %
1	urban	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100
5	urban	15–44	primary case-finding + domiciliary treatment	100	100	24.4		24.4	100	63.6	100
6	urban	15–44	primary case-finding + ambulatory treatment			75.6	75.6	75.6			
8	urban	15–44	primary case-finding + institutional and ambulatory treatment				24.4			36.4	
20	urban	45–64	primary case-finding + domiciliary treatment	100	100	100	100	100	100	100	100
51	rural	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100
55	rural	15–44	primary case-finding + domiciliary treatment	75.7	75.7	92.1	97.4	92.1	75.7	83.6	75.7
56	rural	15–44	primary case-finding + ambulatory treatment	16.4	16.4				16.4	16.4	16.4
58	rural	15–44	primary case-finding + institutional and ambulatory treatment	7.9	7.9	7.9	2.6	7.9	7.9		7.9
70	rural	45–64	primary case-finding + domiciliary treatment	100	100	100	100	100	100	100	100
efficiency of standard programme (%)				99.9	99.9	100	99.9	99.9	99.9	99.9	99.9

[a] Activity level is expressed as the percentage of the number of eligible individuals in the population subgroup (cf. p. 46, constraints m_7 to m_{20}).

[b] Used in the standard programme.

The standard programme, which is optimum when the discount rate is 5%, would not be fully optimum if other discount rates were more appropriate. In the case study, a measure of the efficiency of the standard programme has been obtained by calculating the output of the standard programme using each of the various discount rates and comparing the output thus derived with the output of the alternative subprogramme corresponding to the alternative discount rate. The efficiency was never less than 99%. In other words, within reasonable ranges the discount rate used would have no appreciable effect on the total outputs.

Preventive effects of treatment and vaccination

Among the many parameters of the model, those that were considered most likely to affect the decision process were: (1) the pattern of the epidemiological effectiveness (E) of treatment over the 4 age groups, and (2) the level of preventive effectiveness (E) of vaccination in the age group 0–14 years. Low, intermediate, and high values for treatment effectiveness alternated between 3 of the age groups gave rise to 6 possible combinations. When combined with a high, intermediate, and low value for vaccination effectiveness, there were 18 combinations, which are enumerated in Table 22.

The values selected for this sensitivity test correspond (*a*) for vaccination: to the best estimate of effectiveness (used in solving the allocation problem in Chapter 8), and to 75% and 50% of that estimate, and (*b*) for treatment: to the best estimate of effectiveness when chemotherapy is given in age groups 0–14, 15–44, and 45–64 years respectively. Thus the sensitivity test undertaken here poses the question: What if vaccination were 25% or 50% less effective than estimated on the basis of present knowledge, and if at the same time the best estimate of the preventive effectiveness of treatment related not to the age group to which it was assigned in the model, but to another?

The activity content and level of 18 optimum programmes, corresponding to the 18 assumptions, are shown in Table 23.

The efficiencies of the standard programme under all the 18 assumptions were computed and found to be always more than 99%. Thus, the uncertainty attaching to these two important epidemiological parameters was not found to be serious, at least within the range of assumptions tested.

Investigations of this type would help to assess the extent of confidence one could have in a decision based on the allocation model, when the basic data are subject to considerable variation.

Table 22. Preventive effectiveness of treatment and vaccination

Assumption	Preventive effectiveness of treatment by age at intervention				Preventive effectiveness of vaccination by age at intervention
	Age group (years)				Age group (years)
	0–14	15–44	45–64	≥65	0–14
1	1.14	2.48	5.17	0.0	0.079
2	1.14	2.48	5.17	0.0	0.120
3	1.14	2.48	5.17	0.0	0.158
4	1.14	5.17	2.48	0.0	0.079
5	1.14	5.17	2.48	0.0	0.120
6	1.14	5.17	2.48	0.0	0.158
7	2.48	5.17	1.14	0.0	0.079
8	2.48	5.17	1.14	0.0	0.120
9	2.48	5.17	1.14	0.0	0.158
10	2.48	1.14	5.17	0.0	0.079
11	2.48	1.14	5.17	0.0	0.120
12	2.48	1.14	5.17	0.0	0.158
13	5.17	1.14	2.48	0.0	0.079
14	5.17	1.14	2.48	0.0	0.120
15	5.17	1.14	2.48	0.0	0.158
16	5.17	2.48	1.14	0.0	0.079
17	5.17	2.48	1.14	0.0	0.120
18	5.17	2.48	1.14	0.0	0.158

CONCLUSIONS

In the foregoing an attempt has been made to present a number of optimum solutions obtained under certain assumptions that were considered reasonable or most likely with regard to a few critical parameters. Several additional sensitivity tests, not reported here, have been attempted, bearing on other uncertain parameters over a wide range of likely values. Similar insensitivity of the optimum programme has in general been observed. Obviously not all possibilities have been exhausted, but since this study is essentially methodological, these findings and their discussion should be taken

Table 23. Optimum activity levels [a] (%) for the objective of reducing economic loss using various assumptions of the epidemiological effectiveness of BCG vaccination and chemotherapy

Activity				Assumption [b]																	
Code number	Stratum	Age group (years)	Content	1	2	3	4[c]	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	urban	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100	100	100	100	100	84.9	100	100	84.9	100	100
3	urban	0–14	selective vaccination and chemoprophylaxis													15.1			15.1		
5	urban	15–44	primary case-finding + domiciliary treatment	100	100	100	24.4	24.4	24.4	24.4	24.4	24.4	100	100	100	64.2	65.1	65.1	64.2	64.6	64.6
6	urban	15–44	primary case-finding + ambulatory treatment				75.6	75.6	75.6	75.6	75.6	75.6									
7	urban	15–44	primary case-finding + institutional and domiciliary treatment													35.8	34.9	34.9	35.8		
8	urban	15–44	primary case-finding + institutional and ambulatory treatment																	35.4	35.4
20	urban	45–64	primary case-finding + domiciliary treatment				100	100	100	100	100	100				100	100	100	100	100	100
22	urban	45–64	primary case-finding + institutional and domiciliary treatment	100	100	100							100	100	100						
40	urban	⩾65	referral case-finding + domiciliary treatment														100	100		70.5	70.5
51	rural	0–14	direct BCG vaccination	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
55	rural	15–44	primary case-finding + domiciliary treatment	100	100	100	92.1	92.1	92.1	92.1	92.1	92.1	100	100	100	100	100	100	100	100	100
58	rural	15–44	primary case-finding + institutional and ambulatory treatment				7.9	7.9	7.9	7.9	7.9	7.9									
70	rural	45–64	primary case-finding + domiciliary treatment	95.8	95.8	95.8	100	100	100	100	100	100	95.8	95.8	95.8	100	100	100	100	100	100
72	rural	45–64	primary case-finding + institutional and domiciliary treatment	4.2	4.2	4.2							4.2	4.2	4.2						
80	rural	45–64	mass case-finding + domiciliary treatment														0.56	0.56			
82	rural	45–64	mass case-finding + institutional and domiciliary treatment	52.4	52.4	52.4							52.4	52.4	52.4						
efficiency of standard programme (%)				99.8	99.9	99.9	100	100	100	100	100	100	99.5	99.6	99.7	99.6	99.8	99.8	99.9	99.9	99.8

[a] Activity level is expressed as the percentage of the number of eligible individuals in the population subgroup (cf. page 46, constraints m_7 to m_{20}).
[b] See Table 22, page 104.
[c] Used in the standard programme.

as indicative of the validity of the model. In the particular case study of tuberculosis control in the Republic of Korea, certain strategies, such as direct BCG vaccination and simple treatment procedures for symptomatics in the middle age groups, demanded so little input, either of money or of scarce personnel, in relation to the benefits that the choice of strategies remained unaffected over a wide range of assumed values for the parameters. In other words, the uncertainty associated with any of the parameters, whether demographic or epidemiological, was not crucial to decision-making. There is, no doubt, a large class of public health programmes where a similar situation may obtain. The uncertainties surrounding the natural history of many diseases are great, and the efficacies of specific treatment or preventive procedures are not known with accuracy. An operational model based on such imprecise knowledge may therefore seem to be unwarranted. The sensitivity testing used in this case study suggests that a rational planning approach based on optimization models is nevertheless feasible. In any case, sensitivity tests on a computer should at least indicate areas where very precise knowledge is a prerequisite for attempting solutions using the standard techniques of linear programming.