AN INTERACTIVE APPROACH FOR THE MINIMIZATION OF ANNOYANCE DUE TO AIRCRAFT NOISE

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Chapter I

INTRODUCTION

The advent of the 60's and 70's heralded the jet age and along with it associated problems, especially that of jet noise. With people becoming increasingly aware of their environment, the problem of jet noise took on added significance. As aircraft operations increased, so did the annoyance and noise complaints of airport communities.

The problem of jet noise, or, more specifically, reduction of jet noise has been approached in diverse ways. Of the measures that have been suggested, some offer short-term noise mitigation whereas others are long term in nature. Among the measures suggested are the long term possibility of retrofitting aircraft with sound absorbing material, land rezoning or the more short term alternative of improving operational procedures. One such measure is the imposition of curfews on flights of certain aircraft. This study will focus on operational procedures that may lead to a reduction in perceived aircraft noise around existing air terminals.

The model developed will seek to minimize the annoyance from aircraft noise in geographical areas in the immediate vicinity of the airport. The primary emphasis of this research will be a multiple objective consideration of this problem.

Some background material on noise and annoyance is presented prior to the development of a mathematical model for this problem. A literature review of multiple objective solution techniques is then presented. The mathematical model is then presented and the results discussed. The thesis concludes with suggestions for further research.

Chapter II

BACKGROUND

2.1 NOISE

Noise can be defined as unwanted and/or unorganized sound. The measurement of sound , expressed in decibels(dB), involves the measurement of sound pressure level which is easily recorded by a sound level meter. The measurement of noise, however, involves a subjective measure based on the loudness of a sound which, in turn, depends on the frequency of the sound.

The measurement of noise at a point over a period of time takes into account such factors as the duration and spectral content of the sound [26]. To assess single event aircraft noise several measures have been proposed. Two of the more popular measures are :

i) Effective Perceived Noise Level (EPNL)
ii) Noise Exposure Level (NEL)

To account for events such as multiple aircraft flyovers, several metrics have been proposed. Two of the more common measures used in the U.S. are,

i) Noise Exposure Forecast (NEF)
ii) Day-Night Level (LDN)
iii) Community Noise Exposure Level (CNEL)

iv) Equivalent Noise Level (LEQ)

These metrics differ in the unit of measuring single event noise and weighting factors for time of day. All metrics give a higher weighting to night-time flights because of the increased annoyance caused. These are shown in the Table 1.

Noise Exposure (NE) at a point due to multiple aircraft flyovers is computed as, [1]

$$NE = 10 \log_{10} \left\{ \sum_{i:1}^{n} (aD_i + bE_i + cN_i) 10^{\frac{EL_i}{10}} \right\} - A \qquad (1)$$

where,

i= index for the i th operation

n= number of distinct flights

a,b,c = respectively, the Day, Evening and Night weighting factors

(Table 1 above)

D_i, E_i, N_i = the actual number of Day, Evening and Night operations for the flight i

EL = single event exposure level (EPNL or NEL)

A = correction factor (88.0 for NEF , 49.4 for LDN, CNEL and LEQ)

TABLE 1

Comparison of Noise Metrics

Metric	Single event unit	Weighting Factor Day	Evening	Night
NEF	EPNL/EPNdB	1	1	16.7
LDN	NEL/dB(A)	1	1	10.0
CNEL	NEL/dB(A)	1	3	10.0
LEQ	NEL/dB(A)	1	1	1.0

Source:

Caroll Bartell.,

"Integrated Noise Model - Computation of Noise Exposure Values",

Wyle Laboratories, California, Jan. 1977.

Besides the noise metrics discussed above, there are others used for measuring noise. One such is the Aircraft Sound Description System (ASDS) proposed by the Federal Aviation Administration. It measures the time that noise level exceeds a certain threshold. The noise metrics are not uniform worldwide as different countries have proposed their own measure. These include the Noise and Number Index , NNI (U.K), Total Noise Load, B, (Netherlands) and the Noisiness Index, NI (South Africa) [11]

2.2 NOISE IMPACT INDEX

The noise measures discussed above calculate noise at a point. But this does not take into account the effect on the population of the impacted area. An annoyance measure which does consider the population is known as the Noise Impact Index (NII). The Noise Impact Index is used to compare the relative impact of one noise environment with that of another. It is defined as [44],

$$NII = LWP / P(Total) \qquad (2)$$

where,

LWP = sound level weighted population

P(Total) = total population under consideration

The sound level weighted population represents the integrated effect of given noise environments on a particular population. An approximation for the calculation of NII is,

$$NII = P_k W((LDN)_k) / \sum P \tag{3}$$

where

P_k = population in area k

$W((LDN)_k)$ = Day-Night average sound level weighting function

$(LDN)_k$ = Day-Night level for area k

The weighting function, described in [1] is as follows,

$$W(LDN) = \frac{(3.364 \times 10^{-4})\ (10^{0.103LDN})}{(0.2)\ (10^{0.03LDN}) + (1.43 \times 10^{-4})\ (10^{0.08LDN})} \tag{4}$$

2.3 EFFECTS OF NOISE

The effects of noise on man are varied and have been studied by numerous researchers. These range from temporary or permanent hearing loss, speech interference and interference with sleep, to anxiety and distress symptoms.

In a study conducted in 1971 [42], it was reported that noise disturbed sleep, conversation, TV and radio reception.

These noise effects on the human samples are summarized in Table 2.

In addition to the effects on the individual, there are also effects on the community as a whole. Land and Property values can be affected. It has been reported that in one instance, property values around airports were depressed by an estimated $3.25 Billion annually due to aircraft flyovers [43].

The degree of the noise measure, in this instance NEF, in terms of its forecasted effect on the community is shown in Table 3. It may be recalled that NEF is based on the single event noise measure, Effective Percieved Noise Level (EPNL). EPNL together with the number of daytime (0700 to 2200) and nighttime (2200 to 0700) flights is used to determine NEF at a specified location. A higher weightage is given to nighttime flights because of the added disturbance.

2.4 AIRCRAFT NOISE SOURCES

The major sources of aircraft noise are: propellers, rotors, fans, jet noise, boundary layer noise and sonic boom [17]. Two of these have received attention resulting in noise reduction technology developement: Fan Noise and Exhaust noise.

TABLE 2

Effects of Noise on Man

Activity	percentage who found an activity highly disturbed
TV/Radio reception	21
conversation	15
telephone use	14
relaxing out	13
relaxing in	11
listening to music	9
sleep	8
reading	6
eating	4

Source

Tracor Staff

"Community Reaction to Airport Noise - Vol. 1."

NASA CR - 1761, National Aeronautics and Space Administration, Washington, D.C., 1971.

TABLE 3

NEF Interpretation

NEF Value	Interpretation
Less than NEF 30	No complaint expected
NEF 30 to NEF 40	Individual may complain; group action possible.
More than NEF 40	Repeated vigorous complaints expected, group action probable.

Source:

U.S. Department of Transportation. "Aviation Noise Abatement Policy." Washington, D.C., November 18, 1976.

Fan and Engine Noise predominate at approach when the aircraft is flying at idle thrust. This noise is the high-frequency whine of the engine. Exhaust noise, on the other hand, predominates at takeoff when the aircraft is at maximum thrust. Thus noise reduction procedures should consider not only Fan and Engine noise, but simultaneously, exhaust noise as well.

2.5 NOISE ABATEMENT PROCEDURES

2.5.1 Aircraft Noise

The options available for noise reduction include nacelle retrofit, engine refan retrofit, engine replacement and aircraft replacement.

Nacelle retrofit involves acoustically treating nacelles to reduce noise. (Nacelles are the housing in which the engine is enclosed.) Nacelles are treated with sound absorbing material (SAM) in order to reduce noise. It has been estimated that retrofitting costs about $250,000 per aircraft in terms of 1978 dollars [43]. At many of the nations' airports, however, 2- and 3- engine narrow-body aircraft (B-727,B-737,DC-9,BAC-111) predominate. Hence the Federal

Aviation Regulations (FAR 36) has set a deadline of retrofitting all 2- and 3-engine aircraft by 1990. The effect of retrofitting on the population around a sample airport, Boston-Logan International Airport, is shown in Table 4.

Refan involves replacing the low-bypass fan with a high-bypass ratio fan. (Bypass ratio is the ratio of the weight flow of air discharged from the fan exhaust duct to the weight flow of air passing through the engine). Other advantages of this include increased total engine thrust and reduced fuel consumption.

2.5.2 Land Rezoning

This measure essentially involves rezoning of land that fall within a particular noise contour. However, this necessitates purchase of occupied land within the impacted area and converting it to airport use as well as relocating the people affected and hence is a costly alternative. This would be considered only as a last alternative.

TABLE 4

Effect of Retrofitting on Population

Boston Logan International Airport

	runway number					all runways	percentage reduce after
EPNL values	4L&R	15R	22L&R	27	33L	combined	retrofit
Before Retrofit							
EPNL							
105	1220	4000	3910	440	0	9570	-------
100-105	1750	7420	3990	500	0	13660	-------
95-105	8090	18190	7780	800	0	34940	-------

Table 4 (continued)

EPNL values	4L&R	15R	22L&R	27	33L	all runways combined	percentage reduce after retrofit
After Retrofit							
EPNL							
105	0	740	490	90	0	1320	87.2
100-105	1460	3640	2920	440	0	8460	38.1
95-100	2040	7690	4650	0	0	14380	58.8

Source

U.S. Senate, 95th Congress.

Aircraft and Airport Noise Reduction

Hearings before the Subcommittee on Aviation

of the Committee of Commerce, Science and Transportation.

May 24, 25, and June 13, 14 and 17, 1978.

2.5.3 Sound Barriers

Erection of sound barriers and insulation of homes around the airport is another long-term noise abatement alternative to be considered. The effectiveness of this must be compared based on the number of people in the impacted area and the cost of insulation. A range of $1000/acre to $10,000/acre is the figure quoted for building insulation [20].

2.5.4 Improved Operational Procedures

Improved Operational Procedures typically refers to modifying aircraft approaches and takeoffs. It also includes measures such as imposing restrictions on flights of certain aircraft at certain times of the day or night.

The standard commercial aircraft approach is the 3 degree glide slope as shown in Figure 1. In addition, other approaches have been suggested such as the two-segment approach. Figure 2 shows the various approach procedures as a function of the total area highly annoyed. This is based on tests carried out at the Royal Aircraft Establishment at Bedford, United Kingdom using a TRIDENT 3 short haul airliner.

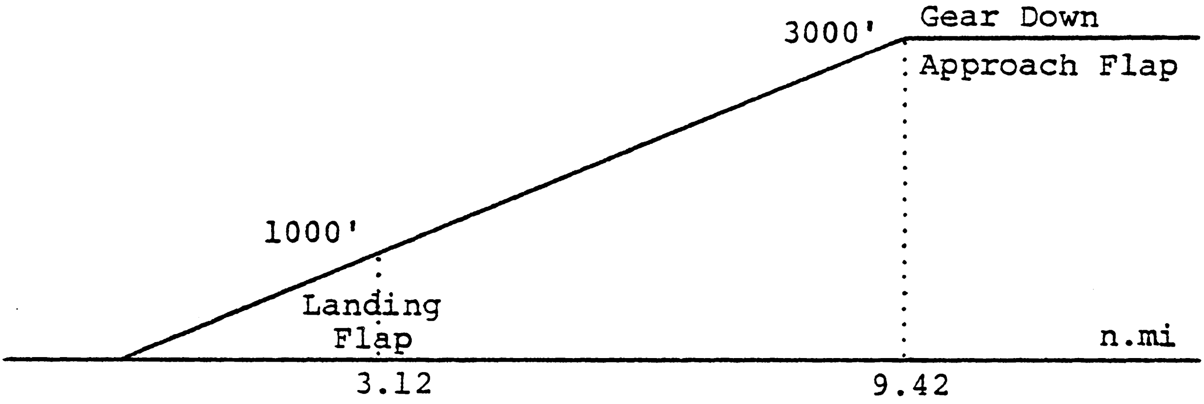

Figure 1: Standard 3 Degree Approach Profile

CASE	INITIAL APPROACH	UPPER SLOPE	TRANSITION HEIGHT	LOWER SLOPE
1	3000 FEET LEVEL	3 DEG	---	3 DEG
2	CONTINUOUS DESCENT	3 DEG	---	3 DEG
3	CONTINUOUS DESCENT	4 DEG	---	4 DEG
4	CONTINUOUS DESCENT	6 DEG	1500 FEET	3 DEG
5	CONTINUOUS DESCENT	6 DEG	500 FEET	3 DEG
6	CONTINUOUS DESCENT	5 DEG	500 FEET	3 DEG
7	CONTINUOUS DESCENT	4 DEG	500 FEET	3 DEG
8	3000 FEET LEVEL	6 DEG	500 FEET	3 DEG
9	CONTINUOUS DESCENT	6 DEG	---	6 DEG

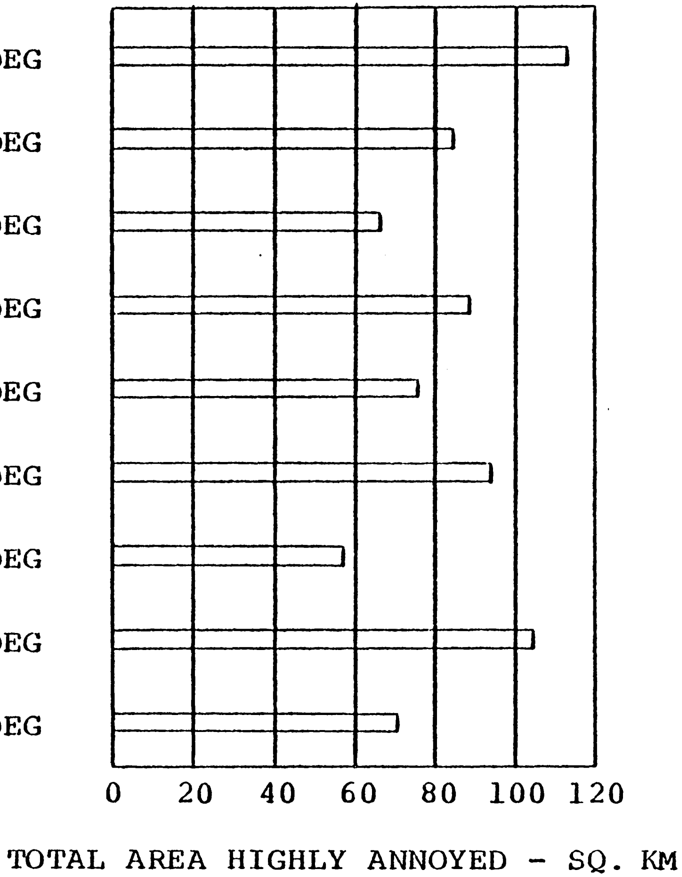

Figure 2: Highly annoyed population as a function of approach procedure - TRIDENT 3 [33]

Modifications to take-off procedures involve designing trajectories that affect the minimum number of people. An example of this is a proposed take-off procedure for Los Angeles Airport involving taking off towards the sea and then flying back inland , if required, so as to affect the least number of people during initial take-off. Other procedures have been attempted such as thrust cutback to reduce noise emmisions.

Other measures attempted to reduce noise include selective runway usage and increased usage of satellite airports especially in big cities. The use of satellite airports could also help reduce congestion at major airports.

Some other work in the area of noise minimization includes that of Jacobson and Cook [28] wherein the approach is the design of noise optimal trajectories based on the given runway orientations and population data for the area around an airport. This research does not take into account multiple flyovers of the same aircraft nor does it consider a flight mix of aircraft.

Another approach due to Frair [13], is where the total annoyance to the airport community is minimized. An optimum set of arrivals and departures is arrived at using the Noise Impact Index as the annoyance measure. Annoyance is minimized over all areas subject to operating restrictions. This may lead to a concentration of noise in low population areas. In certain cases, the Decision Maker may wish to exercise control over the noise levels allowed in specified geographical areas. To consider such a problem, a multiobjective approach is considered.

The emphasis in this study will be to minimize annoyance in several sub-groups of areas simultaneously leading one to consider a multiobjective problem.

The next section provides a description of the problem and the development of a corresponding mathematical model.

Chapter III

MODEL DEVELOPMENT

The primary focus of this research is to minimize annoyance to airport communities due to aircraft noise. Noise Annoyance is defined in terms of a noise annoyance metric. 'Airport communities' refers to the people living close to the airport who are affected by aircraft noise.

The next section contains a description of the problem. The assumptions on which the study is based and the notation used follows. Then a mathematical model for the problem is presented.

3.1 PROBLEM DESCRIPTION

The objective of this problem is to minimize noise annoyance to airport communities. A set of areas is defined for a geographical region around the airport center. For a certain set of operations (arrivals and departures), the annoyance in each area or group of areas is minimized, separately, subject to a set of operating restrictions. There are thus one or more objectives to be minimized.

The annoyance measure used is the Noise Impact Index, NII, defined in Equation (3). This depends on the Noise Exposure, NE, Equation (1), reproduced below:

$$NE = 10 \log_{10}\left\{ \sum_{i=1}^{n}(aD_i+bE_i+cN_i)10^{\frac{EL_i}{10}} \right\}-A \qquad (1)$$

where, it will be recalled, n refers to all distinct flights or unique combinations of track and aircraft type. From the above , the following parameters can be identified as affecting annoyance:

i)trajectory selection

ii)aircraft operations by type and time of day

Further, a distinction needs to be made between arriving and departing aircraft because the noise characteristics are different in the two cases.

3.2 ASSUMPTION

The assumption on which the model is developed is that aircraft arrive and depart on fixed predetermined trajectories designated as either arrival trajectories or departure trajectories.

3.3 VARIABLES

The control parameters are the aircraft operations by type and by time of day for the trajectory selected. Also, in the case of take-offs, annoyance depends on the stage length of the flight. This is defined in terms of the distance the aircraft has to fly non-stop. The further the aircraft has to travel non-stop, the more fuel it would have to carry. This would mean more weight on departure which would necessitate a higher take-off thrust. Stage length is defined as follows:

Distance to be Travelled	stage length
0- 500 miles	1
500-1000 miles	2
1000-1500 miles	3
>2000 miles	4

The following variables are defined for the problem:

X_{ikjl} =number of departures of type i aircraft with with stage length k utilizing trajectory j during time period l

Y_{ijl} =number of arrivals of type i aircraft utilizing trajectory j during time period l

3.4 NOTATION

A = area designation

i = type of aircraft

j = ground track j

l = time period l

P = total population affected

NA = number of areas

NI = number of aircraft types

NJ = number of ground tracks

NK = number of stage lengths

NL = number of time periods

Nd = limitation on use of ground track d

Np = limitation on operations in time period p

Ns = limitation on operations with stage length s

PA = population in area A

NX_l = number of aircraft available for take-offs during time period l

NX_{il} = number of type i aircraft available for take-offs during time period l

NX_{kl} = number of stage k aircraft available for take-offs during time period l

NY_l = number of aircraft available for arrivals during time period l

NY_{il} = number of type i aircraft available for arrivals during time period l

3.5 OBJECTIVE FUNCTIONS

In the multiobjective model, the goal is to minimize the annoyance in each geographical area or group of areas of concern. The noise annoyance in each area is defined as,

$$NII_a = (P_a/P)*(WLDN)_a$$

where

NII is the Noise Impact Index

P_a is the population in area a

P is the total population

$WLDN_a$ is the weighting factor based on the LDN noise measure

The relation between the arrival and departure variables and the noise measure LDN is defined by the following relations,

$$LDN_a = 10 \log_{10} S_a \qquad (5)$$

$$S_a = \sum_{i}^{NI} \sum_{k}^{NK} \sum_{j}^{NJ} \{ 10^{\left(\frac{NEL_{ikja}}{10} - 4.94\right)} (X_{ikj1} + 10X_{ikj2}) + 10^{\left(\frac{NEL_{ija}}{10} - 4.94\right)} (Y_{ij1} + 10Y_{ij2}) \}$$

The objective function for a group of areas is then,

$$\min \sum_a P_a/P * (WLDN)_a \qquad (7)$$

The Multiobjective model for this problem is,

$$(\min NII(A1), \min NII(A2), \ldots\ldots\ldots\ldots, \min NII(Ak)) \qquad (8)$$

where Ai refers to a specific area or group of areas considered at level i

k is the number of levels (geographical areas) considered.

3.6 CONSTRAINTS

Two types of constraints are imposed,

i) Operating conditions limitations

ii) Demand restrictions as dictated by current and projected operating conditions

These constraints are,

i) Departure aircraft availability in each time period

$$\sum_{k}^{NK}\sum_{j}^{NJ} X_{ikjl} \leq NX_{il} \quad i = 1,2,\ldots,NI;\ l = 1,\ldots\ldots,NL \qquad (9)$$

ii) Availability of arrival aircraft in each time period

$$\sum_{j}^{NJ} Y_{ijl} \leq NY_{il} \quad i = 1,2,\ldots,NI;\ l = 1,\ldots\ldots,NL \qquad (10)$$

iii) Number of operations on ground track j during time period l is limited to b_{jl} per day

$$\sum_{i}^{NI} Y_{ijl} + \sum_{i}^{NI}\sum_{k}^{NK} X_{ikjl} \leq b_{jl} \quad j = 1,\ldots,NJ;\ l = 1,\ldots,NL \qquad (11)$$

iv) Take-off Flight Demands: the number of take-offs of stage length s on runway r is not to be below N_{rs} per day

$$\sum_{i}^{NI}\sum_{j}^{NJ} X_{ikjl} \geq N_{rs} \forall j \in R\ ;\ k = 1,\ldots,NK;\ l = 1,\ldots,NL \qquad (12)$$

where R is the set of Departure runways

v) Demand for Incoming flights : the number of arrivals on runway r during time period l is not to be less than N_{rl} per day

$$\sum_{i}^{NI}\sum_{j}^{NJ} Y_{ijl} \geq N_{rl} \quad l = 1, \ldots, NL \tag{13}$$

Chapter IV

LITERATURE REVIEW

In the previous section, the problem was defined as a multiple objective problem. This section contains a review of available literature on multiobjective methods as a prelude to proposing a solution strategy.

In decision-making situations, the terms multiple objective, multiple attribute, and multiple criteria are often used interchangeably. However, a distinction can be made between these terms.

Multiple attribute problems involve choosing among a set of alternatives based on their attributes. Usually there is a discrete set of alternatives from which a choice has to be made based on their attributes.

Multiple Objective decision problems deal with the design of alternatives that "best satisfy" the objectives of the Decision Maker.

Multiple Criteria problems involve either multiple attributes or multiple objectives or both.

The scope of this review will be limited to Multiple Objective and Multiple Criteria Decision Methods (MODM, MCDM). The scope is further limited to Single Decision Maker methods.

Hwang [25] has classified available MODM methods based on the availability of preference information from the DM:

i)No articulation of Preference Information
ii)'A Priori' Articulation of Preference Information
iii)Progressive Articulation of Preference Information
  -Iterative Methods
iv)'A Posteriori' Articulation of Preference Information
  -Generating Techniques

i)No Articulation of Preference Information

A method called the Method of Global Criterion has been proposed by Boychuk and Ovchinnikov [4] and Salukvadze [39] where the objective is to minimize the relative deviations of all the objectives from the "ideal" solution. An "ideal" solution is one obtained by optimizing each objective individually.

ii)'A Priori' Articulation of Preference Information

These methods depend on the 'ordering' of the objectives by the DM. The differences in the methods are in the nature of preference information required - cardinal, ordinal or a combination of both. These methods are:

Utility Function Method
Goal Programming
Electre Method

Utility Function Method

This method is based on obtaining cardinal information from the DM in the form of specific objective preference levels. A most satisfactory solution can be obtained if the proper utility function is available and used in conjunction with the DM's prefences. However, the disadvantage of this method is that it is difficult to predict the exact utility function of the DM. Also, this method is computationally intensive, the burden increasing exponentially with the number of objectives.

Goal Programming

Goal Programming methods seek to minimize the absolute deviations of the objectives from their predetermined targets or "goals". Originally proposed by Charnes & Cooper in 1961 [5], different approaches have been developed; by Lee [32], Ignizio [27] and others.

The simple GP formulation for a Vector Maximum Problem (VMP) is given by,

$$\min \sum_j (n_j + p_j)$$

$$\text{s.t } g_i(x) < 0 \qquad i=1, 2, \ldots\ldots, m \qquad (14)$$

$$f_j(x) + n_j - p_j = b_j \qquad j=1, 2, \ldots\ldots, k$$

$$n_j,\ p_j > 0 \quad \text{and } n_j . p_j = 0 \quad \text{for all } j$$

where n_j is the negative deviation from the goal b_j

and p_j is the positive deviation from the goal b_j

The various approaches differ in the formulation of the objective function: either an ordinal ranking of the objectives is considered or, in addition, the deviations are weighted. Goal Programming is computationally efficient and requires less effort on the part of the DM because all that is required of him is that he rank the objectives. The disadvantage of this method is that the adequacy of the solution is dependent on the goals set by the DM and his priority structure. A change in either one or both of these parameters could change the solution. This is overcome, partly, by performing sensitivity analysis on the "optimum" solution.

Electre Method

The Electre Method, proposed by Roy [37], is based on an 'outranking' relationship for noninferior solutions. A partial ordering of the solutions is obtained based upon two conditions: a concordance condition and discordance condition. The function of the former is to indicate tolerance for errors in comparing noninferior solutions. The latter indicates which solutions may be compared.

This method begins with the set of nondominated solutions or a representative sample of it thus making it computationally unattractive because of the size of the solution set involved.

Other methods have been proposed which utilize prior preference information. The Lexicographic method proposed by Waltz [45] optimizes each objective iteratively starting with the most important. As soon as a unique solution is obtained, the algorithm is terminated thus ignoring lower ranked objectives in favor of the higher ranked. A variation of the GP method is proposed by Gembicki [18] called the Goal Attainment method. This method requires in addition to the goals, a weight vector relating the under- or over-attainment of the desired goals.

iii)Iterative methods

Iterative methods have received a lot of interest in recent years as evidenced by the number of papers dealing with this approach. All these methods involve basically two steps: 1)generation of a solution 2) eliciting the DM's reaction to the solution and modifying the problem and resolving, the modification indicating either a trade-off or a change in priority structure. The major methods in this category are reviewed below.

Surrogate Worth Trade-off Method (SWT)

STEM:method of Linear programming with Multiple

Objective Functions-Step Method

Surrogate Worth Tradeoff Method

This method, proposed by Haimes and Hall [21], consists of two steps: 1)Generation of non-dominated solutions which form the trade-off functions and 2)search for a preferred solution using a surrogate worth function. The trade-off function is formed from the relative trade-off of marginal increases or decreases from any two objective functions. The surrogate worth function is the DM's assessment of how much (on an ordinal scale -10 to +10) one prefers trading one objective for another.

The trade-off functions are generalized between any two objectives assuming fixed values for all the remaining objectives. Hence it provides limited information to the DM of the nondominated solution set. The advantage of this method is that the DM has only to compare two objectives at a time thus making it specially attractive when there are a large number of objectives.

STEM

This method, proposed by Benayoun and others [2], involves the following steps: 1)construction of a pay-off table after solving p subproblems to optimize each of p objectives separately 2)calculation phase:solving a LP which is nearest, in the MINIMAX sense, to the ideal solution

3)specification of a trade-off by the DM thus changing the feasible region in space.

The advantage of this method is that it involves at most p iterations. However it assumes that if at any stage no satisfactory value is found for any of the objectives, no solution exists.

Among the other interactive methods are, the Method of Geoffrion [19], Method of Zionts and Wallenius [50], the GPSTEM method of Fichefet [12], Sadagopan and Ravindran [38], Interactive Goal Programming [9], to name but a few.

iv)Generating Techniques

Generating Techniques involve the generation of the entire nondominated solution set. These seek to develop an exact or approximate representation of the entire solution set. Thus they are computationally intensive and feasible only for problems with a small number of objectives. The major methods are discussed below:

Parametric Method

This method, proposed by Gal and Nedoma [16], Zadeh [46] and others solves the VMP by parameterically varying a weighted LP to obtain the complete nondominated solution set.

E-Constraint Method

Marglin [34] suggested this approach where one objective is optimized while keeping all the others constrained to some value. The set of nondominated solutions is generated by systematically varying the minimum allowance levels for each objective.

Another Generating Technique is the Multiple-Objective Linear Programming method proposed by Zeleny [47].

The next section presents a comparitive analysis of the solution techniques discussed above.

Chapter V

CHOICE OF SOLUTION TECHNIQUE

The problem as formulated is a multiple objective, nonlinear programming problem. When the multiple objective problem is relaxed to a single objective , it becomes one of minimizing a nonlinear objective subject to linear constraints.

In this problem, each variable corresponds to an arrival or departure. For a moderate sized airport, this number would be fairly large. Further, there could also be a large number of constraints. There could be as many as 1000 variables and several hundred constraints. Hence, it would appear that the best method to solve the NLP would be to use a method that involves solving a series of related linear programs.

The method of Separable Programming has been considered to solve the problem. However, a significant amount of computational effort has to be expended just to obtain an initial basic feasible solution. This effort could be reduced by employing the Generalized Upper Bounding (GUB) option but this is not available at VPI&SU.

Another method is proposed based on an earlier work by Frair [13] shown in Figure 3. This method combines linear programming with a gradient projection technique to solve the nonlinear problem.

The choice of technique for solving the multiple objective problem is dictated by the need for flexibility of usage. This is necessary because of the diversity among decision makers (DM) and their method of usage of the model. The choice of technique involves a trade-off between the amount of information it provides the DM and computational feasibility. Of the techniques discussed above, Generating Techniques provide the most information to the DM at the expense of considerable computational effort However, in this problem, the primary concern is the computational feasibility because of the potentially large number of variables and constraints involved. Thus it would appear that Generating Techniques would be inappropiate for use in solving this problem.

Techniques for no articulation of Preference Information are similarily impractical as they depend on first optimizing each objective individually. At this stage, both Goal Programming and the Iterative/Interactive methods are likely choices. However, solving a nonlinear Goal Program is more complex and requires considerable computational effort. Hence an Iterative/Interactive method can be used to solve the problem. Some other criteria that the method has to deal with are discussed below [14].

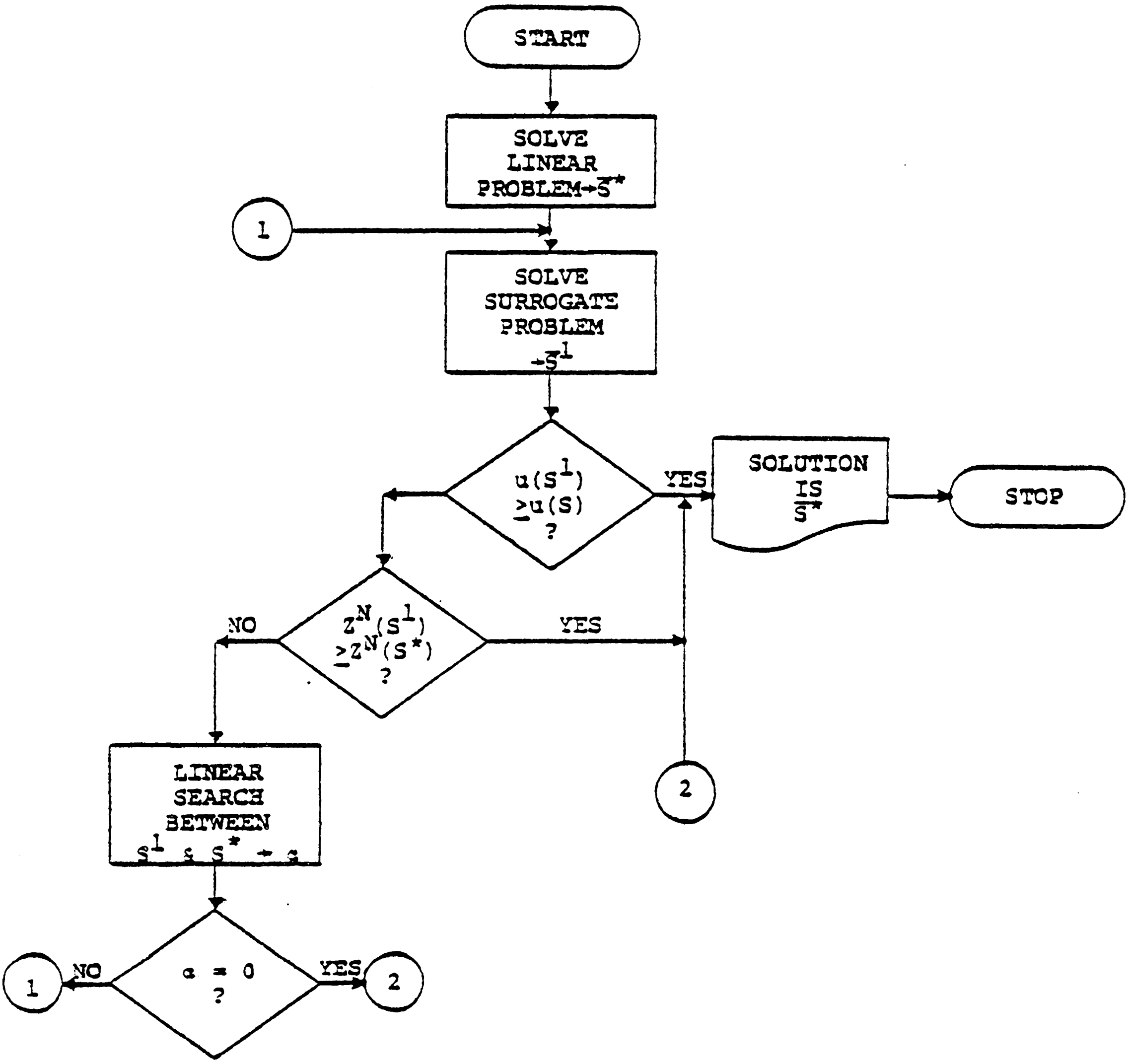

Figure 3: The NLP Algorithm

1) Not all DMs can be expected to use a rational, predictable decision strategy. For instance, a DM may decide to minimize noise in only a few select areas (geographic regions) of concern and stop. This may lead to the total noise annoyance being increased while the noise impact in the few selected areas is reduced.

2) The technique should be flexible enough to account for the differences between DMs and in the way they approach the problem. For instance, one DM may decide to group the areas according to current noise levels or previous annoyance analyses. Another may choose to do so using political districts.

3) Differences will also exist in the way the DM views the model. It could be used to aid the DM in his decision process in a prescriptive mode. It could also be used by the DM to simulate different operating scenarios.

4) The technique should be simple enough so that the information required of the DM is a minimum while at the same time being sufficient to realistically run the model.

5) Finally, there should be provisions for backtracking if needed by the DM to revise any earlier decisions. For instance, one DM may decide after minimizing noise in one group of areas to include some of the same areas while forming the second objective. One may further want to

revise their priorities/ ranking of objectives after running the entire model. For instance, the DM may decide that some other areas not currently being considered need to be included in the analysis at priority one. The technique developed should be capable of facilitating this type of analyses.

Based on the above criteria and associated analysis, an Interactive Algorithm for solving the Multiobjective approach is proposed that will facilitate the desired analyses.

The Interactive algorithm

The solution of the Multi-Objective Problem (MOP) involves the solution of successive related nonlinear problems, each problem being formulated on the basis of the analysis of results of the previous problem.

The procedure for the Interactive Algorithm is shown in the flowchart, Figure 4. The method includes the selection of the objective set (of areas) where annoyance is to be minimized and the formulation of the constraints or restraints that are to be placed on the problem.

The greatest advantage of this approach is the degree of flexbility it affords the DM .

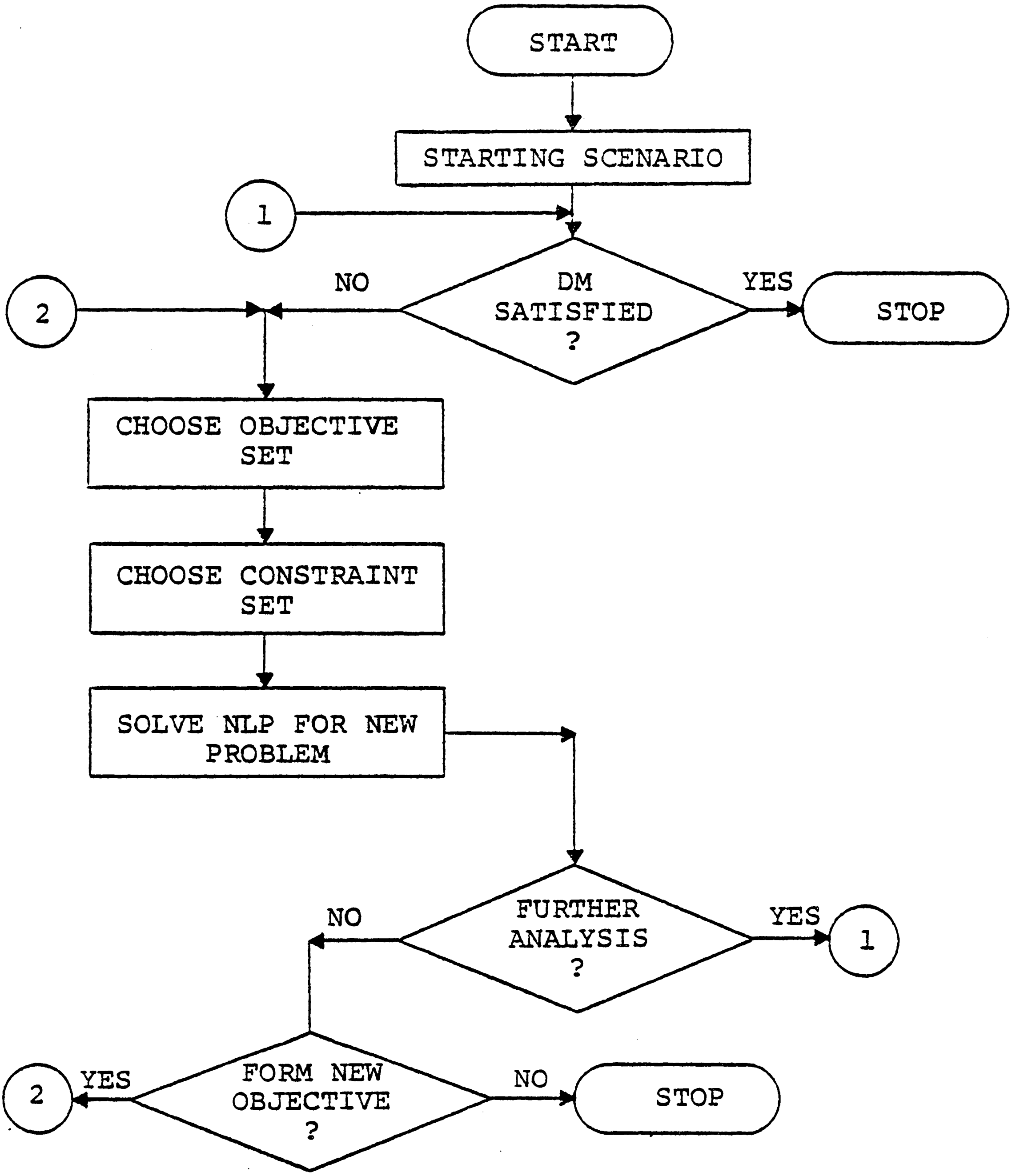

Figure 4: The Interactive Algorithm

To initiate the algorithm, the DM chooses a scenario. A scenario is a set of operations consisting of aircraft arrivals and departures. This could be, for instance, the current operating conditions. An analysis of this scenario is made to determine the noise and annoyance levels over all areas as well as the total annoyance.

Based on this analysis, the DM may decide to stop. If not the DM then chooses a set (or sets) of areas where annoyance is to be minimized. Each set of areas then comprises one objective. If more than one objective is chosen, the DM could rank these in terms of importance, objective 1 being those areas where annoyance is to be minimized first.

The DM chooses the set of areas on the basis of one or more of the following criteria.

1)Noise Measures (NEF, LDN)

2)Noise Annoyance Measures (NII, HB)

3)Population

4) Others specified by the DM, explicitly or implicitly.

Next, the DM decides what restrictions or constraints on the problem are appropiate at this point. This is the level of complexity of the problem. At the simplest level, the only restrictions placed are those on the minimum number of day and night flights. Further levels of complexity could include curfews on flights of certain aircraft over a certain period and/or a certain track or runway. The objective set of areas together with the resrictions then comprise the nonlinear problem to be solved.

Some of the constraints that can be included are shown below:

Limits on maximum number of

1) day and night flights
2) flights of each aircraft
3) flights of each stage length
4) flights on each track or track group
5) flights of certain aircraft along a track

At this point, after the problem formulated above has been solved, an analysis is again carried out. The DM may wish to stop at this stage. If not, another set of areas is chosen for optimization as well as the appropiate restrictions. One such restriction could be that the annoyance levels achieved in the previous set of areas is not to be exceeded. This process is repeated until the DM decides to stop.

The choice of the second and subsequent objective set of areas could be based on the analysis of the starting scenario. In this case, areas are grouped according to similarity of criterion value. For instance, if the noise

(LDN) is chosen as the criterion and if the values range from 10dB to 70dB over all areas, one could group those areas where LDN exceeds 65dB to comprise objective 1, areas where LDN is between 60dB and 65dB as objective 2 and so on.

On the other hand, the choice of areas for the second and subsequent objectives could also be based on the results of the previous optimization. For instance, the DM might find that after optimizing objective 1, some other areas are severely affected, the noise levels being much higher than at present. In that case, those areas (say set A) might be chosen to be included in the next objective to be optimized.

At this stage, if the DM is not satisfied with the noise reduction obtained, the second set of areas (set A) might be chosen to be optimized first.

The information made available to the DM at any iteration is discussed below:

1) Gradient Information (for the objective function)

The nonlinear objective function in this case is a measure of noise annoyance. Hence the gradient displays the relative increase/decrease in noise annoyance for a corresponding increase/decrease in variables S. (The S variables are related to noise measure via Equation 5). Hence the gradient can be used by the DM to determine which areas are more annoyance sensitive than others.

Note: Since the nonlinear problem is solved by solving a series of related linear programs, the gradient of the nonlinear objective is only approximate as it is evaluated at the current solution to the linear program. However it can be used to compare the gradients for different areas (S variables).

2) Slackness

This information is displayed for the constraints ((8)-(12)).

Availibility Constraints

A slackness in availability constraints (≤), would indicate that there is provision for increasing the number of flights for the arrival and/or departure aircraft concerned.

The slackness for the demand constraints would be zero as in a minimization problem, all greater than or equal to constraints would be satisfied at their lowest value which is as an equality.

3) Area Specific Information

This would include such information as :

i) Noise Measure (NEF, LDN)

ii) Noise Annoyance (NII)

iii) Population

This information would be used by the DM to decide whether to stop or continue. If the process is continued, the generated information would be used to delineate the areas of interest for further optimization.

Some examples of the kinds of constraints that the DM may formulate, are shown below:

i)demand increase/decrease

For instance, the DM may want to test the effect of a 20% increase in demand for incoming flights. With reference to Equation (13), this could be modelled as,

$$\sum_{i}^{NI}\sum_{j}^{NJ} Y_{ijl} \geq N_{rl} + 0.2N_{rl} \quad l=1,\ldots,NL \qquad (15)$$

ii)runway /track restrictions

For instance, there might be a restriction imposed by the airport that a certain track j is to be used only for take-offs. This would imply that total arrivals on that track should be zero.

$$\sum_{i}^{NI}\sum_{j}^{NJ}\sum_{l}^{NL} Y_{ijl} = 0 \qquad (16)$$

iii)flight restrictions such as night curfews

For example, there is to be no take-offs or landings of type i aircraft at night. This could be modelled as,

$$\sum_{i}^{NI} Y_{ij2} + \sum_{i}^{NI}\sum_{k}^{NK} X_{ikj2} \leq b_{jl} \quad j = 1,\ldots,NJ; \qquad (17)$$

iv) bounds on noise/annoyance in specific areas

Other constraints could be added or current constraints modified so as to limit noise in any area(s) to a certain value. This would mean that noise could be reduced further in that area. This is done by placing a bound on the S variable for the area(s) concerned.

In each case above, the corresponding constraints are added to the problem.

To summarize, the interactive approach allows the DM to choose any geographical area of interest and optimize over it with a set of restrictions such as imposing a curfew on certain aircraft, restricting the use of any runway and putting a limit on noise over certain areas. This can be done without any change in the input data. On the other hand, to test the effects of changing the take-off or approach profile or a change in the runway configuration would require a change in the input data.

The next section involves an application of the algorithm.

Chapter VI

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

6.1 RESULTS

The procedure outlined in the previous section is applied to an example airport. The input data for this airport is included in Appendix II. The results of the initial analysis are also included. First, the objective set of areas have to be chosen over which annoyance is to be minimized. This choice is made on the basis of the noise levels (LDN). Three areas (14, 24 & 34) were chosen where noise was highest (> 80 LDN dBs).

Next the constraint set is chosen. In Scenario I, the only set of constraints included are that the requirements for the total number of day and flights be met regardless of the type of aircraft. The right hand side values are obtained from Tables 11, 12 and 13. By solving the problem for this set of constraints alone, it would be possible to determine which aircraft(s) are the least noisy in terms of annoyance to the chosen areas. It could be possible that the same aircraft may not be the least noisy for both take-offs and arrivals. This is because the noise coefficients (thrust) for one aircraft may be lower than the other for arrivals but higher for take-offs. If one wanted to determine the noisiest aircraft so as to impose a curfew on it, one would have to solve the same problem with a maximization objective with the constraints above included as equalities. These constraints can modelled by the following equations,

$$\sum_{i}^{NI}\sum_{j}^{NJ}\sum_{k}^{NK} X_{ikjl} \geq NX_l \qquad l = 1,..,NL \qquad (18)$$

$$\sum_{i}^{NI}\sum_{j}^{NJ} Y_{ijl} \geq NY_l \qquad l = 1,..,NL \qquad (19)$$

In Scenario II, restrictions are imposed on number of aircraft of each type. The input for this set of constraints is as shown in Tables 9 and 10. That is, the number of aircraft of different types for day and night arrivals and departures are limited to those available. However, these aircraft are free to choose any track from the set of arrival and departure tracks. The DM might wish to use this run, for instance, to determine how to route the available aircraft so as to cause the least annoyance to the chosen areas. The additional constraints can be modelled by the following equations.

$$\sum_{k}^{NK}\sum_{j}^{NJ} X_{ikjl} \leq NX_{il} \qquad i = 1,..,NI \qquad l = 1,..,NL \qquad (20)$$

$$\sum_{j}^{NJ} Y_{ijl} \leq NY_{il} \qquad i = 1,..,NI \qquad l = 1,..,NL \qquad (21)$$

Scenario III includes demands on flights of each stage, in addition to those above. Aircraft are still free to choose any track from the arrival and departure tracks. The input for this Scenario is obtained from Tables 11, 12 and 13. In this run, more realistic constraints are included in that there are demands on flights of various stage lengths (trip lengths) to be met. The constraints (12 & 13) above would be modified to,

$$\sum_{i}^{NI}\sum_{j}^{NJ} X_{ikjl} \geq NX_{kl} \qquad k = 1,..,NK \qquad l = 1,..,NL \qquad (22)$$

$$\sum_{i}^{NI}\sum_{j}^{NJ} Y_{ijl} \geq NY_{l} \qquad l = 1,..,NL \qquad (13)$$

Finally, in Scenario IV the constraints are modified so that demands are placed on flights on each runway in addition to those above. That is, there is a minimum number of flights using each runway that have to be met. The input for this Scenario is also obtained from Tables 11, 12 and 13. One purpose of this could be not to overuse any one runway. This can be modelled as,

$$\sum_{i}^{NI}\sum_{j}^{NJ} X_{ikjl} \geq NX_{kl} \forall j \in R \ ; \ k = 1,..,NK \qquad l = 1,..,NL \qquad (23)$$

$$\sum_{i}^{NI}\sum_{j}^{NJ} Y_{ijl} \geq NY_{l} \forall j \in R \ ; \qquad l = 1,...,NL \qquad (24)$$

From the results of the above run, two areas (48 & 49) were chosen where rate of change of annoyance with respect to the noise (that is, with respect to the S variables) is maximum. The next run, Scenario V then involved optimizing over this second set of areas subject to the constraints in the previous run.

An additional restraint was placed in the form of a bound on the annoyance levels in the first set of areas. That is, annoyance in the first set of areas is not to exceed that reached in the previous run, Scenario IV, while optimizing over areas 48 and 49. This is done by placing bounds on the S variables for the associated areas (S14, S24 & S34).

The last run was made to see the effect of removing the bounds on the first set of areas. The bounds placed on annoyance in areas 14, 24 and 34 are removed thus making areas 48 and 49 primary objective areas. The results of these runs are shown in Tables 5, 6, 7 and 8 below:

Note: 1) For the purposes of comparison, the annoyance measure chosen is the number Highly annoyed (HB) since the magnitude of the Noise Impact Index (NII) is small (< 0.2). 2) For the example airport, tracks 1-12 are designated as departure tracks and tracks 13, 14 and 15 as arrival tracks.

The following observations may be made from the above data. From Table 5, it may be observed that the annoyance in individual areas as well as total annoyance increases with the number of constraints placed. With reference to Table 7, there is redistribution of flights from Track 6 to Track 7 with about half the flights on track 7 from Scenario III to IV. From Figure 5, it may be seen that Track 7 would have a major impact on Areas 24 and 34 thus causing an in-

TABLE 5

Comparison of Annoyance - Highly Annoyed Population

Objective 1 (Areas 14, 24 and 34)

Scenario	Total	Area14	Area24	Area34
Current	77539	581	784	527
I	1189	3	9	2
II	13331	86	176	52
III	25534	130	285	94
IV	29550	166	492	174

TABLE 6

Comparison of Annoyance -Highly Annoyed Population

Objective 2 (Areas 48 and 49)

Scenario	Total	Area14	Area24	Area34	Area48	Area49
Current	77539	581	784	527	1462	1925
IV	29550	166	492	174	1567	1891
V	29550	166	492	174	1567	1891
VI	25813	187	749	174	385	638

TABLE 7

Track Usage (fraction of total) - Day Flights

Scenario Track	I	II	III	IV	V	VI
1	0	0	.07	.38	.42	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	.04	0	.42
5	1	.39	0	0	0	0
6	0	.61	.84	.02	.02	.02
7	0	0	.09	.49	.49	0
8	0	0	0	0	.05	0
9	0	0	0	.05	0	.05
10	0	0	0	0	0	.49
11	0	0	0	.02	.02	.02
12	0	0	0	0	0	0
13	0	0	0	.46	.46	.46
14	0	0	0	.51	.51	.51
15	1	1	1	.03	.03	.03

TABLE 8

Track Usage (fraction of total) - Night Flights

Scenario	I	II	III	IV	V	VI
Track						
1	0	0	.36	.44	.44	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	.44
5	0	0	0	0	0	0
6	0	.61	.64	.04	.04	.04
7	0	0	0	.44	.48	0
8	1	.39	0	.04	0	.04
9	0	0	0	0	0	0
10	0	0	0	0	0	.44
11	0	0	0	.04	.04	.04
12	0	0	0	0	0	0
13	0	0	0	.45	.45	.45
14	0	0	0	.5	.5	.5
15	1	1	1	.05	.05	.05

crease in annoyance in those areas but only a slight increase in Area 14. Similarily, it may be seen from Tables 7 and 8 that from Scenario IV (Areas 14, 24 and 34) to Scenario V (Areas 48 and 49) there is no change. This is because in optimizing over areas 48 and 49, more flights would have to be routed away from Track 6. However, this would not be posible because of the bounds on Areas 14, 24 and 34.

It may be observed from Tables 7 and 8 that there is no change in distribution of arriving flights. This is because there is a minimum number required on each of the three arrival tracks and these are satisfied as equalities in the optimization.

In general, an increase or decrease in annoyance would depend on the location of the second set of areas relative to the first set. For instance, if the second set of areas lie along the same tracks as the first set or close to the first set, then there would be relatively little change in the total annoyance because the same set of arrivals and departures would be maintained. On the other hand, if the second set lie along a different set of tracks (that is, from another runway) and the optimization is performed over this set first the annoyance would be reduced at the expense of the other set of areas as in the case of Scenario VI. Here, the bounds placed on the first set (14, 24 and 34) are removed and thus the annoyance in those areas has increased at the benefit of areas 48 and 49 as can be seen from Table 5.

6.2 CONCLUSIONS AND RECOMMENDATIONS

This research has focussed on the minimization of noise annoyance due to aircraft flyovers in the vicinity of an airport. The approach taken to solve the problem is an interactive one to permit interaction with the Decision Maker. The immediate vicinity of an airport, in a 20 mile by 20 mile grid around the airport center, is grouped into geographical areas. The model then permits the minimization of annoyance in any or all areas subject to a set of restrictions imposed by the DM. The advantage of this approach is the degree of flexibility afforded the DM who is able to choose not only the objective set but also the constraint set.

The Interactive approach allows the DM to analyse the results after each optimization by variation of the objective set or constraint modification. The analysis includes the noise and annoyance for each area as well as a measure of the gradient of the objective with respect to noise in each area and the slackness associated with each constraint. This provides the user not only with results on which to

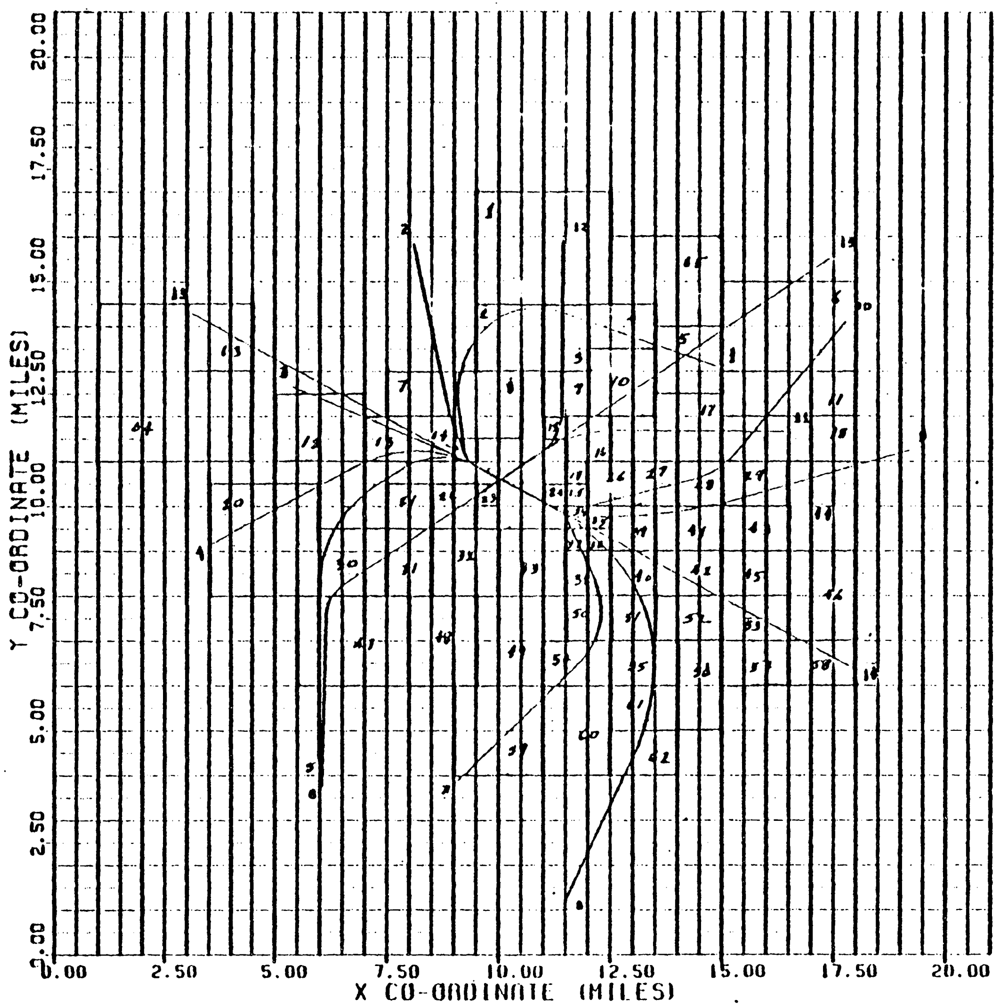

Figure 5: Example Airport Configuration

base a decision, but also information that may be very useful in conducting sensitivity analyses.

This research may be extended in several ways. One is with respect to the data input to the model. At present, geographical areas are grouped roughly so that the more noise sensitive areas close to the airport center are smaller than those less sensitive. This is done on the basis of visual inspection of the population grid for an airport. One could devise a standard scheme to group the areas for any airport. One such method is to group areas in concentric grids around the airport center.

Another extension relates to the formulation of the objective. The use of the annoyance factor, NII, makes the objective highly nonlinear. One could investigate the use of the other noise and annoyance metrics discussed in Chapter 2, in the objective function to see the if better results are obtained.

Finally, a recommendation regarding the computer programs used in this research. The integration of the linear program with the Integrated Noise Model [1] could be done to obtain the contours of equal noise and the area and population within each contour. This would permit better analysis of the results of each run.

Chapter VII

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Appendix A

DATA PREPARATION

The software package used to solve the sequential linear programs in this research was the MPS III Mathematical Programming Package which is a version of IBM's similar package, MPSX. The package is made up of two subsystems to perform the optimization and manage the data and results. The first part consists of the Program Control statements to set up the problem and optimize it. The second subsystem, called DATAFORM is a Data Management subsystem to manage and store the data associated with the mathematical program including data tables, problem files and solution data.

For more detailed information, consult the following manuals:

MPS III Users Manual, Ketron Inc., Management Science Systems Division, Arlington, Va.

Mathematical Programming System - Extended (MPSX) and Generalized Upper Bounding (GUB), Program Description, Program Number 5734-XM4, (SH20-0968-1).

As illustrated in the flowchart, Fig 4, several phases are involved in running a case. The first of these, termed Step 0, involves obtaining data for the current operating conditions. If the DM so chooses, he may start with another starting scenario. However, the problem still needs to set up. The steps involved in this phase are shown below.

1) Extracting aircraft noise data for the aircraft under consideration. This includes the approach and takeoff profile characteristics as well as the noise data (EPNL or NEL) for each aircraft.

2) Track data for the airport in question. This involves demarcation of the areas to be considered in the model and the track distances from each area. This is needed to compute the noise/annoyance effects of aircraft flyovers along each track on each area.

3) Setting up the linear programming model. This has been subdivided into three phases in order to facilitate error checking.

a) Setting up the DATAFORM Tables to be used in forming the objective function coefficients.

b) Setting up the Matrix for the model - the variables, constraints, right hand sides and bounds.

c) Setting up the control statements to run the sequential LP model.

Appendix B

INPUT DATA

The input data for the example airport is presented in this section. The available aircraft are the following:

1) DC-9-32
2) 727-200
3) DC-8-55
4) L-1011

The available aircraft for arrivals and departures is shown in Tables 9 and 10 respectively. The orientation of the runways as well as the tracks and the geographical areas under consideration are shown in Figure 5. Of the 15 tracks for this airport, tracks 1-12 are the departure tracks and tracks 13, 14 and 15 are arrival tracks. The demand for incoming flights is shown in Table 11. The demand for departures for each stage for each aircraft is shown in Tables 12 and 13. It may be recalled from Chapter 3 where the model is developed, that stage length depends on the distance between source and destination for take-offs. The population for the geographical areas is shown in Table 14.

TABLE 9

Available Aircraft for Arrivals

Type	Day	Night
1	79	9
2	90	10
3	23	3
4	12	1

TABLE 10

Available Aircraft for Departures

Type	Day	Night
1	79	9
2	90	10
3	23	3
4	12	1

TABLE 11

Demand for incoming flights

	Day				Night			
Type	1	2	3	4	1	2	3	4
Track								
13	36	41	11	5	4	4	1	1
14	39	44	11	6	4	5	1	1
15	4	5	1	1	0	1	0	0

TABLE 12

Demand for departures - Day

Type	1				2				3				4			
	stage				stage				stage				stage			
Track	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	6	2	0	0	4	3	1	1	1	1	0	0	0	0	0	0
2	10	4	1	0	7	5	2	1	2	1	1	1	1	1	1	1
3	3	1	0	0	2	2	1	1	0	0	0	0	0	0	0	0
4	3	1	0	0	2	1	1	0	0	0	0	0	0	0	0	0
5	9	3	0	0	6	5	2	1	2	1	1	1	1	1	1	1
6	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
7	5	2	0	0	4	3	1	1	1	1	0	0	0	0	0	0
8	6	2	0	0	4	3	1	1	1	1	0	1	0	0	1	0
9	4	1	0	0	2	2	1	1	1	0	0	0	0	0	0	0
10	9	3	0	0	6	5	2	1	2	1	1	1	1	0	1	1
11	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

TABLE 13

Demand for departures - Night

Type	1				2				3				4			
	stage				stage				stage				stage			
Track	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2	2	1	0	0	1	1	0	1	1	0	1	0	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 14: Population data

Area	Population	Area	Population	Area	Population
1	20078	23	453	45	9578
2	16176	24	1250	46	10334
3	8022	25	1570	47	6639
4	8732	26	4109	48	17991
5	11887	27	5833	49	17268
6	12317	28	6908	50	6714
7	4987	29	10716	51	3048
8	5822	30	11813	52	8144
9	7053	31	2399	53	13093
10	19680	32	15610	54	5193
11	9494	33	10661	55	5359
12	3579	34	879	56	21192
13	5596	35	2127	57	13785
14	944	36	1161	58	5640
15	96	37	2591	59	16827
16	8918	38	7449	60	17408
17	5339	39	4294	61	7977
18	9475	40	3585	62	15239
19	532	41	4401	63	10034
20	8874	42	8060	64	36311
21	3799	43	6075	65	10852
22	3996	44	13940	Total	559926

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INTERACTIVE APPROACH FOR THE MINIMIZATION OF ANNOYANCE DUE TO AIRCRAFT NOISE

by

A. V. Desai

(ABSTRACT)

This research is concerned with the minimization of annoyance due to aircraft noise to airport communities. The approach developed is an interactive one which permits interaction with the Decision Maker. The immediate vicinity of an airport is divided into several areas based on population and proximity to the runways. The user can then minimize annoyance over any set of areas subject to the appropiate constraints. After any optimization, the results may be reviewed. The results provided include noise and annoyance in each area as well as the gradient of the objective and slackness associated with each constraint. This would assist the user in making a decision and aid in sensitivity analyses.

At each stage of optimization, the problem solved has a nonlinear objective function and linear constraints. This problem is solved by solving successive surrogate linear problems. The method uses a first order Taylor series

expansion about the solution point to set up the surrogate linear problem. The first solution point is obtained by solving an approximate linear problem.

The approach suggested is then applied to an example airport. Different Scenarios are considered to illustrate the use of the model. Both the formulation of the objective as well as the constraints are illustrated.