21st Australasian Transport Research Forum
Adelaide, September 1997

Airport Location Planning and Environmental Values

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Abstract:

The location of a proposed airport with particular attention given to environmental effects in the form of noise under flight paths in a directional pattern is considered Model application to the Sydney airport is described The model takes into account that the facility may be used only occasionally by residents, and perceived benefit of the proximity to the facility may not be high compared to their desire for negligible level of noise pollution. This paper shows that it is possible to analyse the location selection problem in the face of environmental considerations by application of optimisation techniques. Development of such methods is necessary to satisfy the emerging demands for better assessment of environmental aspects associated with transport infrastructure projects An important step of this process is the recognition of the need for quantitative methods which deal with measurable entities reflecting the qualitative objectives of the community and policy makers. Transformation of the qualitative aims to quantifiable targets is an important step that has been discussed. Then, theme of the forum, 'value of transport research and policy' takes a wider meaning with the ability to incorporate non-monetary concepts prevalent in environmental impact assessment into planning work

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Introduction

Planners and policy makers dealing with selection of airport locations have to incorporate a new dimension to their work because of the growing awareness of environmental impacts. There is a growing body of literature which deals with various environmental aspects mainly in a qualitative and descriptive manner. These publications provide a valuable basis for policy formation leading to planning and engineering design work. However, a common feature of a large proportion of the body of literature is that often the concept of 'environmental value' is described only in a descriptive manner. This by itself is not a deficiency, but in practice this leads to a certain degree of fuzziness and different interpretations to policy requirements where a debate is not necessarily warranted.

The traditional location selection problem is handled as a cost minimisation problem. For example, the ideal location for a post office or a business centre, in a given road network, is usually derived through a travel minimisation process. This cost minimisation strategy can be extended to include environmental costs so that we can realistically include them in the analysis of location of facilities which are likely to have environmental effects on their surroundings. This methodology is useful for airports, hazardous material depots, waste depots and certain recreational facilities which have negative environmental impacts on communities situated in a certain orientations with respect to the facility. It is shown that it is possible to quantify the sum total of the environmental impacts on the community.

Previous work of this author in the area of location of facilities has addressed cost components such as construction cost, operating cost and access cost. Vandebona and Wirasinghe (1988) as well as Wirasinghe and Vandebona (1990) have documented inclusion of such costs in cost minimisation in relation to the development of underground mass transit systems. Also, an application to assist selection of an inter-city bus terminal location in a developing country has been developed by Vandebona and Yusman (1994) who adopted a layer method to simplify initial computations in generation of alternative sites.

The proposed methodology also provides an insight into possible alternative solutions to the problem of location selection and the sensitivity of these solutions to community perceptions associated with environmental considerations. In this manner, this research work is intended to inform planners of the value of a chosen policy.

Spectrum of location problems

There are number of variations of the location selection problem that may interest the transport modeller. Although cost minimisation for introduction of a new facility attracts the most attention in literature, there are some interesting innovations in facility closure problems such as the removal of number of primary schools in Canberra (Vandebona, 1990). Identification of locations for closure of selected number of branch offices of public sector service offices within a city may also fall into this category of location removal problems. Cost rationalisation in private sector industries also lead to applications of this form, for example, in closure of retail bank branches.

Figure 1 shows some of these variants of the location allocation problems. In the problem area of addition of facilities, i.e. introduction of new facilities to an area, the simplest form of the problem is when only a single facility is required. For example, consider a transport terminal in a catchment. Then the facility is likely to be introduced centrally, as the transport objective of access minimisation is applied.

Location of number of new facilities is an extension of the above application and lead to more complex computational work. Therefore, in some multiple facility location applications an attempt is made to introduce heuristic methods to reduce the computational complexity. Although Figure 1 does not show it, within the family of facility removal problems the removal of multiple of facilities need special consideration and therefore can be treated as a different strand of problems.

Competition or lack of competition among facilities is another consideration (Figure 1). The location selection problem in a competitive environment can be treated as a maximisation of catchment area problem, and therefore often conflicts with the travel time minimisation objective. When there is no competition among facility providers, locations of facilities are likely to be spaced out within the region. On the other hand, when there is competition among facilities for the market share, all competing facilities are likely to be in one area because competing facility providers are likely to individually treat it as a problem of selection of location for a single facility and select the same centrally situated locality.

Location selection specifically related to airports has been discussed by De Neufville (1976), Hart (1985), Horenjeff (1975) and Sealy (1976) and typically trade off land availability against access distance. It is widely accepted that the noise under flight path is a significant, if not the most seriously felt, environmental consideration. Relevance of such considerations in the location determination of the second Sydney airport has been discussed by Federal Airports Corporation (1990) and MANS Study (1978).

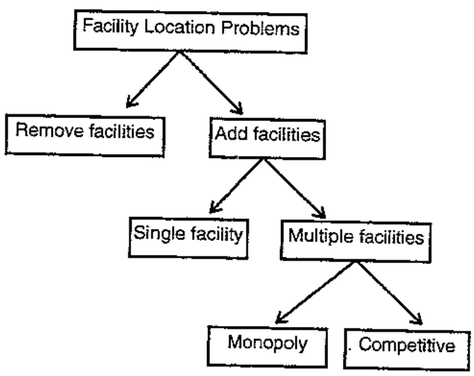

Figure 1 Scope of location problems

Methodology to incorporate environmental impacts

Conceptually, modelling the effect of environmental impacts should take into account the number of people affected and the magnitude of the environmental exposure. The modelling process for this purpose can then follow the typical zone and transport network structure.

From the point of view of users of the airport, the access to the airport is an important issue. To compute a measure of accessibility, the population in the zone i, is denoted by P_i and the travel time between zones i and j is denoted by t_{ij}. Also consider the fraction of air travellers in the general population as α. Thus the total of the access time for all airport users when the airport is located in zone i is given by the following summation:

$$T_i = \alpha \Sigma_j P_i \cdot t_{ij}$$

Now consider noise impacts due to the location of the airport. It is important to note that the noise exposure is directional. In other words, the exposure to adverse levels of noise is a issue for those under the flight path. Thus the orientation of the flight path plays an important role in the analysis.

The level of noise experienced in zone j when the airport is located in zone i is denoted by q_{ij} in the following analysis. This leads to a total measure of the environmental exposure by the community:

$$E_i = \Sigma_j P_i \cdot q_{ij}$$

Ideally, the community would like to minimise both T and E. In other words, the airport with the least access costs and environmental costs would be preferred. But these two requirements are generally contradictory, that when the access cost is minimised by locating in a relatively central location, the environmental effect is likely to be maximised due to flight paths lying over densely populated areas.

From a computational point of view, the minimisation problem mentioned here can be written as follows.

$$C = \min\{ v_T \Sigma_j P_i \cdot t_{ij} + v_E \Sigma_j P_i \cdot q_{ij}\}$$

Where C is the total location specific costs in monetary units and v_T and v_E are introduced to convert access and environmental costs to monitory units.

The objective here is to determine the zone at which access and environmental impacts are minimised. The simplified example shown in the next section is included to better describe the computational process.

Simplified example

Consider a road network connecting five suburbs as shown in Figure 2. Suburbs are named C1 to C5 in the figure. Population values are arbitrarily selected as shown

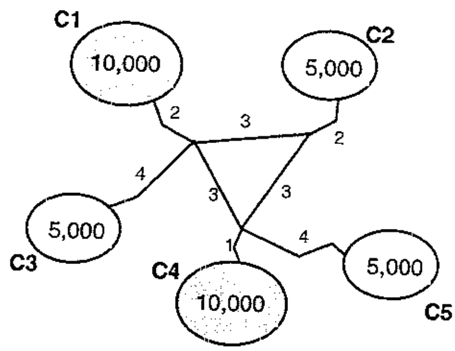

Figure 1 Example Network

within each shaded area denoting suburbs. Travel time, in minutes, are also arbitrarily specified as given in the figure for the purpose of this example.

The potential location for a proposed facility which minimises the accessibility measure is a node (suburb) and it has been proven that the location solution will not be midway on a link (see Rushton, 1979).

The general solution can be reached efficiently by setting up the problem in a matrix form. For this purpose, it is necessary to develop the shortest distance matrix and the population array. Dijkstra's method has been a popular technique to resolve the shortest path problem. Revised cascade method is perhaps an even more powerful tool here (see Chachra, 1979).

The shortest path matrix for road users in this particular urban area is given below. For simplicity it is assumed that all roads allow two way operation. The solution can be readily modified if there are one-way roads

Least travel time matrix is:

$$\begin{pmatrix} 0 & 7 & 6 & 6 & 9 \\ 7 & 0 & 9 & 6 & 9 \\ 6 & 9 & 0 & 8 & 11 \\ 6 & 6 & 8 & 0 & 5 \\ 9 & 9 & 11 & 5 & 0 \end{pmatrix}$$

Next, consider the population array which provides relevant population figures. This array may have to be adjusted to account for mode usage and activity levels according to gender and age classifications. In this example $\alpha = 0.1$ is assumed, in other words, one tenth of the population is considered as air travellers. Thus the population array may be written as (10, 5, 5, 10, 5) in hundreds of travellers.

Now, consider the multiplication of each row in the shortest travel time matrix by the corresponding value from the population array. This leads to:

$$\begin{pmatrix} 0 & 70 & 60 & 60 & 90 \\ 35 & 0 & 45 & 30 & 45 \\ 30 & 45 & 0 & 40 & 55 \\ 60 & 60 & 80 & 0 & 50 \\ 45 & 45 & 55 & 25 & 0 \end{pmatrix}$$

Note that this matrix is useful to seek the solution for the facility removal problem mentioned before. The minimum of the passenger minute values shown in the above matrix becomes the best target for removal of a facility. The additional total transport cost is the lowest if the facility in that particular node is removed, assuming that all nodes started off with a single facility. In our example, the lowest value in the above matrix is at the fourth column of the fifth row. Therefore, assuming there was, say a post office in each suburb, removal of the post office from the suburb C5 means that the access cost for the nearest post office in suburb C4 adds a cost proportional to 25 thousand passenger minutes. It has been assumed that residents select the nearest available facility. In some applications, it may be necessary to modify this computation to allow for the probability distribution of residents travelling to remaining facilities. In some applications it is possible to have the minimum value occur at two different cells. In those circumstances, the facility removal problem has equally applicable two alternative solutions.

Now, let us consider the location problem in the context of introducing a single new facility. The column sums of the above matrix provide the total travel time to access each node from all other nodes and therefore, it is these figures that need investigation if a facility is to be introduced. In our example, these sums are given by the array (170, 220, 240, 155, 240) in thousands of units. To convert these quantities to monetary values it is required to use the value of time concept here. In the example, the value of time is used as $10 per person hour. The minimum occurs at the 4th cell indicating that C4 is the best location for a single new facility from the point of view of transport access.

If multiple facilities are to be provided, say a retail shopping chain wants to set up two shopping centres in this region, then the methodology requires further manipulations to find the minimum overall access cost for two centres. Also note that the removal of a facility is equivalent to addition of four facilities in our five node problem. Therefore, the facility removal problem and the addition problem are complements of each other.

Quantification of environmental impacts

Now consider the location of the typical airport which has environmental effects in a directional pattern. What is required is a tabulation (matrix) showing the intensity of environmental effects if the facility is located at a given suburb. For example, let us assume that the location of an airport is likely to have the following environmental effects distribution:

$$\begin{pmatrix} 2 & 0 & 1 & 0 & 0 \\ 0 & 2 & 0 & 1 & 0 \\ 1 & 0 & 2 & 0 & 0 \\ 0.5 & 1 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 2 \end{pmatrix}$$

Note that the diagonals consist of 2 arbitrarily selected here. Therefore, this matrix is intended to show that the area where the facility is located has negative environmental effects of intensity 2 per resident in appropriate units. The noise impact diminishes as distance from the airport increases. Thus adjacent suburbs in north-west or south-east (assuming that is the orientation of the runway) direction have an intensity of 1. An intensity of 0.5 is in the first column, 4th row, representing that an intensity of 0.5 is expected in suburb C1 if the facility is located in suburb C4.

Performing a computation similar to that for total access time, it is now possible to compute a weighted total intensity of environmental exposure. The resulting array in this example is given by (30, 20, 20, 25, 10) in thousand of residents affected. This indicates that the exposure is minimum if the new facility is located at C5.

Let us compare this array with the access travel time array already shown. According to access distance criteria, C5 is the fourth ranking solution. Table 1 summarises previous computations to assist this comparison. The second and third rows of Table 1 shows access travel costs and their ranking The fourth and fifth rows show the environmental exposures and their ranking

To collectively include the two considerations on access distance and environmental impact, it is required to introduce the weighting factor that converts environmental effects to monetary units. Thus, in Table 1, the sixth row is computed by weighting the environmental exposure by ten and adding to the access cost estimate. The last row shows the new ranking. The necessity to further research this weighting factor is acknowledged For the purpose of this discussion the term 'value of environment' (VOE) is adopted to refer to this multiplying factor

Table 1 Summary of overall costs

	Suburb				
	C1	C2	C3	C4	C5
Population in 1000s	10	5	5	10	5
Value of Access (in $1000)	170	220	240	155	240
Ranking	2	3	5	1	4
Environmental exposure	30	20	20	25	10
Ranking	5	3	2	4	1
Total at VOE weight 10	460	420	440	405	340
Ranking	5	3	4	2	1

From the decision making point of view, it is interesting to find the sensitivity of location selection solutions to this 'value of environment'. Figure 2 shows the sensitivity of the optimum location to different 'values of environment'. Plot of combined costs for different 'values of environment' allows the problem to be interpreted as the conventional optimisation problem In this example, for any given 'value of environment', suburbs C3, C2 and C1 can be rejected outright because they always show combined costs higher than one of the other suburbs. However, C4 is the best candidate for the location of this facility, if the VOE is smaller than 5.7. In other words, this suburb is the best solution, if the VOE is deemed low. Observation of the layout in Figure 1 shows that this is a logical location for the facility when it is frequently used by residents Note that the author is suggesting that VOE is likely to be low when residents use the facility often This point is worth further research. Further investigations may reveal the relationship among VOE and other variables.

On the other hand, if the facility is used only occasionally by residents, then it is likely that this VOE weighting is high. Also, there can be other reasons associated with real estate values or health issues that may lead residents to associate a high nuisance value to aircraft noise. In that situation the ideal location for the facility is the suburb C5 as shown in Figure 2.

Analysis of Sydney airport locations

Kinsford-Smith airport in Sydney catered for about 17 million passengers, including transit passengers, in 1995 when both international and domestic trips are considered. On a daily basis this is about 2 trips per 1000 population. Thus $\alpha = 0.002$ is applied in the following analysis. Observation of the methodology adopted here would later reveal that final conclusions are not much sensitive to the α value, the trip rate, selected here.

Computation of access cost depends on the population distribution in the urban area and travel time characteristics from various local government areas to the airport. Note that the analysis here is performed based on LGA boundaries selected as zone boundaries

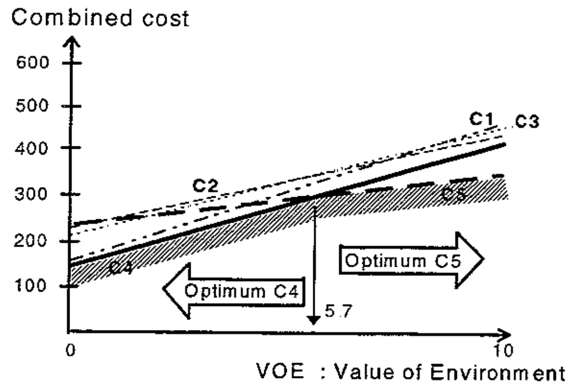

Figure 2 Possible location solutions

because of the ready availability of population data and travel distance data. Travel time data were difficult to establish due to variations in travel time with the time of day. Therefore, it has been decided to perform the access cost computation based on travel distance in the initial calculations.

If the location of the facility is solely based on minimising the access to the facility then it will be located centrally in the urban area. Because of the particular layout of Sydney metropolitan area, the minimum access distance in terms of person km is not expected to be the central business area. The analysis according to the method proposed earlier in the paper allows us to rank LGAs according to their centrality, based on the ease of access quality. Table 2 shows the ranking of LGA according to this measure. It is seen that the first five ranking LGAs according this access measure are Burwood, Strathfield, Ashfield, Concord, and Drummoyne in that order.

The existing major airport is in a LGA which ranks 22 according to this measure and the proposed new Badgerys Creek airport is located in a LGA which ranks 32 (see Table 2). Only the road network has been considered here in the access effort computation. It is possible to perform calculations based on public transport options and is likely to lead to a different result because of their particular network characteristics. Quantification of this access measure provides an insight into the relative increase in travel distance experienced by airport users when the airport is moved to the new location. This will be further discussed later in this paper.

Facility location selection problems where environmental considerations are not significant could rely on the analysis shown above as in the conventional location allocation problem. However, location of an airport invariably raises environmental concerns, and it is attempted here to estimate the effects of noise levels on the resident public. For illustration purpose a noise weight was attributed to relevant LGAs by

Table 2 Ranking of LGA according to ease of access distance

Rank	LGA	Rank	LGA	Rank	LGA
1	Burwood	16	Lane Cove	31	Baulkham Hills
2	Strathfield	17	Holroyd	32	Liverpool
3	Ashfield	18	Hustville	33	Blacktown
4	Concord	19	Rockdale	34	Manly
5	Drummoyne	20	North Sydney	35	Sutherland
6	Auburn	21	Willoughby	36	Warringah
7	Leichhardt	22	Botany	37	Penrith
8	Marrickville	23	Kogarah	38	Hawkesbury
9	Canterbury	24	Ku-ring-gai	39	Campbelltown
10	Ryde	25	Woollahra	40	Camden
11	Hunters Hill	26	Fairfield	41	Blue Mountains
12	Parramatta	27	Randwick	42	Wollondilly
13	South Sydney	28	Waverley	43	Gosford
14	City of Sydney	29	Mosman	44	Wyong
15	Bankstown	30	Hornsby	-	-

Table 3 Noise exposure input used in the environmental effects computation

	Airport Location	
LGA	Mascot	Badgerys Creek
Randwick	1	0
Botany	2	0
Marrickville	1	0
Leichhardt	2	0
Drummoyne	1	0
Rockdale	2	0
Kogarah	1	0
Hustville	1	0
Liverpool	0	1
Camden	0	1
Campbelltown	0	0.5
Penrith	0	1
Hunters Hill	1	0

inspection of noise contours. It is possible to include noise measurements (actual or forecast) but here a simplified approach is followed in the interest illustrating the concept without undue complexity in units of measurements and computations. Therefore, noise effects on LGAs under flight paths are input to the model as selected in Table 3. It is acknowledged that values used here are used for indicative purposes only. Information available from Federal Airports Corporation (1990) in relation to noise effects can be applied in a more accurate computation.

As expected, the measure of noise effects is low at the second airport site (Table 4). What is interesting with this method is that it allows a quantitative comparison. The reduction of noise impact, as measured by exposure multiplied by the affected population shows a 66% reduction (Table 4). In other words, the present site subjects the public to three times the level of noise impact compared to the new site. The actual magnitude estimated here can be further refined using more accurate noise measurements and predictions. Nevertheless, these values are in agreement with what is generally expected as it is almost unanimously agreed by the public that the new site will show much lower levels of noise imposed on the community. What this paper has achieved is to provide an estimate of the new level of noise exposure compared to the

Table 4 Comparison of two sites according to access and noise measures

	Mascot	Badgerys Creek
Access measure (Distance x population)	140357.1	166854.1
Ratio		1.188
Increase %		18.8
Noise effects measure (Exposure x population)	558240	186596
Ratio		0.334
Reduction %		66.6

existing site. As mentioned before, Table 4 has shown that the new site would reduce the noise problem to about one third of the present size.

Now, going back to the issue of ease of access, notice how much the access measure has increased. It is seen that the access measure is increased by about 20% (18.8% as shown in Table 4) because of the airport site relocation. The proposed methodology provides policy makers with important information as the method yields the relative change of access and noise impact measures compared to the present site. This allows policy makers to be aware of the worth, or lack of it, of the site relocation.

Conclusions

Questions related to research and policy, particularly the value of research, indicate the necessity to provide solutions that minimise the cost to the community of transport infrastructure facilities such as airports. In the example shown, the analysis has been specifically designed to include environmental costs in addition to the access costs considered in the traditional location allocation method.

This paper has reviewed the location allocation problem as applied to the selection of an airport site, to demonstrate a method which incorporates environmental costs of noise impacts associated with air traffic operations. This methodology is also useful for transport planners in other fields such as location of incinerators and waste dumps which cause direction specific pollution levels. The methodology presented also demonstrates that it is worthwhile to encourage transport research in this particular field.

It is possible to analyse the location allocation problem for facilities which involve environmental considerations by modification of conventional optimisation techniques. The methodology takes into account road transport network effects, usage level of the airport, population distribution and the directional nature of environmental impacts. For the success of this method, decision makers and the community would be required to ponder and specify the value of environment weighting associated with environmental costs.

Transport infrastructure development policy requires sound analytical methods providing quantifiable measures. The proposed methodology allows quantification in a logical manner. An example has been included to describe the numerical method. It is demonstrated that it is possible to provide quantitative measures in an application to the airport location problem.

The proposed methodology also provides an insight into possible alternative solutions to the location selection problem and the sensitivity of these solutions to the community weighting associated with environmental considerations.

Research work described here is important because it provides an analytical framework to include geographical directionality of environmental considerations related to transport infrastructure development.

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