An Economic Analysis of Terminal Aerodrome Forecasts with Special Reference to Sydney Airport

R. J. Leigh, L. Drake, and D. J. Thampapillai

1. Introduction

This paper examines economic aspects of weather forecasts for aviation known as Terminal Aerodrome Forecasts (TAFs). TAFs are predictions of weather conditions within an eight-kilometre radius of an aerodrome; they are issued every six hours, have a twenty-four hour validity, and are produced for all major airports in the world (BoM, 1981). In Australia, TAFs are produced by the Bureau of Meteorology (BoM), an agency of the Australian Federal Government. Although TAFs have many safety-related and operational roles, their use during flight planning is the focus of this paper. Many airlines rely on TAFs during flight planning; for example to determine the carrying of additional (alternate) fuel for diversion to an alternative airport if weather conditions around the intended destination are adverse. Inaccurate TAF information may cause unnecessary diversions or mean that additional fuel is carried unnecessarily.

Aviation is both weather and weather information sensitive (Marks, 1980). Information has economic value only if it affects human decision making; TAF information affects decisions. The objective of this paper is to assess the economic benefits and costs of TAFs. The analysis involves the estimation of: (1) the direct benefits of improved TAF accuracy; (2) the direct value of TAFs at a particular accuracy level and over a specified time period; (3) the net social benefits of the TAFs; and (4) the optimal level of TAF accuracy. Twenty-two years of historical TAF verification data, and real airline cost data, are analysed within the decision making framework formulated below. The results presented are based on the international operations of Qantas Airways Limited into Sydney Airport. The direct benefits and costs are defined in terms of the role of TAFs in determining aircraft fuel load for airlines employing a discretionary alternate fuel policy.1

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1 The meteorological and operational background for the study, derivation of the decision-analytic methodology, and calculation of the direct benefits to Qantas Airways of Sydney Airport TAFs, are reported in detail in Leigh (1995).
2. Direct Economic Benefits of TAFs

2.1 Analytic framework
Decisions made by airline management based on TAF information may be modelled using the cost-loss ratio. In the meteorological context, the cost-loss ratio generally involves the decision to take, or not to take, protective action against the probable occurrence of adverse weather. If protective action is taken, a cost of protection \( C \) is incurred regardless of weather conditions. If protective action is not taken and adverse weather occurs, then a loss \( L \) is incurred. If no protective action is taken and adverse weather does not occur, then no cost or loss is incurred. In this study, the protective action is to carry 15,000 kg of extra fuel and the cost of protection differs if adverse weather does or does not occur (\( C_1 \) or \( C_2 \); see Table 1). In the simplest terms, if the TAF predicts weather conditions at the expected time of arrival (ETA) to be worse than that specified for the alternate fuel criteria (including cloud height and visibility) then the pilot will load additional fuel. If the aircraft is not carrying additional fuel because of the TAF-related decision made before departure, and on arrival at Sydney: (1) the weather conditions at Sydney Airport are worse than the alternate criteria, the pilot must make an en-route diversion to another airport; or (2) the weather conditions are better than alternate criteria, the aircraft may proceed and land. If the aircraft is carrying additional fuel and conditions are worse than the alternate criteria, the aircraft can legally proceed, perhaps make a low-level approach, and the pilot decides whether: (1) the conditions are unacceptable, whereupon there is enough fuel to abort the landing and proceed to another airport; or (2) the conditions are acceptable and the landing may proceed (this occurs for about 90 per cent of approaches under alternate conditions, so on average \( C_1 = 0.9C_2 + 0.1(C_2 + L) \)). If additional fuel is carried and conditions are better than alternate criteria the aircraft lands as normal, but has unnecessarily carried an extra 15,000 kg of fuel. Monetary values of the direct costs and losses are derived by considering these operational scenarios in conjunction with airline cost data provided by Qantas.

2.2 Expected cost
Monthly TAF verification data held by the BoM ARE simplified to the form of two-by-two contingency tables to suit the cost-loss ratio framework. Forecasts and observations are classified as being above or below the specified alternate fuel criteria, and the terms expressed as relative frequencies (see Table 2). Approximately 10 per cent of the verification data is discarded during the simplification.\(^2\) From Tables 1 and 2 the expected cost \( (EC) \) associated with the alternate fuel decision for a single flight on a given route is:

\(^2\) The raw TAF verification data consist of four-by-four contingency tables wherein the forecasts and observations are classified as: alternate fuel required (alt); no alternate fuel required (no-alt); alternate fuel required intermittently through the period (inter); and alternate fuel required temporarily through the period (tempo). Operationally, tempo and inter forecasts are similar to alt and no-alt forecasts respectively; however, they are different meteorologically, so it is not appropriate to add them together. Since, on average, 90 per cent of forecasts are alt or no-alt, it was decided to use only these forecasts.
Table 1
Airline Direct Cost Matrix
C1 is the average cost of carrying additional fuel and requiring it
C2 is the cost of carrying additional fuel and not requiring it
L is the cost of not carrying additional fuel and requiring it (necessitating a diversion)

<table>
<thead>
<tr>
<th>Actual Weather Observation</th>
<th>Airline Management Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Additional fuel carried</td>
</tr>
<tr>
<td></td>
<td>(protective action)</td>
</tr>
<tr>
<td>Additional fuel required</td>
<td>C1</td>
</tr>
<tr>
<td>(adverse weather)</td>
<td></td>
</tr>
<tr>
<td>No additional fuel required</td>
<td>C2</td>
</tr>
<tr>
<td>(good weather)</td>
<td></td>
</tr>
</tbody>
</table>

\[ EC = f_{11}C1 + f_{12}C2 + f_{21}L. \]  \hfill (1)

This equation is consistent with a game theoretic result that is derived in standard micro-
economic theory (Varian, 1992). The average monthly expected cost for all flights on
the same route \( EC_m \), where \( n \) is the average number of daily flights per month on that
route, is:

\[ EC_m = n(f_{11}C1 + f_{12}C2 + f_{21}L). \]  \hfill (2)

TAFs are verified for each six-hour period following the time of issue (see BoM,
1973, for details of the verification procedure), and the data are divided accordingly. The
TAFs are issued no less than one hour before the commencement of the validity period
so the periods are: \( T+1 \) to \( T+7; \) \( T+7 \) to \( T+13; \) \( T+13 \) to \( T+19; \) and \( T+19 \) to \( T+25 \) (where
\( T \) is the time of issue). The \( T+19 \) to \( T+25 \) period is not operationally significant because
no flights are long enough to require forecasts verified in that period. The relevant peri-
ods are denoted as \( T7, T13, \) and \( T19. \) Routes to Sydney are divided into three groups to
correspond with the forecast verification periods. Variable operating costs are generally
proportional to the length of the route, so each group may be represented by a single
route with length close to the average for the group. Cost parameters \( (C1, C2, \) and \( L) \) for
each representative route are derived from operating costs provided by Qantas by con-
sidering the operational impact of the TAFs. Operating cost information is based on
Boeing 747-400 aircraft, so scaling factors are used to incorporate different types of air-
craft. The expected cost \( EC_m \) is calculated from equation (2) using the cost parameters
for each group of routes and contingency tables for each month from January 1972 to
December 1994.

The contingency tables are also used to determine accuracy measures \( (A) \) that corre-
spond with each \( EC_m \). The accuracy measure employed here is the conditional proba-
bility of observing conditions better than the alternate fuel criteria, given a TAF for
conditions better than the criteria. It is assumed that this probability characterises the ac-
Table 2
Simplified Monthly Contingency Table Showing Relative Frequencies of Coincident TAF Predictions and Actual Weather Observations

<table>
<thead>
<tr>
<th>Actual Weather Observation</th>
<th>BoM TAF Prediction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Additional fuel</td>
<td>No additional fuel</td>
</tr>
<tr>
<td></td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>(adverse weather)</td>
<td>$f_{11}$</td>
<td>$f_{21}$</td>
</tr>
<tr>
<td>No additional fuel</td>
<td>$f_{12}$</td>
<td>$f_{22}$</td>
</tr>
<tr>
<td>required (good weather)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$f_{10}$</td>
<td>$f_{20}$</td>
</tr>
</tbody>
</table>

Table 3
Direct Benefits to Qantas of More Accurate TAFs for Sydney Airport and Direct Value to Qantas of TAFs for Sydney Airport

<table>
<thead>
<tr>
<th></th>
<th>A$ per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit of 1% improvement in TAF accuracy</td>
<td>$1.23 \times 10^6$</td>
</tr>
<tr>
<td>Value of TAFs in 1993</td>
<td>$6.86 \times 10^6$</td>
</tr>
<tr>
<td>Maximum potential value of TAFs</td>
<td>$8.46 \times 10^6$</td>
</tr>
</tbody>
</table>

Accuracy of all forecasts for the month. It is further assumed that the accuracy measure ($A$) fully defines forecast accuracy, so that $EC = 0$ when $A = 1$. In fact, a scalar measure cannot fully define the quality of the forecasts (Murphy and Ehrendorfer, 1987); however, more comprehensive measures (such as the fraction of correct forecasts) exhibit multifunctional relationships with $EC$ and are not appropriate for this simple economic analysis. There are strong negative correlations between $EC_m$ and $A$ for each forecast verification period which are significant at the 99 per cent level ("students $r' = 94.57, 81.58, $ and 80.70 for the T7, T13, and T19 periods respectively). The relationships $EC_m = f(A)$ are estimated by linear regression ($R^2 = 0.97, 0.96, 0.99$ for the T7, T13, and T19 periods, respectively). The benefits of an improvement in accuracy are determined in terms of a reduction in expected cost (Figure 1), and the results summed to give the total benefit to Qantas of a unit improvement (1 per cent) in TAF accuracy (Table 3). The average accuracy of TAFs for Sydney Airport is high, and based on the accuracy measure used in this study a 1 per cent increase (roughly 98 to 99 per cent) is a substantial increase.
2.3 Economic value

The economic value of forecasts (VF) may be defined as the difference between the costs incurred if there was no TAF information ($EC_{ni}$), and the costs incurred using the TAF information ($EC$). It is assumed that, in the absence of adequate forecast information, the airline will require all flights to carry additional fuel. The expected cost in this case is the weighted sum of the costs of protection associated with the two weather states (see Tables 1 and 2):

$$EC_{ni} = f_{01}C1 + f_{02}C2.$$ 

Therefore the forecast value is:

$$VF = EC_{ni} - EC = (f_{01}C1 + f_{02}C2) - (f_{11}C1 + f_{12}C2 + f_{21}L) = f_{21}C1 + f_{22}C2 - f_{21}L = f_{21}(C1 - L) + f_{22}C2.$$ 

The average monthly forecast value for all flights on a particular route, where $n$ is the average number of daily flights per month on that route, is then:

$$VF_m = nf_{21}(C1 - L) + nf_{22}C2.$$ 

There is a similarly strong positive linear correlation between $VF_m$ and $A$, and the procedure for estimating the relationships $VF_m = g(A)$ is similar to that described above for $EC_{ni}$. The maximum value of the TAFs and the threshold accuracy levels below which the forecasts have negative value are estimated by setting $A = 1.0$ and $A = 0$ (see Figure 2). The value of the TAFs for a particular year is simply the sum of the values for each month for each forecast period (see Table 3).
3. Indirect Costs and Externalities

Incorporating indirect and external costs into the direct cost matrix of Table 1 creates a "social cost matrix". Replacing Table 1 with this matrix and following the procedure outlined above yields the estimated social benefits and values (Table 4). The "social cost parameters" are defined as follows. The social loss ($L^*$) consists of the direct loss ($L$) as given above, indirect loss ($L_i$), and external loss ($L_e$). That is:

$$L^* = L + L_i(pt) + L_e(ap,np,mt).$$

The indirect loss ($L_i$) is the economic value of the disutility to the passengers of "an average" three-hour diversion (Qantas Airways, personal communication) and is assumed to be a function of passenger time ($pt$). The external loss ($L_e$) is the economic value of appreciable damages conferred on third parties because of the diversion. It is assumed to be a function of the marginal increase in air pollution ($ap$) and noise pollution ($np$) caused by the diversion, and the cost of the time wasted by people meeting the passengers ($mt$).
Table 4

*Social Benefits of More Accurate TAFs and Social Value of TAFs for Sydney Airport*  
(includes direct costs, estimates of the cost of passenger time, and low and high estimates of the marginal social cost of additional CO₂ emissions)

<table>
<thead>
<tr>
<th></th>
<th>A$ per year (low)</th>
<th>A$ per year (high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit of 1% improvement in TAF accuracy</td>
<td>1.44 x 10⁶</td>
<td>1.53 x 10⁶</td>
</tr>
<tr>
<td>Value of TAFs in 1993</td>
<td>7.77 x 10⁶</td>
<td>14.78 x 10⁶</td>
</tr>
<tr>
<td>Maximum potential value of TAFs</td>
<td>9.66 x 10⁶</td>
<td>16.71 x 10⁶</td>
</tr>
</tbody>
</table>

The social cost of protection in the context of good weather (\(C_{2}^{*}\)) consists of the direct cost of unjustified protection (\(C_{2}\)) and the external cost of unjustified protection (\(C_{2e}\)). That is:

\[
C_{2}^{*} = C_{2} + C_{2e}(ap).
\]

\(C_{2e}\) is assumed to be equal to the economic cost to society of the air pollution attributable to the extra fuel burned to carry the unnecessary additional fuel.

Finally, the average social cost of protection in the context of adverse weather (\(C_{1}^{*}\)) is:

\[
C_{1}^{*} = 0.9C_{2}^{*} + 0.1(C_{2}^{*} + L^{*}).
\]

31. Air pollution

Air pollution from aircraft may be categorised into pollution produced during take-off and landing, where the main effects are assumed to be localised (for example, reduced health of local residents, damage to buildings); and pollution produced while cruising, where the main effects are assumed to be global (for example, enhanced greenhouse effect, ozone layer depletion). It is difficult to draw links between localised pollution effects and particular sources (Wippeney, 1993), but Small (1977) has estimated the damage costs in American cities attributable to air pollution from one landing and take-off cycle of a Boeing 747 at US$24.82. Although it is difficult to translate this to the Australian context in 1994, it suggests that this component of \(L_{e}\) is very small compared to other components of \(L^{*}\) (for example, \(L_{t} = \$5,875/flight\) from the following paragraphs).

In this study the localised effects are omitted, and the external cost of carrying unnecessary fuel (\(C_{2e}\)) is approximated by considering the incremental effect on global warming of the extra CO₂ emitted by aircraft carrying additional fuel. Commercial aircraft produce about 3.2 tonnes of CO₂ per tonne of fuel consumed (Nusser and Schmitt, 1990), and according to Davies (1990) additional fuel carried is burned off at a rate of 4 per cent per hour to carry itself. We can say that the additional CO₂ produced from burning extra fuel to carry the typical 15,000 kg additional fuel load to Sydney is given by
\[ \Delta \text{CO}_2 = 3.2 \times 0.04 \times 15 \times T = 1.92T \text{ tonnes/hour}, \] where \( T \) represents the length of the flight (in hours).\(^3\)

This effect is incorporated using an estimate for the social costs of carbon emissions to the atmosphere (in $/tonne). There are two possible approaches to this (Drake, 1993). The first involves working backwards from cost estimates of the impact of global warming, and relating the costs to \( \text{CO}_2 \) concentrations, to estimate a damage cost per tonne of carbon emitted. This approach is fraught with difficulties because of the uncertainties associated with quantifying global climate change, predicting the impacts, and attributing costs to the impacts. The second approach is based on political decisions, that is, either a tax on carbon emissions or the marginal cost of reducing emissions to a specified level set by government or international agreement. The cost of achieving the specified level is assumed to be equal to the value of a carbon tax on emissions that would lead to the required reduction. A review of 14 economic models by the Energy Modelling Forum (1993) indicates that the average tax required to reduce emissions to 1990 levels by 2020 would range from A$26 to A$184 per tonne. 2020 is the least stringent target and a likely one for Australia to adopt, so these figures are assumed to equal the marginal cost of abatement, and therefore equal the social cost of the emissions. Thus for the T7 period, the external cost of carrying the alternate fuel \((C_{2e})\) ranges from $158 to $1119. Similarly, for the T13 and T19 periods, \( C_{2e} \) ranges from $361 to $2558, and $485 to $3434 respectively.

3.2 Noise pollution

It is possible to estimate monetary values for aircraft noise nuisance using contingent valuation (for example, Roskill, 1971), preventative expenditure (for example, Starkie and Johnson, 1975), or hedonic pricing methods (for example, Pennington et al., 1990). Hedonic pricing methods (evaluation of noise nuisance in terms of changes in property prices) are most prevalent in the literature, and are generally based on long-term average noise levels such as the NEF (Noise Exposure Forecast) measure used in the USA and Australia. These levels are not sensitive to sporadic noise level increases such as those caused by diverted aircraft, so the techniques are not appropriate for estimating the cost of noise pollution in this study. Since a reasonable estimate of the cost of noise pollution associated with a single aircraft taking off or landing is not readily available, the noise pollution component of \( L_e \) is omitted.

3.3 Passenger time

Henders (1977) undertook a study in 1973 to investigate business travel-time savings associated with a proposal for a second Sydney Airport. Although the study is twenty years old, it was selected as the basis for the value-of-time estimates employed in this study because: (1) the values determined were specifically for air travel under Austral-

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\( ^3 \) For example, carrying additional fuel on the Singapore-Sydney route \((T = 7.25 \text{ hours})\) releases an additional 13.9 tonnes of \( \text{CO}_2 \) into the atmosphere. Approximately 230 tonnes of \( \text{CO}_2 \) is produced when not carrying additional fuel.
ian conditions; (2) travel-time savings were reported as a percentage of average gross salary rates so they are temporally transferable; (3) both business and leisure travel time values were reported; (4) the values reported were resource values (they represent changes in net social welfare, rather than the welfare of individuals); and (5) the methodology derived values directly and independently, based on the opportunity cost of time and incorporated survey data. Average values of in-flight time savings on international flights estimated by Hensher (1977) were: 30 per cent of gross average salary rate for business travel time; and 15 per cent of gross average salary rate for leisure travel time (by business travellers). At the time of Hensher’s investigation the average wage rate of the travellers was 2.5 times the average gross wage rate. For this study we are concerned with both leisure and business travellers. Thus the current gross average hourly wage rate of $16.48 for a 37.5 hour week (ABS, 1994) is used for leisure travelers, and 2.5 times that rate (that is, $41.21/hr) for business travellers. In the 1993-94 financial year, 40 per cent of Qantas international passengers were travelling on business (Qantas, 1993), so the average value of in-flight passenger time is \( VPT = (0.3 \times \text{business wage rate} \times \text{fraction of business passengers}) + (0.15 \times \text{leisure wage rate} \times \text{fraction of leisure passengers}) = $6.43/hr. Based on 406 seats for a 747-400, an average load factor of 75 per cent, and an average total delay of three hours for a diversion to Brisbane (Qantas Airways, personal communication), the indirect loss \( L_i \) is \( L_i = 0.75 \times 406 \times 3 \times 6.43 = $5,875 \) per flight.

In taking this approach it is assumed that delays have the same value per unit as time savings, that the traveller’s personal utility of travel is less than the utility of normal routine, and that the disutility is unrelated to the time when the delay occurs. The monetary value of time used is low compared to commonly applied values. This is because Hensher (1977) acknowledges that much business travel occurs during uncompensated leisure time. This reduces the value of business time, and his value for leisure time is itself also quite low. Common sense supports this, and suggests that the productivity-based, opportunity-cost resource value of lost travel time attributable to airline delays (of about three hours) is not very high. Compared with urban commuting time the competition for alternative uses is less; the alternatives are fewer, less immediate, and less accessible. Thus the values employed seem reasonable. The value of the time wasted by people meeting the diverted aircraft is an external cost \( (mt) \). It is difficult to estimate how many people meet each aircraft and how long they would wait, so this externality is omitted.

4. The Social Cost of Producing TAFs
The social cost of producing TAFs may be estimated from the bottom up, or from the top down. The former approach involves building a total production cost based on the wage of a forecaster and the time taken to produce a single TAF; the latter is based on the fact that aviation forecasts are considered to be incremental cost recovery services (Anaman et al., 1995). Both approaches are applied in this paper.
TAFs are generally produced by a Senior Technical Officer Grade 2 (STO 2) with a salary range of $35,424 to $41,560 p.a. (BoM, personal communication). Based on a 35-hour working week and 52-week year, the maximum wage rate is $22.80/hr. Assuming 15 minutes’ labour to produce a Sydney TAF (BoM, personal communication), and doubling the wage rate to cover overheads, the production cost per TAF becomes $11.40. For an average of 120 TAFs produced per month this is a production cost of $1,370/month (given that all necessary weather information exists).

The aviation sector indirectly pays the BoM $15 million per year (BoM, 1993) for all recoverable costs associated with the production of aviation forecasts, observations, and other services, in the whole country. This includes wages plus overheads such as office rent, equipment costs and depreciation, insurance, sick leave, superannuation, and so on, for the 90 employees directly related to aviation services (BoM, personal communication). In 1992 the BoM produced 632,551 aviation forecasts and warnings, of which 321,065 were TAFs (BoM, 1993). If we assume each service is of equal difficulty and takes approximately the same amount of time to produce, then the cost of a single TAF is simply $15 million divided by 632,551. That is, $23.71/TAF or $2,846/month. A similar figure is arrived at by considering that the $15 million funds 90 people, many of whom do not produce the TAFs but who may be considered “overheads”, and using the average recoverable cost per employee as the wage rate. The cost of producing Sydney TAFs is therefore likely to be between $1,370 and $2,850 per month. Although producing TAFs may include some indirect and external costs, they are assumed to be quite small. Preferring to overestimate, rather than underestimate, the “social cost of production” of Sydney TAFs, the figure $2,850 per month is used.

5. Estimating the Optimal Level of TAF Accuracy

5.1 The airline's optimal level of TAF accuracy
The marginal private benefit (MPB) curve for the airline can be approximated by the expected cost curve in Figure 1. The marginal benefit of a unit increase in TAF accuracy is the corresponding incremental decrease in costs (that is, the slope of the curve $EC = f(A)$, namely $\Delta EC/\Delta A$). Since the airline pays a fixed amount for the forecasts (unrelated to their accuracy), the marginal cost to the airline of increasingly accurate TAFs is constant and equal to zero; that is, a horizontal line along the $x$-axis. Thus the profit-maximising (equilibrium) level of accuracy is $A = 1.0$, the point at which marginal cost equals marginal benefit. This is intuitive; however, if the cost of the TAFs to the airline was proportional to the accuracy of the forecasts, then the optimal level of accuracy from the airline's perspective would be less than 1.0.

5.2 Socially optimal level of TAF accuracy
The marginal social benefit (MSB) and marginal social cost (MSC) curves may be approximated by incorporating indirect and external costs, and estimating the social cost
of producing forecasts of differing accuracy. The socially optimal level of accuracy \( (A^*) \) then occurs at the intersection of the MSC and MSB curves. As noted earlier, the relationship between total expected cost and accuracy is close to linear, so the marginal social benefit is assumed to be constant and equal to the slope of the relationship. For a one per cent unit of accuracy this equals the benefit recorded in Table 4 (that is, \( MSB = \Delta ESC/\Delta A(1\%) = \) at least $120,000/month). That is, \( MSB \) is a straight horizontal line from $120,000 on the y-axis.

Threshold accuracy levels, below which TAFs have negative value to the airline, differ for each forecast verification period. The lowest level is \( A = 95.3 \) per cent for the T19 period. That is, for a given month with a characteristic accuracy of less than 0.953 the airline would have been better off ignoring the forecasts and always carrying additional fuel. We assume that forecasts consistently below this level would be ignored by the airline, so improvements in accuracy up to this level would not yield any benefits. Thus the MSB curve is a step function as shown in Figure 3.

Accepting that the average social cost of producing Sydney TAFs is $2,850/month does not reveal the marginal cost of producing better TAFs. The fact that the magnitude of the benefits is large, relative to the cost of production, suggests that unless the cost of producing TAFs with higher accuracy increases manifold, the socially optimal accuracy level will remain very close to 100 per cent. This is illustrated by considering a hypo-
6. Risk Analysis

An important basis for this study, and one of the reasons for the high economic value of TAFs at Sydney Airport, is Qantas' fuel policy. The policy can be examined in terms of the company's attitude to financial risk. Qantas' objective is to minimise its expected fuel and diversion costs by basing its actions on forecast information provided by the BoM. By basing decisions purely on the information provided, the airline demonstrates that it is indifferent to which action is taken; the fuel policy is risk-neutral. As noted earlier, under this policy the expected cost to the airline is:

$$EC_{neutral} = f_{11}C1 + f_{12}C2 + f_{21}L.$$ 

A risk-averse fuel policy would involve the airline ignoring the available forecast information and always carrying additional fuel. Under this policy, the expected cost to the airline is equal to the weighted sum of the costs of carrying additional fuel associated with the two possible weather states (see Tables 1 and 2):

$$EC_{averse} = f_{01}C1 + f_{02}C2.$$ 

This is the benchmark cost against which forecast value is measured. The value of the forecasts to Qantas is therefore equal to the costs saved by taking a risk-neutral, rather than a risk-averse, approach to carrying additional fuel.

It is assumed that a risk-taking fuel policy would involve aircraft never carrying additional fuel, and diverting every time a TAF predicting weather conditions better than the alternate fuel criteria was incorrect. (This is hypothetical, because such behaviour is prohibited by international and Australian regulations.) Under a risk-taking fuel policy, the expected cost is the weighted sum of the losses ($L$ and $0$) associated with the two possible weather states:

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4 While such an increase in funding is unlikely, it is fair to assume that increasing funding when accuracy levels are low would improve the accuracy (say from 97 to 98 per cent). However, when accuracy is very near to 100 per cent it is most unlikely likely that the improvement required to achieve perfect forecasts will occur, no matter how much the funding is increased.

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Figure 4

*Monthly Expected Cost for Christchurch-Sydney Route (T+1 to T+7 Forecast Verification Period) Based on Different Additional Fuel Policies:*
- Risk-averse Policy ($\mu = $14,750, $\sigma = $2,517); Risk-neutral Policy ($\mu = $15,054, $\sigma = $11,235); Risk-taking Policy ($\mu = $25,824, $\sigma = $25,175)

Figure 5

*Monthly Expected Cost for Singapore-Sydney Route (T+7 to T+13 Forecast Verification Period) Based on Different Additional Fuel Policies:*
- Risk-averse Policy ($\mu = $84,850, $\sigma = $2,570); Risk-neutral Policy ($\mu = $22,440, $\sigma = $17,300); Risk-taking Policy ($\mu = $27,175, $\sigma = $25,698)
Figure 6

Monthly Expected Cost for Honolulu-Sydney Route (T+13 to T+19 Forecast Verification Period) Based on Different Additional Fuel Policies:
Risk-averse Policy ($\mu = $136,615, $\sigma = $2,415); Risk-neutral Policy ($\mu = $26,635, $\sigma = $20,541); Risk-taking Policy ($\mu = $27,643, $\sigma = $24,161)

$$EC_{taker} = f_{01}L + f_{02} 0 = f_{01}L.$$  

Figures 4 to 6 show the time series of the expected costs associated with the three potential management policies for each of the three representative routes. Based on standard deviation ($\sigma$) as a measure of risk, we can see that the figures are consistent with theory; the expected costs associated with the risk-averse policy show little variation around the mean, costs associated with the risk-neutral policy show larger variation, and costs associated with the risk-taking policy have the largest variation. This holds for all the routes. The relationship between the mean expected costs ($\mu$) is different for different routes. For the medium- and long-haul routes (Figures 5 and 6) the risk-neutral policy yields the lowest mean expected cost, and the risk-taking policy yields the highest mean expected cost (higher than for the risk-neutral policy). For short-haul routes (Figure 4) the risk-averse policy yields a slightly lower mean expected cost than the risk-neutral policy. Interpolation indicates that the cross-over point at which the policies have equal status is very close to the length of the representative route for the short-haul routes. This preliminary analysis suggests the following conclusions: (1) in addition to being illegal, the risk-taking policy leads to higher average costs than the risk-neutral policy and is economically inefficient; (2) Qantas' current risk-neutral policy leads to the lowest average costs for the long- and medium-haul routes; and (3) a risk-averse policy would lead to slightly lower average costs for short-haul routes, but the risk-neutral policy be-
comes more economically efficient at routes only marginally longer than the short-haul representative route (of three-and-a-quarter hours). Further analysis in this direction could reveal whether the timing of the current 6, 12, and 18 hour TAFs is the most economically efficient from the airlines' perspective.

7. Conclusion

The model used in the study has been shown to be suitable for the economic evaluation of Terminal Aerodrome Forecast information. Improvements in TAF accuracy would yield significant positive benefits to airlines. In terms of the case study reported here (Qantas international flights into Sydney), the economic benefit of a hypothetical increase in TAF accuracy of 1 per cent is approximately A$1.2 million per year. The annual value to Qantas of the Sydney TAF service, based only on international routes, is estimated to be at least A$6.9 million for 1993 — approximately 80 per cent of the potential maximum value of the forecasts. A rough estimate of the value of the TAF service nationally is made by noting that 43 per cent of Qantas international flights arrive in Sydney (Qantas, 1994); so the national value is about $16 million/year. The study indicates that Qantas' current risk-neutral additional fuel policy results in lower average costs than the alternative risk-averse policy. Theoretically, implementing a risk-averse policy for short-haul routes would yield lower costs for those routes. However, a risk-neutral policy becomes more economically efficient at routes only marginally longer than the short-haul representative route, so a policy change is not recommended.

The social value of TAFs was estimated by including the cost to passengers of time lost by diversions, and the cost of the additional CO₂ emitted by carrying unnecessary additional fuel. Estimates of the social cost of additional CO₂ are variable, and the social value is sensitive to the magnitude of these estimates. The MSB curve is less sensitive, and (based on an assumed production-cost function) it seems that the socially optimal accuracy level is very close to the private optimal accuracy level of 100 per cent. This analysis only considers the role of TAFs in the additional fuel decision and neglects other important operational and safety-related roles. The estimated benefits and values are therefore minimum values.

References


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