# Economic Value of Meteorological Services to Switzerland's Airlines: The Case of TAF at Zurich Airport

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ABSTRACT

Just as in other state-subsidized service areas, in the field of aviation weather there is political pressure as well as a growing economic need to substantiate or at least evaluate the economic benefits of meteorological information. The research presented in this paper has been conducted as part of a broad study concerning the economic benefits of the meteorological services in the Swiss transport sector. For the aviation sector, interviews revealed that meteorological information is a pivotal input factor in the decision-making process of airlines: In addition to security and safety purposes, airlines use meteorological information to optimize the economic efficiency of daily operations as well as for strategic decisions regarding flight routes and flight planning.

In this paper a decision-making model is used to evaluate at least part of the economic benefits of the meteorological services to Switzerland's domestic airlines by analyzing the use of terminal aerodrome forecasts (TAF) at Zurich Airport (Switzerland). By lowering the probability of costly wrong decisions, meteorological information generates direct economic benefits for the airlines. The total benefits for all domestic airlines at Zurich Airport amount to between 11 and 17 million Swiss francs per year [12 to 18 million USD; 1 U.S. dollars (USD) = 0.934 Swiss francs (CHF), average exchange rate 2012]. By extrapolating the results based on the number of flights, the total economic benefits of TAF to Switzerland's domestic airlines at both main Swiss airports (Zurich and Geneva) add up to somewhere between 13 and 21 million Swiss francs per year (14 to 22 million USD).

## 1. Introduction

The aviation industry, and airlines in particular, rely very heavily on meteorological information to economically optimize their daily operations as well as their strategic decisions on flight routes and flight planning. Besides that, meteorological information is also important for the security and safety of air and ground operations. In the context of increased political pressure on state-subsidized services, the need to assess the economic benefits of meteorological information for the industry as well as for the national economy is growing in the field of aviation weather services.

The use of meteorological information and the economic benefits from that use in specific industries and sectors has been a topic of several studies carried out in Europe, the United States, and Australia. Anaman and Lellyett (1996) assessed the benefits of enhanced weather information services on the cotton industry, Frei et al. (2014) assessed the economic benefits of meteorology on the Swiss road transport system, and Lazo and Chestnut (2002) analyzed the economic value of weather forecasts to the U.S. household sector. Moreover, the literature on the methods for assessing the economic benefits of meteorological service provision is also rather broad, as the following examples show: Frei

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(2010), Leviäkangas (2009), Leviäkangas and Hautala (2009), Gunasekera (2004), Freebairn and Zillmann (2002), and Anaman et al. 1995.

In weather-sensitive activities, meteorological information may be a pivotal input in the decision-making process and influence the behavior of people and organizations. Although even a deterministic forecast is always connected with some degree of uncertainty, it indicates an evolution of the weather that is more likely to happen than other possible meteorological situations. This allows better informed decisions based on individual risk tolerance by considering the additional information provided by the meteorological forecasts. The economic benefits of meteorological services can therefore be assessed by comparing the outcome in the case of meteorological information being available in the decision-making process with the outcome in the case of decisions having to be made without such information (see Katz and Murphy 1997). Often the use of meteorological information leads to lower production costs for the required output or to a better quality of output at equal production costs (e.g., Freebairn and Zillmann 2002; Frei et al. 2014). A straightforward way of using the decision-making approach to assess the benefits of meteorological services is therefore to ask companies how much their costs would rise if the same output had to be produced without the use of meteorological information. This *ceteris paribus* ("other things being equal") analysis requires companies to be able and willing to isolate the benefits of meteorological information in their corporate processes. The benefits of meteorological information are, however, not only driven by direct cost savings but also comprehend indirect benefits (e.g., fewer delay costs or a higher customer satisfaction) and influences on the company's reputation with regard to safety and security, which are very difficult to quantify.

The key importance of weather information for airlines and the aviation industry in general makes the use of a decision-making approach difficult for two main reasons. First, in the absence of meteorological information, the aviation industry would operate, if at all, very differently from today. Therefore, the comparison has to be made with a very hypothetical situation, far from today's reality. In fact nobody knows exactly how the aviation industry would operate if no meteorological information were provided. Second, the airlines do not think extensively about the value of meteorological information since the regulations require the use of such information anyway. Hence, unlike in other industries where the decision whether to use meteorological information is a conscious decision and a matter of strategy, within the airlines only little knowledge is available

about the magnitude of the economic benefits meteorological information can provide. Interviews with airline managers and flight dispatchers conducted as part of a broad study concerning the benefits to the national economy of meteorological services in the Swiss transport sector (Bade et al. 2011) confirmed this observation: The airline officials stressed the fact that meteorological information is very valuable and important for their business, but they were not able to quantify the economic benefits (see section 5).

In this paper a straightforward decision-making model was used to analyze the economic benefits of terminal aerodrome forecasts (TAF)[1] to Switzerland's domestic[2] airlines at Zurich Airport. The role of TAF in the airlines' decision-making processes and its influence on costs were identified with the help of explorative interviews with airline pilots and flight dispatchers. Subsequently, two separate decision-making processes were modeled, one with and one without meteorological information. Finally the model was filled with appropriate data provided by two airlines and the national meteorological service (MeteoSwiss). This approach enabled the authors to draw *ceteris paribus* conclusions concerning the influence of TAF on the profitability of airlines.

It is important to note that the model developed here only captures the economic impact of one particular meteorological product (TAF) and therefore the results obtained only reflect a limited part of the total impact of meteorological services to the aviation industry.

## 2. Model

A method to assess the economic costs and benefits of TAF to the airlines was developed and applied by Leigh (1995) and Leigh et al. (1998). They analyzed the inbound flights of the Australian airline Qantas to Sydney International Airport and assumed that the airline's decision to carry additional fuel on a particular flight is determined by the forecasted weather conditions. Inaccurate forecasts would therefore result in unnecessary fuel costs, if extra fuel were carried but not used, or in avoidable costs due to flight deviations to other airports, if extra fuel was not carried but was necessary for a safe landing in Sydney. To the best of the authors' knowledge, the present paper is the first attempt to update Leigh's work and the first study to assess the economic costs and benefits of TAF in a European setting. This

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[1] TAF is a coded and formally clearly defined weather forecast applied to a 5-mile radius around an airport.
[2] The discrimination in foreign and domestic airlines is based on the Swiss Civil Aviation statistic (FSO 2010).

last point has to be stressed because weather conditions as well as the organization of the air space are very different between Australia and Europe.

The model presented in this paper is able to analyze the impact of weather forecasts (TAF) on the amount of extra fuel carried on inbound flights to Zurich. The amount of extra fuel carried is larger if adverse weather conditions are expected at the destination airport because pilots and flight dispatchers decide to carry an additional fuel reserve to better deal with weather-related extensions of the flight time (e.g., weather-related holding, touch-and-go, congestion). Without this additional fuel reserve the risk that a flight has to deviate and land at an alternative airport is higher. Flight deviations always lead to additional costs (e.g., passenger compensation, additional transfers, landing fees, fuel, and reputation costs). Economically speaking, the additional fuel carried is therefore an insurance (protection) against the risk of costs from avoidable deviations. In the model the price of this insurance is equal to the price of the fuel burned to carry the additional fuel. In other words, airlines face a trade-off between the insurance fee (cost of carrying additional fuel) and a downside risk (cost of deviation).

### a. Decision modeling

During preflight planning the cockpit crew together with the flight dispatchers decide if an additional adverse weather fuel reserve should be carried or not. This decision is based on the expected weather conditions at the destination airport, reported by the TAF. For the sake of simplification only two meteorological conditions were considered in the model presented here: "good" and "adverse."[3]

Depending on the actual weather conditions at the destination airport and the previous decision to carry extra fuel or not, landing at the destination airport will be possible or not. In our model we assume the following.

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[3] As explained in section 3, the definition of "good" versus "adverse" weather condition in this study is based on the TAF parameter VIS (visibility). For the scope of this study weather conditions have been defined as adverse if visibility is less than 5000 m and good otherwise. This simplification assumes that the cockpit crew is faced with only two options: carrying additional fuel or not. In reality, however, the decision making process is more complex and the decision is not binary but rather about a continuum ("amount additional fuel"). There are no strict rules that define how much additional fuel has to be carried under certain weather condition, hence, the cockpit crew considers all available information and takes into account personal experience as well. The final decision is taken by the pilot who is responsible for the flight.
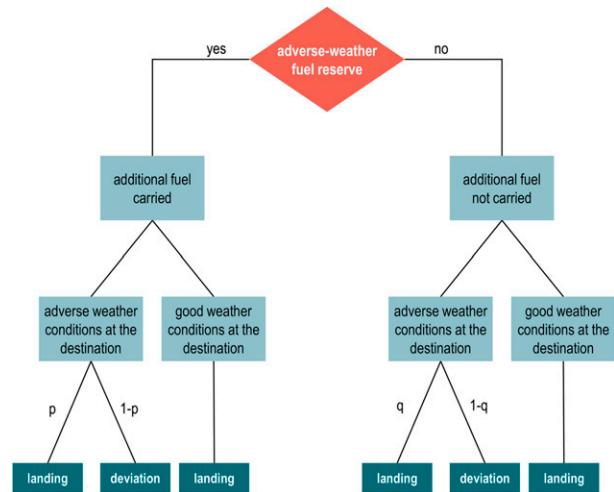


FIG. 1. Decision paths implemented in the model.

First, if the weather is good, landing is always possible. Second, during adverse weather conditions, landing is possible with probability $p$ if extra fuel was carried, and with probability $q$ without extra fuel. Hence, a deviation to another airport occurs with probability $1 - p$ if extra fuel was carried and with probability $1 - q$ without extra fuel. The decision process can be visualized using a decision tree (see Fig. 1).

### b. Costs for the airlines

For the airlines, the following cost components occur:

1) Costs $D$ if the flight cannot land (cost of deviation).
2) Costs $I$ if an adverse weather fuel reserve is carried (insurance costs).

Following Leigh (1995) and Leigh et al. (1998), for each combination of forecasted and actual weather, a specific cost variable was defined (see Table 1).

C2 is equal to the insurance costs $I$, as no other costs occur in that case. Costs C1 and $L$ can be calculated from the insurance costs $I$, the deviation cost $D$, and the probabilities $p$ and $q$, as follows:

$$C1 = C2 + (1 - p)D,$$

$$L = (1 - q)D.$$

TABLE 1. Overview of the cost variables (e.g., C2 are the costs that occur when actual weather conditions are good and adverse weather was forecasted).

|                        |         | Forecasted weather conditions | |
|------------------------|---------|---------|------|
|                        |         | Adverse | Good |
| Actual weather conditions | Adverse | C1      | L    |
|                        | Good    | C2      | 0    |

TABLE 2. Relative frequencies of forecasted and actual weather conditions. The relative frequency refers to the absolute frequency of an event normalized by the total number of events.

| | | Forecasted weather conditions | | |
| | | Adverse | Good | Total |
|---|---|---|---|---|
| Actual weather conditions | Adverse | $F_{11}$ | $F_{21}$ | $F_{01}$ |
| | Good | $F_{12}$ | $F_{22}$ | $F_{02}$ |
| Total | | $F_{10}$ | $F_{20}$ | 1 |

Furthermore, the relative frequencies $F_{nn}$ for the combination of forecasted and actual weather conditions were defined as discussed below (see Table 2).

### c. Economic benefits of TAF for a single airline

As in Leigh et al. (1998) the economic benefits of TAF are defined as the difference between the expected costs in a situation with TAF ($EC_T$) and the expected costs without TAF ($EC_{NT}$). The expected costs can be calculated by the cross-multiplication of Table 1 and Table 2, as follows:

$$EC_T = F_{11}C1 + F_{12}C2 + F_{21}L,$$

$$EC_{NT} = F_{01}C1 + F_{02}C2.$$

In most cases[4] airlines have to carry enough fuel to reach one alternative destination airport (e.g., Basel or Geneva when flying to Zurich) in case of an emergency. In a situation without TAF at the destination airport, regulations require that airlines plan as if the destination airport were closed. In this case airlines have to carry additional fuel to reach two alternative airports instead of one. We define the costs of carrying the extra fuel for the second alternative airport as $A$. These additional costs must be taken into consideration to calculate $EC_{NT}$, as follows:

$$EC_{NT} = F_{01}C1 + F_{02}C2 + A.$$

This allows us to calculate the economic value (EV) of the TAF, as follows:

$$EV = EC_{NT} - EC_T.$$

Because fuel consumption per flight depends on the duration ($t$) of the flight and on the airplane type ($a$) used, EV must be calculated separately for each flight, as follows:

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[4] We abstract from the proceedings, where the flight planning is carried out without an alternative airport. Such proceedings can only be used for flights of less than 6-h duration and only under specific meteorological conditions.

$$EV(t, a) = EC_{NT}(t, a) - EC_T(t, a).$$

By summing up the $EV(t, a)$ of all the flights ($f = 1$ to $n$) we can calculate the economic value of TAF for an airline, as follows:

$$EV_{Airline} = \sum_{f=1}^{n} EV(t, a).$$

## 3. Data

To assess the economic value of TAF for Switzerland's domestic airlines in the case of Zurich Airport, economic and aeronautical data provided by two different airlines, a network carrier and a point-to-point carrier, as well as meteorological data provided by the Federal Office of Meteorology and Climatology (MeteoSwiss) were used.

### a. Economic and aeronautical data

Both airlines involved in this study provided estimates of airplane-based cost components, fuel prices, and the probabilities $p$ and $q$. Moreover, the authors received detailed information about flight plans and landing frequencies at Zurich Airport. Flights were classified by their duration into different categories. For each category a typical airplane was defined and airplane-specific cost components assigned accordingly. As fuel consumption is directly related to the duration of the flight, fuel costs were additionally scaled within the category by the actual flight duration per flight.

Probabilities $p$ and $q$ were estimated by the airlines at $p = 0.9999$ and $q = 0.9984$. These values were supported by the fact that feeding the model with these probabilities resulted in approximately the same number of deviations as effectively happened.

### b. Meteorological data

The meteorological data used for the study were taken from the verification of TAF forecasts between April 2008 and March 2010, carried out on a regular basis by Austrocontrol (see Mahringer 2008) on behalf of the MET Alliance group, of which MeteoSwiss is a member. This TAF verification is based on the comparison of the forecasted and the actual meteorological parameters of visibility, cloud base, wind speed, and wind direction as well as the present weather. As no data were available concerning the forecast quality of combined situations and as the forecast probabilities of the single weather parameters are not independent, it was decided to use the parameter visibility (VIS) to determine the two weather situations needed for the model. We defined good weather conditions when VIS ≥ 5000 m and

TABLE 3. Relative frequencies of forecasted and actual weather conditions used to compute the model (based on the verification of TAF forecasts between April 2008 and March 2010). Example: In 4.93% of all cases, the forecasted weather conditions were good; however, the actual weather conditions were adverse.

|  |  | Forecasted weather conditions | | |
|  |  | Adverse | Good | Total |
| --- | --- | --- | --- | --- |
| Actual weather | Adverse | 0.0796 | 0.0493 | 0.1289 |
| conditions | Good | 0.1266 | 0.7444 | 0.8711 |
| Total |  | 0.2062 | 0.7938 | 1.0000 |



FIG. 2. Average economic benefit per landing for different flight duration categories.

adverse weather conditions when VIS < 5000 m. With visibility of more than 5000 m, weather-caused interferences during the landing procedure are not expected. The choice of VIS as the leading parameter was based on the following reasoning: first, various weather conditions affect visibility, and second, the forecast quality for visibility is worse than for other parameters, which prevents the overestimation of the economic benefits connected with the use of TAF. Additionally, visibility is connected with clear rules concerning airport operations (e.g., time between landings, closure of runways), whereas the same cannot be said for the other available parameters.

Based on the verification of the TAF forecasts between April 2008 and March 2010 and the definitions stated in the section above, the relative frequencies of the forecasted and the actual weather conditions were calculated (see Table 3).

## 4. Results

### a. Economic value of TAF for Switzerland's domestic airlines

The results shown in this section were calculated using the data described in the previous section and are based on an average fuel price of 1.08 CHF kg$^{-1}$ (0.524 USD lb$^{-1}$).[5] For each inbound flight connection into Zurich Airport the cost variables (see Table 1) were calculated individually based on the information provided by the airlines. By multiplying the cost variables with the relative frequencies shown in Table 3 the expected economic benefits for each flight connection could be calculated (see section 2 for details about the methodology). The average economic benefits of the TAF forecast for the two analyzed airlines amounts at yearly 70 500 CHF (74 489 USD) per flight connection with

a standard deviation of 135 367. Roughly 75% of these benefits can be attributed to the "useless" adverse-weather fuel reserve that has to be carried in absence of TAF. By dividing the benefits per flight connection through the number of landings, estimates about the benefit per landing were calculated. The point estimate of the average economic benefits of the TAF forecast for the two analyzed airlines is between 73 CHF and 1780 CHF (78 USD and 1906 USD) per landing in Zurich, depending on the duration of the flight. As Fig. 2 shows, the economic benefits grow overproportionally with the duration of the flight. This is mainly due to the fact that on long-haul flights (bigger airplanes and longer distances) the amount of additional fuel carried and the duration this fuel has to be carried are larger than on short-haul flights. Both factors increase the amount of fuel burned, even if the adverse weather fuel reserve carried is not used.

In 2009 a total amount of roughly 110 000 landings on regular services were registered at Zurich Airport (see FSO 2010), of which 60% were generated by domestic airlines. Together, the two airlines analyzed in this study generated more than 95% of all the landings by domestic airlines at Zurich Airport. The overall economic benefits of TAF to Switzerland's domestic airlines at Zurich Airport were therefore obtained by adding up the benefits of all the landings carried out by the two airlines and by additionally extrapolating the missing 5% of landings by other domestic airlines using the average benefits per landing. The resulting point estimate for the total economic benefits of TAF to the domestic airlines at Zurich Airport comes to 14 million CHF (15 million USD) per year.

The results obtained are based on costs estimated by the airlines involved in the study.[6] To take into account the uncertainty associated with these subjective

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[5] 1 USD (U.S. dollars) = 0.934 CHF (Swiss francs) (average exchange rate 2012).

[6] The airlines estimated the additional fuel reserve that has to be carried as well as the additional fuel burned to carry the fuel reserve depending on the aircraft type and the flight duration. Moreover, they estimated the cost of a deviation based on the aircraft type.
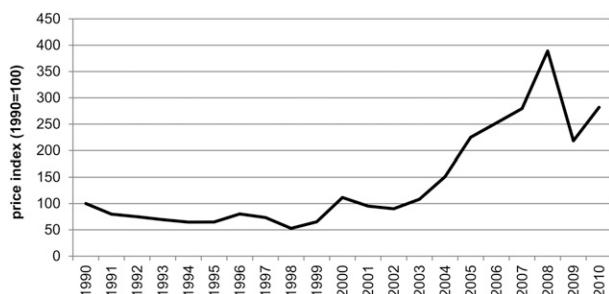
FIG. 3. Index of prices (1990 = 100) for ''Jet Fuel A1'' between 1990 and 2010 (International Energy Agency; www.iea.org).

estimations, a minimum and a maximum scenario were additionally computed, based on the benefit-maximizing and benefit-minimizing estimates provided by the airlines. The relative frequencies shown in Table 3 were not changed to compute the scenarios because they were not estimated but calculated from actual weather and forecast verification data. These calculations yield a range of values for the economic benefits to domestic airlines at Zurich Airport of between 11 and 17 million CHF (12 to 18 million USD) per year.

By extrapolating the results to Geneva Airport by using the number of flights,[7] the estimate of the total economic benefits of TAF to Switzerland's domestic airlines at the two main Swiss airports adds up to an amount of between 13 and 21 million CHF (14 to 22 million USD) per year. However, this estimate does not account for the different economic and aeronautical conditions at Geneva airport and must therefore be taken with considerable caution. For a more accurate estimate, airport-specific decision models and cost components would have to be developed.

### b. Comparative statistics

Not surprisingly, fuel prices have an important impact on the economic benefits of TAF. Their impact is approximately linear: rising (falling) fuel prices in the model lead to a rise (fall) in the economic benefits of the same magnitude. This makes the results presented above very sensitive to changes in fuel prices. Jet fuel prices have been very volatile in the last few years (see Fig. 3).

The impact of TAF quality on the economic benefits is more complex than the impact of fuel prices. To analyze the impact of quality, forecasts have to be split into ''too optimistic'' and ''too pessimistic'' forecasts. A TAF is

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[7] In 2009 a total amount of roughly 59 000 landings on regular services were registered at Geneva Airport (see FSO 2010), of which 40% were generated by domestic airlines. However, fewer long-haul flights are operated through the Geneva airport, a fact which has to be taken into consideration.

TABLE 4. Hypothetical relative change in the benefits from TAF with additional too optimistic forecasts.

| Relative frequency of **too optimistic** forecasts (F21) | 5% | 7% | 8% | 10% | 11% | 13% |
|---|---|---|---|---|---|---|
| Benefits from TAF relative to today's benefits | 100% | 104% | 107% | 111% | 114% | 118% |

too optimistic if the forecasted weather condition was good but the observed weather was adverse. On the other hand, a too pessimistic forecast occurs if the forecasted condition was adverse but the observed condition was good. To assess the effect of the forecast quality on the economic benefits, the model was computed with changed (hypothetical) forecast qualities, which led to the following results:

1) More too pessimistic forecasts lead to smaller benefits from TAF.
2) More too optimistic forecasts lead to higher benefits from TAF.
3) The effect of the too pessimistic forecasts is stronger than the effect of the too optimistic forecasts.

Tables 4 and 5 show the results of the simulation in detail.

The relative frequencies of too optimistic forecasts were changed by adding more incorrect good forecasts until all the forecasts were good. The maximum possible relative frequency of too optimistic forecasts is naturally given by the relative frequency of actual adverse weather conditions at Zurich Airport (see Table 3). An analogous procedure was used to simulate more too pessimistic forecasts. The maximum possible relative frequency of too pessimistic forecasts is given by the relative frequency of actual good weather conditions at Zurich Airport.

If the forecasts were often more adverse than the actual weather conditions, then the airlines would protect against this too often by carrying additional fuel and therefore they would increase their expenses without reducing any losses. Even if the overall protection costs are higher than the expected losses, airlines cannot reduce their protection costs significantly, as they are required by regulations to take action in the case of

TABLE 5. Hypothetical relative change in the benefits from TAF with additional too pessimistic forecasts.

| Relative frequency of too pessimistic forecasts (F12) | 13% | 28% | 42% | 57% | 72% | 87% |
|---|---|---|---|---|---|---|
| Benefits from TAF relative to today's benefits | 100% | 85% | 70% | 55% | 40% | 26% |

adverse TAF forecasts, even if the forecasts are of bad quality.[8] The results of the simulation (see Table 4) confirm that hypothesis.

In the case of too optimistic forecasts, however, the airlines can decide to carry additional fuel anyway, even if the forecast is good. If the expected losses are much larger than the costs of protection, the airlines would possibly carry extra fuel all the time, regardless of the forecast. The results depicted in Table 5 suggest that the expected losses are not big compared to the protection costs. However, the results from Table 5 have to be taken with considerable caution because the expected losses caused by the deviation of aircraft not carrying an additional fuel reserve in adverse weather conditions could rise dramatically with falling forecast quality. Under the present conditions, deviations are very unlikely, as probabilities $q$ and $p$ show (see section 3). According to the experts interviewed during the study, this is mainly due to the fact that air traffic control is able to handle aircraft with inadequate fuel reserves by giving them landing permission with a higher priority. In a hypothetical situation with more incorrect good forecasts, more aircraft would find themselves without adequate fuel reserves at the same time, which means that handling would become more difficult, and the probability of deviations would rise. Based on the available data and the explorative interviews carried out during this study, a relationship between the probability of a deviation and the forecast quality is probable but not quantifiable. Hence, this relationship could not be included in the model.

## 5. Other benefits of meteorology in the aviation sector

The research presented in this paper was conducted as part of a broad study concerning the benefits to the national economy of meteorological services in the Swiss transport sector (see Bade et al. 2011). In the field of air transport, interviews with the most important stakeholders and users of meteorological services (e.g., airline pilots and managers, flight dispatchers, Swiss air traffic control, airfield maintenance, airport authority, Swiss Accident Investigation Board) were carried out. The interviews were explorative and lasted between one and two hours. A set of questions was distributed in written form before the interviews to structure the conversation. The questions addressed the following general topics: Processes and internal organization, the influence of weather on the daily business, the use of meteorological information, and the benefit of meteorological information (e.g., in terms of costs, output or damage reduction). The detailed formulation was adapted to the interviewed person. In most cases information about actual figures was also asked. The interviewees often provided ad hoc guesses and added more accurate information after the interview. Sometimes the interviewees had prepared themselves with the questions provided in advance and answered with educated guesses or in some cases even with accurate figures. Overall, the compliance and motivation of the interviewees was very good.

The interviews revealed potentially high economic benefits from the use of meteorological information. The main results can be summarized as follows:

- Airlines reduce costs by selecting the optimal flight route and by handling weather-related irregularities such as deviations and cancellations more efficiently. Furthermore, airlines reduce operational delay costs (e.g., passenger compensation costs) as well as strategic delay costs caused by additional time buffers in flight plans.
- Airport operators reduce the costs of weather-related problems, particularly during the winter. The benefits therefore arise from the possibility of better planning the employment of staff and material for snow-clearance activities. Without adequate meteorological information more resources (people and machines) must be kept on standby and more precautionary measures must be taken in advance. These effects are important for Swiss airports, particularly for Zurich Airport, as heavy snowfall and ice must be expected during every winter.[9]
- With reliable meteorological information, air traffic control authorities are able to maximize the average capacity of the air space. This is done by minimizing the temporary capacity reductions or closures of parts of the air space, which can be achieved if the exact time and extent of weather-related issues are known in advance.
- Moreover, the use of meteorological information leads to a generally higher level of safety in air transport,

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[8] Even in the very hypothetical case, when the forecasts are always adverse regardless of the actual weather, the economic benefit from TAF is not zero. This is because the regulations require airlines to carry additional fuel to reach **two** alternative airports instead of one if no TAF is available (see section 2).

[9] On the long-term average (reference period 1961–90) Zurich Airport records snowfall during 19.9 days yr$^{-1}$, the maximum temperature is below 0°C during 22.6 days yr$^{-1}$, and the minimum temperature is below 0°C during 114.8 days yr$^{-1}$ (climatological standard normals computed by MeteoSwiss).

potentially leading to fewer injuries or casualties. However, because accidents are infrequent and the cause often not attributable to a single effect, no quantifiable results were obtained from the interviews.

The interviews showed that meteorological information is very important for the safety and profitability of the aviation industry. However, the interviews also showed that the evaluation of the economic benefits of meteorological information is often very complex and laborious and that in most cases it is not possible to separate the contribution of meteorological information to safety and profitability from other contributions like organizational measures. Nevertheless, the detailed evaluation of the TAF carried out has shown that in some cases it is possible to quantify the economic benefits of meteorological information in terms of isolated aspects and simplified models. The study of such isolated aspects gives an idea of the order of magnitude of the minimum economic benefits that can be expected.

## 6. Conclusions

This paper has demonstrated that the use of TAF at Zurich Airport generates significant economic benefits for the airlines. Using a decision-making model the economic benefits were estimated at between 73 and 1780 CHF (78 to 1906 USD) per landing, depending on the duration of the flight. This leads to a cumulative economic benefit for all domestic airlines at Zurich Airport of between 11 and 17 million CHF (12 to 18 million USD) per year. The total economic benefits of TAF to Switzerland's domestic airlines at the two main Swiss airports (Zurich and Geneva) were estimated at between 13 and 21 million CHF per year (14 to 22 million USD) by extrapolating the results of Zurich based on the number of flights. All results are, however, very sensitive to changing fuel prices, as fuel is the most important cost factor in the context of this study.

It has to be stressed, that the overall benefits of meteorological services to the airlines and to the aviation industry as a whole are probably higher than the quantifiable economic benefits from the use of TAF calculated in this study. This is supported not only by the qualitative results from interviews (see section 5), but also by the findings in Leviäkangas and Hautala (2009) as well as by studies on the influence of meteorological information on delay costs in the U.S. air transport sector (see Treinish and Praino 2005; Klein et al. 2009; Allan et al. 2001), which revealed substantial economic benefits in the field of air transport.

Finally, it must be stressed that the methodology used in this paper is in principle neither limited to TAF nor to a specific airport infrastructure. It can be used as a starting point for analyzing other airports and other meteorological products to amplify the specific knowledge about the economic benefits of meteorological services. In the authors' view, there is one main lesson from the work presented in this paper that can be useful for similar studies: Companies know quite well where and why they use meteorological information; however, often they cannot quantify the benefits related to that use. Therefore, one should not rely on surveys or interviews to directly learn about the monetary benefits of meteorological information. Instead, explorative interviews should be conducted first to understand the decision making process within the companies. Then, based on that knowledge, a decision-making model should be built, validated, and used to estimate the monetary benefits.

Last but not least, attention should also be paid to the current discussions and publications related to the economic benefits of meteorological service provision supported by the World Meteorological Organization (see WMO 2003 and WMO 2007).

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