Economic Impact Assessment of Regulatory Changes: A Case Study of a Proposed New ICAO Standard for Contaminated Runways

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Abstract: The literature on economic impact assessments (EIA) of regulatory changes in the transport sector is scarce. This study examines how a change in the regulatory framework for air transport could affect transport costs. The case in question is the International Civil Aviation Organization (ICAO) State letter AN 4/1.2.26-16/19 that proposed to set a higher minimum friction on runways operated during slippery conditions. This may affect operations, particularly in the northern hemisphere. Four Norwegian airports that operate under severe winter conditions are used as examples. Sudden cancellations or transfers to another airport give additional costs per passenger, ranging from NOK 750 to NOK 5600 per return flight. If these results are generalized to all affected flights in Norway, the annual estimate is NOK 400–450 million. These numbers may not seem exorbitant. However, the costs are mainly borne by a limited number of airports. Some of them may have to close during winter, with severe consequences for local communities. This study illustrates how effects of a proposed regulatory change may be assessed in order to aid the decision-making process. The impacts on aviation safety are not considered. Data on aircraft accidents in Norway do not indicate significant effects from the proposed regulatory change.

Keywords: aviation; economic impact assessment; cost benefit analysis; regulatory changes; runways

1. Introduction

1.1. Background and Research Problem

To ensure that civil aviation operations meet global norms, The International Civil Aviation Organization (ICAO) develops standards and policies for their 193 member states. This study examines how a change in the global regulatory framework for air transport could affect transport costs along with accidents and environmental costs. We assess this issue by means of a cost–benefit analysis (CBA) framework. The regulatory case in question is the ICAO State letter AN 4/1.2.26-16/19 [1], where it is proposed to set a higher minimum friction on runways operated during slippery conditions, mainly from contamination with ice and snow. The main contribution of the paper is to show how we can assess the systemic economic effects from a global change in regulations concerning an important part of the transport market.

This proposed change is likely to affect aircraft operations under specific weather conditions. Without any countermeasures, this may entail a larger number of cancelled or diverted flights because of reduced aircraft maximum landing weight (MLW) and maximum take-off weight (MTOW). The economic impacts of delays and cancellations will depend upon the weather conditions (in terms of duration and severity) and the affected traffic volumes. This may affect air transport operations,

particularly in the northern hemisphere. Four Norwegian airports that operate under severe winter conditions are used as examples.

The main research question is: Given an estimated number of aircraft movements that are affected by the ICAO State letter, what will the economic consequences be for passengers and airlines on four selected airports with contaminated runways during the winter season?

Changes in transport costs are a proxy for the productivity changes that can be expected if regulatory changes affect the performance of the transport network. In addition, changes in accident costs and environmental costs should be taken into account when the overall economic and social impacts of the regulatory change are studied, in order to assess the overall sustainability.

At the outset, it is likely that the changes in ICAO regulations could result in both increased delay stochasticity and the need for seasonal aircraft weight restrictions. In order to account for this, we have used an approach with scenario building where the scenarios differ between planned and unforeseen cancellations or diversions.

Reference to the full study that this article is based upon is given in Bråthen et al. [2].

1.2. Runway Friction and Safety

The aircraft braking performance depends on the friction between the tire and the runway, among other factors like the aircraft weight and the weather conditions. An oil spill contaminates the runway and reduces the friction. The same is for ice, slush, and snow covering the runway (or a part of the runway) and is referred to as "winter contamination". Whenever the runway, or a part of the runway, are contaminated in any way, the aerodrome operators assess the surface, and formulate a runway condition report (RCR). From this RCR, a runway condition code (RWYCC) and a description of the runway surface are developed and reported to the flight crew, who makes necessary adjustments accordingly [3]. The RWYCC consists of a scale from 0 to 6, where 6 being dry surface (no report needed) and 0 is "less than poor" where the friction is minimal to non-existing [4]. Before landing on contaminated runways, the pilots assess the conditions (wind, temperature, runway conditions) and calculate the required braking distance. After the landing, the crew reports their perceived "Runway Braking Action" (the braking friction) to the aerodrome operator, to confirm or dismiss their evaluation of the runway (see Table 1).

Table 1. Runway condition matrix, current status. Source: ICAO [4].

Assessment Criteria		Downgrade Assessment Criteria	
Runway Condition Code (RWYCC)	**Runway Surface Description**	**Description of Braking Deceleration and Direction Control**	**Runway Braking Action (Pilot Report)**
6	- Dry	n/a	n/a
5	- Frost - Wet (visible dampness or water, depth ≤ 3 mm) - Slush, dry snow or wet snow (depth ≤ 3 mm)	Braking deceleration is normal for the wheel braking effort applied and direction control is normal	Good
4	- Compacted snow (−15 °C and lower outside air temperature)	Braking deceleration or directional control is between good and medium	Good to medium

Table 1. *Cont.*

Assessment Criteria		Downgrade Assessment Criteria	
Runway Condition Code (RWYCC)	**Runway Surface Description**	**Description of Braking Deceleration and Direction Control**	**Runway Braking Action (Pilot Report)**
3	- Wet ("slippery wet runway") - Dry snow or wet snow (any depth) on top of compacted snow - Dry snow or wet snow (depth ≤ 3 mm) - Compacted snow (higher than −15 °C outside air temperature)	Braking deceleration is noticeably reduced for the wheel braking effort applied or directional control is noticeably reduced	Medium
2	- Standing water or slush (depth ≥ 3 mm)	Braking deceleration or directional control is between medium and poor	Medium to poor
1	- Ice	Braking deceleration is significantly reduced for the wheel braking effort applied or directional control is significantly reduced	Poor
0	- Wet ice - Water on top of compacted snow - Dry snow or wet snow on top of ice	Braking deceleration is minimal to non-existent for the wheel braking effort applied or directional control is uncertain	Less than poor

Prior to the originally proposed changes in allowed minimum friction on contaminated runways [1], a winter-contaminated runway could score 4 or 5 on the runway condition code (RWYCC) if some compensatory safety measures have been implemented (warm or wet sand on the runway). According to the latest proposed changes, it is not possible to score more than 3 on the RWYCC if the runway is contaminated with ice, slush, or snow. A RWYCC of 3 or less leads to landing restrictions like restrictions on MLW/MTOW as described above. In turn, the proposed changes could lead to reduced regularity, especially on the short track network and in Northern Norway.

Counting for almost 50% of all aviation accidents, runway safety is the main accident category and is considered a global safety priority [4]. Runway safety includes runway excursions, runway incursions, undershoot (land short of a runway), overshoot (land or take-off too far along a runway), tail strike and hard landings. Within runway safety, runway excursions (RE) is defined as a high-risk category. Runway excursions is defined as a veer off of overrun of the runway surface, which can happen during landing or take-off. Globally, around 200 overruns were reported in the period of 1995–2005, and many of these cases were related to inadequate runway friction [5]. A theme report on winter operations in Norway for the period of 1999 to 2010 shows 30 reports of aviation accidents/incidents related to contaminated runways during winter operations [6]. Nine of these were classified as serious incidents, giving an average of one each year. In all cases, there was little or no damage to personnel or aircraft, and hence the benefits of the proposed regulations may not be characterized as significant for Norway where adverse weather conditions occurs quite frequently. A common aspect for most of these accidents was a significant difference between the measured friction

and the crew's perception of the friction. Hence, they may be considered as partly an ambiguous or insufficient information issue.

During the last 10 years, ICAO has published an annual global safety report containing information about safety performance indicators, accident risk factors, and the global accident rate (for scheduled commercial operations of aircrafts of a maximum take-off weight (MTOW) of over 5700 kg). The reports show that the accident rate has varied between 2.1 and 4.6 accidents per million departures in the period between 2005 and 2018 [4,7,8]. With an average flight distance of 200–300 miles and average aircraft size of 100 passengers, this corresponds to 20–30 billion passenger miles, giving an accident rate of between 0.07 and 0.23 per billion passenger miles. To put this in perspective, looking at a study by Savage [9] on the fatality risk across transport modes in the US from 2000 to 2009, the fatality risk per billion passenger miles in a car is 7.38 and on a commercial flight it is 0.07. The flight risk numbers include the risk originating from slippery runways.

2. The Airports Covered in This Study

2.1. Airport Descriptions

Several airports in Norway may to a varying extent be affected by ICAOs suggested change in regulations. This study focuses on four of these airports, which are severely exposed to snow and ice. They are all located in Finnmark County which is Norway's northernmost county. The choice of airports, namely two regional airports with a >2000 m tarmac runway and two local short track airports with a >800 m tarmac runway, makes the method and the results analytically transferrable to other countries with similar winter conditions and airport structure. However airports and communities elsewhere have different characteristics that must be taken into account.

Kirkenes Airport (KKN) is a regional airport that serves Kirkenes town. It has a single 2115 × 45 m (6939 × 148 ft.) runway. SAS and Norwegian operate Boeing 737 (B737)-services to Oslo Airport (OSL). The traffic is partly generated by KKNs function as a hub for regional services to other airports in Finnmark, served by Bombardier Dash-8/100s or /200s and a Dash-8/300 service to Tromsö. There are also summer charter flights to Central Europe to bring tourists to the Hurtigruten (a coastal sea express) cruises. The airport had 258,323 passengers arrived and departed in 2017. This number has not significantly changed for the subsequent years. The same is the case for the other airports in the study.

Alta Airport (ALF) is a regional airport serving Alta town. It has a single, 2253 m (7392 ft.) runway. It served 345,223 passengers in 2017 by means of B737s to Oslo and Dash-8/100 or /200 for regional services.

Honningsvåg Airport (HVG) is a short-track regional airport serving Honningsvåg town. It has an 880 × 30 m (2887 × 98 ft.) runway. Flights are operated to other local communities in Finnmark with Bombardier Dash-8/100 or /200 aircraft. The airport handled 13,133 passengers in 2017.

Vadsø Airport (VDS) is a short-track regional airport in Vadsø town. It handled 62,485 passengers in 2017. The runway is 997 m (3271 ft.) long. Dash-8/100 or /200 aircraft are used between other communities in Finnmark. Vadsø has the county administration for Finnmark, and the city will maintain important administrative functions for the merged Troms and Finnmark counties from 2020 on.

Other airports, like Svalbard/Longyearbyen, Kristiansand/Kjevik (regional airports), and Harstad/Narvik, Sogndal, Mosjøen, Svolvær, and Berlevåg (local short-track airports) are affected to a varying extent as well. This study assesses the two most exposed airports in each of these airport groups.

As mentioned above, Kirkenes (KKN) and Alta (ALF) airports are served by Boeing 737-700 and 737-800 in addition to Dash-8/100 or /200, as well as Dash-8/300 for KKN. The nearest relevant airports for these are Lakselv (LKL) that has a longer runway and no contamination issues. The two short-track

airports Honningsvåg (HVG) and Vadsø (VDS) are supposed to use Lakselv (LKL) and Vardø (VAW) as alternative non- or less contaminated airports, respectively.

Figure 1 shows these airports along with the airports' catchment areas, and the driving time and distance between these airports and the nearest alternative airports Lakselv (LKL) and Vardø (VAW).
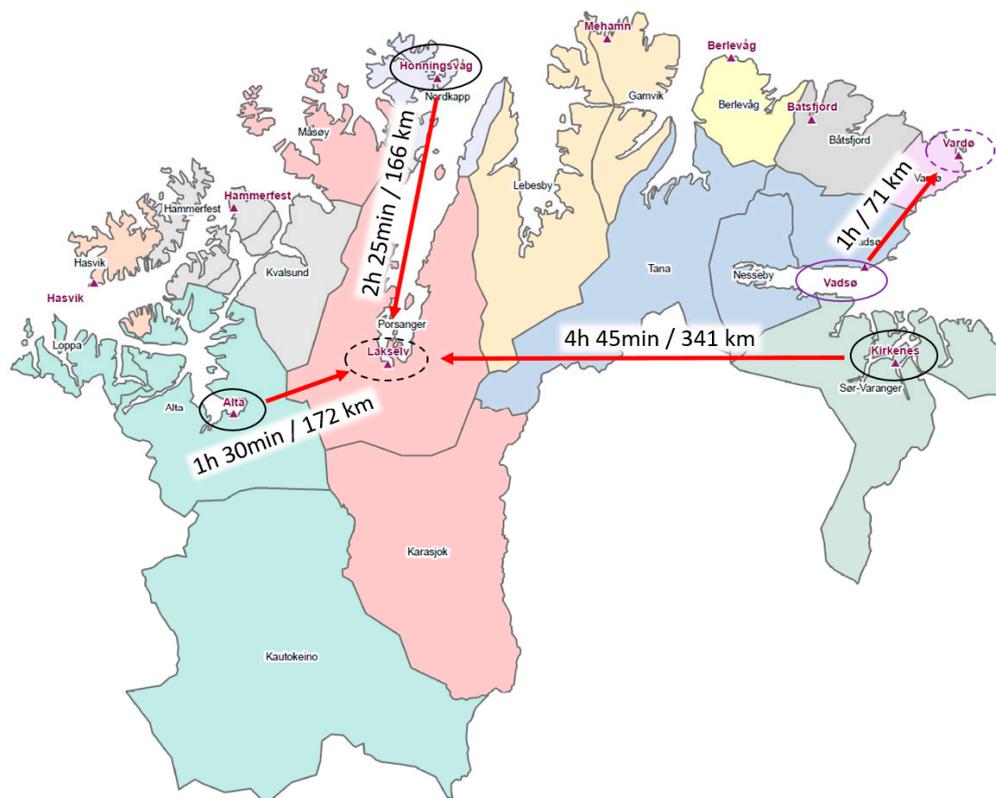

Figure 1. Airports included in the study (dotted ellipsoids show alternative airports).

2.2. Affected Landings

The Norwegian University of Science and Technology [10] has calculated the scope of affected flights and number of passengers from the proposed change in regulations. The calculations of the number of affected flights are based on reported landings in the period 2011 to 2016 and data on contamination and wind. Table 2 below summarizes the number and percentage of landings and affected landings. Affected landings are those where cancellations, diversions, or reduced payload will result when we compared with the flights' unrestricted payload.

Table 2. Impacts on landings and number of passengers, Kirkenes (KKN), Alta (ALF), Honningsvåg (HVG), and Vadsø (VDS). Winter 2016-17.

Factor	Number of Landings (% in Brackets)				Passengers Arrived, All			
	KKN	**ALF**	**HVG**	**VDS**	**KKN**	**ALF**	**HVG**	**VDS**
Affected landings	108 (34)	19 (6)	75 (19)	197 (16)	11,200	2700	950	4100
Other landings	211 (66)	293 (94)	312 (81)	1057 (84)	21,800	42,700	4050	21,500
All landings	319 (100)	312 (100)	387 (100)	1254 (100)	33,000	45,400	5000	25,600

The first column under 'number of landings' in Table 2 shows the impacts on regularity for Kirkenes Airport (KKN). Around one-third of the landings during winter are likely to become affected by ICAO's proposed new regulations. The second column shows the impacts on regularity for Alta Airport (ALF). Around 6% of the landings are likely to become affected by the proposed regulatory change. The third column shows the impacts on regularity for Honningsvåg Airport (HVG). Nineteen percent of the landings are likely to become affected by the proposed change in runway friction coefficient. The fourth column shows the impacts on regularity for Vadsø Airport (VDS) where 16% of the landings are likely to become affected by the proposed regulatory change. The last four columns show the total number of passengers arrived for each of the four airports included in the analysis.

3. Literature Review

The purpose of the review is to identify the main benefit and cost elements, the results of the studies, and whether or not these proposed safety regulations lead to consumer behavioral change. Cost–benefit analysis (CBA) provides a framework for evaluating and ranking projects or policies. For safety measures, and particularly in aviation, governments and regulators are often reductant to not implement measures for known accident risks despite their possible cost inefficiency, because the outcome is potentially disastrous.

Table 3 contains an overview of the most relevant papers applying CBA on regulatory safety changes/health-related cases, and where the impacts of different safety measures are calculated.

Table 3. Cost–benefit analysis (CBA) of safety case regulations.

Sector	Author (Year)	Method	Factors	Main Benefits	Main Cost Elements	Results	Behavioral Changes
Aviation	Stewart and Mueller [11]	CBA	Hardened cockpit doors and Federal Air Marshall Service (FAMS)	Prevent terrorism/hijacks, and save lives	Investment (cockpit door) and operation costs (FAMS)	Hardened cockpit doors: Net Present Value (NPV > 0, hence economically profitable. FAMS: NPV < 0, hence not profitable.	Not mentioned (related to these measures)
Aviation	Stewart and Mueller [12]	CBA (with risk assessment)	Install physical secondary barriers (IPSB), Federal Air Marshall Service (FAMS) and the Federal Flight Deck Officer (FFDO) Program	Prevent terrorism/hijacks, and save lives	Investment (physical barriers) and operation costs (FAMS and FFDO)	IPSB: NPV > 0 if 1 successful attack is avoided every 200 years. FFDO: NPV > 0 if 1 attack avoided each 50 years FAMS: NPV > 0 if 2 attacks avoided each year	Not mentioned (related to these measures)
Railway	Percoco et al. [13]	CBA	Introduction of automated protection systems for monitoring traffic (to increase safety and efficiency)	Avoided investment- and operating costs (other measures), reduce car operating costs and reduction of accidents	Investment- and operational costs	3 out of 4 case studies with NPV > 0.	Not mentioned (and not expected)
Railway	Evans [14]	CBA	Automatic train protection systems; ATP, Train Protection and Warning System (TPWS) and Positive Train Control (PTC)	Lives saved (train collisions and personal accidents)	Investment costs (installation of systems)	Assessed measures with NPV < 0. 2 out of 3 systems up for implementation regardless of these results.	Not mentioned (and not expected)
Railway	Islam et al. [15]	CBA	Identify effective mitigation techniques for rail freight derailments.	Prevent injuries and death, damage on cargo, infrastructure, and environment	Investment, reinvestment and maintenance costs	6 out of 8 sets of derailment mitigations with NPV > 0.	Not mentioned (and not expected)

Table 3. *Cont.*

Sector	Author (Year)	Method	Factors	Main Benefits	Main Cost Elements	Results	Behavioral Changes
Road transport	Elvik [16]	CBA	The effect on road safety in Norway and Sweden from prioritizing effective safety measures	Injuries prevented and lives saved	Investment costs, cost of reinforce measures	If solely implementing policies with NPV > 0, up to 50–60% of current accident fatalities could be prevented.	Not mentioned (some might lead to behavioral change)
Road transport	Cafiso and D'Agostino [17]	CBA	Road safety barriers	Crash savings: injuries and fatalities	Investment costs, retrofitting new road barriers	NPV > 0	Not mentioned (and not expected)
Road transport	Medina-Flintsch et al. [18]	CBA	Lane departure warning (LDW) and roll stability control (RSC) in commercial vehicles	Safety benefits for carriers and society (e.g., injuries)	Carriers investment cost, training, and all operational costs	NPV > 0	Not mentioned (and not expected)
Road transport	Camden et al. [19]	CBA	Automatic emergency braking (AEB), lane departure warning (LDW) and video-based onboard safety monitoring (OSM) for large trucks	Reduce crashes, prevent injuries, and save lives	Investment costs (for new and old trucks), training of drivers	3 out of 3 systems with NPV > 0 for new trucks, 2 out of 3 with NPV > 0 for retrofitting old trucks (the 3rd only with low cost and high efficiency rate)	Not mentioned (and not expected)
Road transport	Daniels et al. [20]	CBA	29 road safety measures, within infrastructure, legislation, enforcement, education, post-crash treatment and vehicle equipment	Prevent crashes and injuries	Investment costs, and operational costs	25 out of 29 measures with NPV > 0 (according to their best estimate)	Not mentioned (but some measures might affect behavior)

Table 3. *Cont.*

Sector	Author (Year)	Method	Factors	Main Benefits	Main Cost Elements	Results	Behavioral Changes
Road transport	Odeck and Engebretsen [21]	CBA	Impact of Norwegian government implement height limit of heavy vehicles to 4.0m (suggested in EU's Directive 96/53/EC).	Prevention of accidents and reduced tunnel repair costs	Accidents (increased no. of vehicles), travel costs, road operating costs, environment, and administration costs (enforcing regulation)	Not profitable, NPV < 0 (authors advice government not to implement this measure)	Smaller trucks lead to more trucks and more driven km
Road transport/environment	Zhou et al. [22]	CBA	Yellow-label vehicles (YLV), light-duty vehicles with high emissions, scrappage subsidy policy	Health benefits (better air quality)	Government scrappage subsidies	NPV > 0	Accelerate the process of scrapping YLV
Road transport/environment	Liu et al. [23]	CBA	Emission reduction measures: scrap MC, scrap yellow-label vehicles (YLV), reduce mobility for private cars and MC, improve fuel quality and update emission standards	Health benefits (better air quality)	Government subsidies and investments in infrastructure	Indications of that all five measures with NPV > 0	Not mentioned (but expected)

We have found the most relevant papers within road transport, railway, and aviation. There are some papers within health care, environmental studies, and construction as well, but we have limited ourselves to papers that deals with transportation. A common denominator is that we have not come across papers that deal with global regulatory changes. The proposed ICAO regulation has a global scope.

Furthermore, there is a number of papers both criticizing and supporting the applicability of CBA for policy changes regarding safety measures in different sectors, and some provide a framework for decision makers to more easily being able to assess the costs and benefits before implementing changes. We have chosen to cite some of them below, even though they do not provide CBA calculations.

Elvik [24] discuss the applicability of CBA for road safety measures. He states that CBA had been applied for assessing road safety measures for 25 years (prior to 2001) and has been criticized for just as long. To answer to its critics, Elvik [24] provided a framework where he used the criticism of the applicability of CBA for road safety measures to create steps for assessing this through the decision-making process. According to Elvik [24], the five steps are to (1) assess the basic principles of CBA, (2) determine the type of issue to be decided, (3) evaluate the suitability of the given objective for being assessed with CBA, (4) determine if suitable policy programs can be developed, and (5) evaluate the consequences of policy programs, especially with respect to the possibility of doing monetary valuation. By going through these steps, the decision maker either finds out that the program is unsuitable for CBA or decides to adapt CBA to evaluate the consequences of the analyzed policy or program.

Other approaches to, or modifications of CBA for safety regulations include Elvik's [25] analysis of The Norwegian Public Roads Administrations (NPRA) system of road safety management by objectives. For the National Transport Plan (NTP) period of 2010–2019, the NPRA's main objective was to reduce the number of road accident fatalities and serious injuries by 50% within 2020. According to Elvik [25], the system is a way of motivating cost-efficient implementation of safety measures. Based on an analysis of a large number of safety measures introduced to help accomplish this overall objective, Elvik [25] found that if all cost-effective measures were implemented, the main objective would still not be met. Elvik [25] concluded there were too many targets, and some of the safety measures were either outside of the Norwegian government's jurisdiction, or they required changes in legislation, or they were too ambitious. The system was not implemented, mainly because a goal of anything but zero fatalities lacked the support of politicians.

Hopkins [26] discusses some problems with standard CBA for assessing safety case regulations, and points to a regulatory change in offshore petroleum production as a result of The Gulf of Mexico oil spill of 2010. The Presidential Order (PO) [27] stating that regulatory changes are required to be assessed based on CBA, is not entirely rigid according to Hopkins [26]. For rare events like major accidents where the consequences are challenging to quantify, the PO opens for arguments based on qualitative assessments. Hopkins [26] points to three ways of overcoming difficulties with standard CBA for deciding safety regulations. The first is "the polluter pays principle", where the measures are not dependent on the benefits of the absence of pollution. The second is the society's perception of the higher value of lives lost in catastrophic accidents compared to individual lives lost. The third is the criminal act of companies' neglected obligation to prevent accidents, and this being treated as a crime. According to Hopkins [26], these principles could be a way of assessing safety case regulatory suggestions. Overall, the analytical approaches in the studies cited above appear to have appropriate applications of the CBA method.

This study applies CBA as an extensively used method for analyzing economic impacts of changes in the transport network, although there are shortcomings and weaknesses connected with almost any method. However, a thorough discussion of these are beyond the scope of this paper. The assessed elements are thoroughly discussed and applied in the transport literature and described in guidelines for economic impact assessment in the transport sector, see e.g., Bråthen et al. [28], Odeck and Engebretsen [21], and The Norwegian Public Roads Administration (Statens vegvesen) [29].

The main contribution of this study to the CBA literature is to show how systemic economic effects from a global change in transport system regulations can be captured through adaptations of rather well-known assessment methods and practices.

4. Theoretical Elements and Inputs

The proposed regulatory change will affect the passengers and the operators in two main ways. Firstly, the passengers are likely to be subject to delays, changes in regularity, and/or increased air fares. Restrictions in maximum take-off weight (MTOW) or maximum landing weight (MLW) affect the payload and possibly the need for downscaling the aircraft size. Smaller aircraft are more costly to operate per passenger km. In many cases, operations will have to cease, and the passengers will have to depart from or land on an adjacent airport, resulting in increased travel costs. In addition, when going by bus/car to/from an adjacent airport, the passengers will also be subjected to an increased probability of being exposed to traffic accidents. Secondly, the operators' revenues will be affected by the number of passengers travelling and the type of aircraft operated. Some passengers will abstain from travelling because of the increase in travel costs.

4.1. Generalized Travel Costs

Figure 2 illustrates the change in consumer surplus (CS) from a general increase in travel costs. The difference in generalized travel costs (time costs + payable travel costs, like fares and shuttle services) together with the deterred traffic (X_0–X_1 in the figure) and the traffic that will use the adjacent airport (X_1), here taken as the best alternative transport is used to calculate the black and crosshatched area. The black area is the loss in consumer surplus for the passengers who will still travel from the adjacent airport even if it is more expensive, while the crosshatched area is the loss for those who will abstain from travelling because of the higher travel costs. The figure shows a composite average. In reality, the black + crosshatched trapezoid are calculated for different market segments, depending on e.g., the passengers' travel purpose and place of visit or residence.
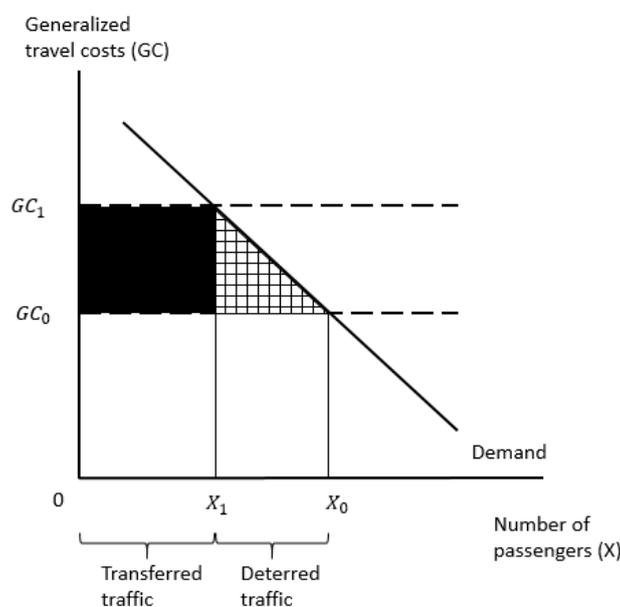

Figure 2. Economic loss for air passengers from increased travel costs.

A general specification of value of the reduction in consumer surplus (CS) discounted over *n* years is (see Equation (1)):

$$N_T = \sum_{i=1}^{40} \frac{X_{1i} + X_{0i}}{2} (GC_1 - GC_0)(1 + r)^i \tag{1}$$

where: N_T = Net present value of the CS loss, here 40 years; X_{1i} = Traffic that will use adjacent airport, year *i*; X_{0i} = Traffic at the existing airport, year *i*; GC_1 = Generalized travel costs by travelling from an adjacent airport; GC_0 = Generalized travel costs by going from the airport that is assessed with respect to possible winter closure or diversion; *r* = Social discount rate (currently 4%).

In this case study, we assess the effects for an average year only, based on annual data for the winter season from 2016/2017. Discounting to net present value can be made by means of traffic forecasts and real growth in factor prices for future years. This can be relevant if assessments of measures like runway extensions are considered as compensatory measures.

However, this framework does not allow for separating between planned and unforeseen delays from changes in runway friction requirements. At the outset, it is likely that the changes in ICAO regulations could result in both increased stochasticity and seasonal MLW restrictions. In order to account for this, we will use an approach where we differ between planned and unforeseen cancellations or diversions, discussed by means of two Figures that build upon Figure 2.

4.2. Passengers' Costs of Changes in Regularity

As an example, a given airport could have a regularity of 98% during winter. The new runway friction requirements could reduce the regularity to 88%. If this had been stochastic events only, we could have considered it as an ordinary regularity issue with a probability of 0.88 for serving a scheduled aircraft movement over the year.

1. In this case however, it is convenient to use two main kinds of impacts; (1) planned and (2) unpredictable accessibility to scheduled aircraft capacity with reduced MLW. Hence, three types of situations may occur from stricter friction requirements: Scheduled reduced aircraft capacity due to runway friction conditions, where the passengers get information well ahead of the departure. Then they are able to reschedule their travel plans in order to use an alternative transport or to do something else. This could be an announced reduction in seat capacity, but with departure according to the schedule, cancellation of specific flights, diversions to an adjacent airport, or a seasonal closure in cases of a severe reduction in winter regularity.
2. A sudden severe reduction in runway friction, which causes a need for immediate abatement plans like alternative surface transport, a full cancellation of the trip, or attempts to use an adjacent airport.
3. An in-between situation of (a) and (b), where a sudden reduction in MLW takes place but the flight is completed according to the schedule but with reduced payload. In this case, a limited number of passengers are affected.

In this study, we have data for about the average number of affected landings, i.e., the average number during the six winter seasons from 2011–2016. Given the new ICAO State letter AN 4/1.2.26-16/19 regulations [1], actions would have to be taken due to lower runway friction mainly with respect to aircraft landing weights and adaptation to wind conditions. In addition, a number of other landings are identified where braking actions reports have been issued. These landings can presumably be made under the new friction regulations, but there are reasons to believe that some of them may become marginal. This category of landings is not further discussed here.

A reduction in regularity will result in a certain number of passengers being affected. As an example, if the traffic is 100,000 during winter and the regularity drops from 98 to 88%, then (100,000/0.98) × 0.88, approximately 90,000 passengers will be served, resulting in a drop of around 10,000 passengers. Ideally, this number must be split into each of the three groups above when we are carrying out the economic impact assessment.

For the passengers that are exposed to a pre-known reduced number of seats available, there are reasons to assume that the economic loss corresponds to the additional costs of using the best alternative transport (i.e., the cheapest alternative when time costs and payable costs are taken into consideration). This could be to travel to/from the nearest airport or by any surface transport mode all the way to the

destination. The passengers for whom the utility of the planned trip is less than the costs of using alternative transport will not travel.

　　Figure 3 illustrates the passenger costs of constrained airport capacity in the case of a temporary airport closure. The distance *c–d* corresponds to the number of passengers that are exposed to a pre-known capacity reduction (situation (a) in the list above) that causes the closure. Using the best alternative transport gives an economic cost *a–d* for the passengers from being offered a more expensive trip. In total, this entails an economic cost for the passengers equal to the area *abcd*. The distance *c–f* corresponds to the number of passengers who abstain from travelling with more expensive alternatives, whereas the distance *f–d* are those who are willing to pay the extra costs and stick to their travel plans by using alternative transport, like e.g. going from an adjacent airport. The slope of the demand curve is fairly well known from recent studies of demand elasticities (to be discussed briefly below), and the costs of the best alternative transport is calculated after some data gathering.
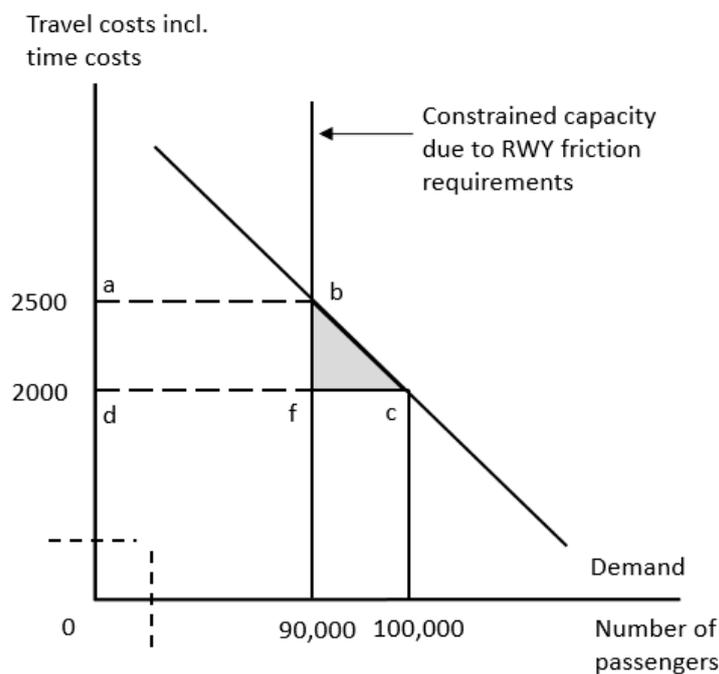

Figure 3. Passenger costs of constrained capacity—planned temporary airport closure.

　　Figure 4 illustrates the costs for the affected 10,000 passengers in our example if the services continue, but with reduced seat capacity for given affected flights. If there is a segment of the market where the change in friction coefficient requirements causes unexpected disruptions in terms of reduced regularity in a more classical sense (situation (b) or (c) in the list above), a higher economic cost *h–d* per affected trip is the likely result. The economic costs for this group of passengers will correspond to the area *hgcd*. The reason that the costs are higher for situation (b) and (c) is mainly due to the higher time costs when unexpected delays and/or disruptions occur. Of this subset, 2000 passengers will abstain from travelling in this example whereas the remaining passengers will use alternative transport.
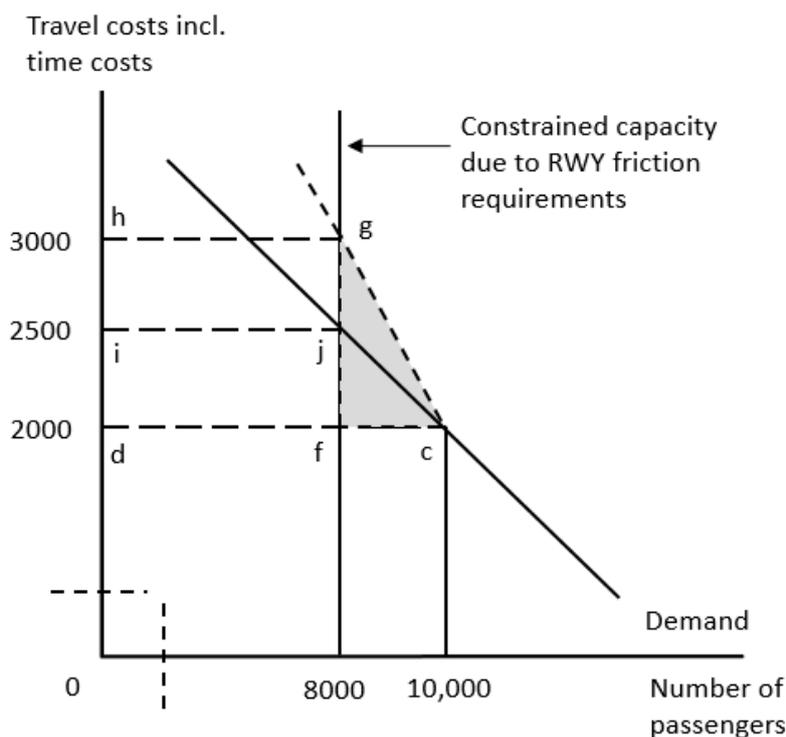
Figure 4. Passenger costs of constrained capacity—stochastic seat capacity reduction.

The kinked demand stems from the fact that a sudden reduction may take place at a time where (a) the trip has started or (b) return trips are affected and the passengers have to get back home. Because of this, the elasticity of demand is highly likely to become reduced, hence the demand curve becomes steeper. The same reasoning can be applied to a planned seat capacity reduction. The additional passenger travel costs will then be lower (area *ijcd)* because the inconveniences of a planned reduction are less. In addition, the elasticity of demand is likely to be on approximately the same level as in the case with a planned temporary closure. In both situations, around 2000 passengers will not travel in this example because of the higher travel costs (deterred passengers). A short note on the demand elasticities needs to be added. The number of studies that addresses this type of air traffic, namely lifeline services between sparsely populated areas, is scarce. A number of studies addresses air transport elasticities (see Bhadra and Kee [30] (US market), Brons et al. [31] (review), Gillen, Morrison, and Stewart [32] (review), Njegovan [33] (tourism), Kopsch [34] (Swedish domestic), Mumbower et al. [35], (flight level, larger routes), and Morlotti et al. [36] (low-cost routes)). The elasticity varies with travel purpose (business travels are less elastic), travel distance (long-haul routes are less elastic), and competing transport modes (short/medium haul routes with rail or road transport as alternatives are more elastic). The literature gives elasticity estimates of between −0.2 and −1.5, some even higher, in particular for low-cost short/medium haul routes with competing transport modes.

For the economic impact assessment, it will be necessary to quantify the changes in predictable and sudden changes in the air transport services as consequences of a change in runway friction regulations. This is carried out by building upon the number of affected landings and the total number of landings during the winter season. If a planned seasonal closure is made, then the passengers throughout the entire season will become affected. The costs are calculated as illustrated in Figure 2. The same procedure is followed if we assume that smaller aircraft with somewhat higher fares can be used instead of having to close because of poor regularity with larger aircraft. Then, the change in travel costs are related to the higher airfares only, assuming that flight times remain unchanged.

Furthermore, we assume that the affected landings divert the corresponding number of passengers to the nearest relevant airport, and that the corresponding departure is made from this same airport. The costs are calculated as illustrated in Figure 4 above.

A couple of comments need to be made with respect to the value of time (VOT) and the consumer surplus/travel costs calculations. Firstly, there are reasons to expect that the value of time is higher when delays happen without notice. We are not aware of any studies that deal with the value of delays in air transport. One has to take into account that in many cases, delays may entail new equilibria in a transport network (e.g., selection of alternative routes), and perhaps with only relatively marginal inconveniences in denser transport networks, like in urban areas. However, when alternative solutions are expensive, time-consuming, and perhaps even non-existent and disruptions happen without notice, significant inconveniences are a likely result. Extra time costs of delays are supported in e.g., Jenelius, Mattsson and Levinson [37]. A recent study of Norwegian values of time and related factors [38] indicates a twofold value of time of avoiding such situations. A study by Cook and Tanner [39] suggest a non-linear VOT function with a steep increase between 30 and 90 min, with values for a 60–90 min delay approximately equal to a twofold VOT value. We have applied a doubling of the value of time in a scenario where we assume that the affected landings happen without notice, in order to include the inconvenience for the passengers per hour of extra waiting and time under way to the airport. Arguably, we have not doubled the VOT for ordinary aircraft on-board time or shuttle time at destination. Henceforth, our calculated economic impacts may be on the lower side.

Secondly, we would like to add that both a seasonal closure (transferring passengers to the nearest airport leading to presumably higher departure frequency there), and smaller aircraft used at the original airport with higher airfares but also with higher departure frequency are likely to result in some benefits from higher frequencies. These benefits are not taken into account. Departures tend to cluster around peak hours and hence without a uniform distribution during the day, we do not believe that significant additional benefits occur as long as necessary capacity is offered.

Ideally, we would like to gain a thorough understanding of how the market actually responds to a sudden cancellation, and what the economic costs are likely to be. This reaction could mainly be one out of three:

- Rebook to a later departure.
- Travel with the best alternative option.
- Cancel the trip or postpone it for a longer period.

It turned out to be demanding to get a sufficiently high level of precision with respect to how the market will respond. Instead, we have assumed that the passengers will use an alternative mode in case of cancellations or sudden reductions in MLW. In case of poor regularity leading to expected seasonal closures, we have assumed that the passengers transfer to the nearest airport. Some will abstain from travelling, as discussed above.

4.3. The Scenarios

As discussed above, the data do not allow for any differentiation between the types of possible actions for the affected landings. These actions could span from reduced MLW in terms of reduced passengers and/or luggage, cancellation, or diversion to an adjacent airport. In some cases, the number of affected landings could give a regularity of much less than 90%. This is likely to cause a seasonal closure of the airport or use of smaller aircraft where practically possible. Based on point (a)–(c) above, we have assessed the following scenarios for airports with expected regularity of less than 90%, for all affected landings:

- Scenario P1: The airport remains open during winter, but with smaller aircraft that can serve under the new ICAO friction regulations; 20% fare increase.
- Scenario P2: As scenario P1, but with 50% fare increase.
- Scenario P3: The airport is closed during winter, and all traffic is transferred to the nearest relevant airport, i.e., an airport can serve today's types of aircraft. The "closure" affects only the routes that are highly likely to become affected by the new ICAO regulations. Routes served by aircraft that are unaffected by these regulations at the actual airport are not included in the study.

- Scenario P4: Diversion of all affected landings to adjacent airports, under the assumption that the cancellations are published well ahead.
- Scenario U1: Diversion of all affected landings to adjacent airports, under the assumption that the cancellations occur without notice.

Hence, we do not assess situation (a) in case of seat reductions only, or situation (c), the effects of transferring a limited number of passengers on affected landings (described in Section 2). However, we have calculated the increased travel costs per passenger. This information can be used if more disaggregated data becomes available.

4.4. Accidents and Costs

When transferring passengers to an alternative airport, the in-vehicle distance increase, and hence the probability of traffic accidents increases in comparison with air transport. The change in number of accidents is calculated based on the increased surface distance and the accident probability per million vehicle kilometers. The accident probability varies, among other factors, with physical environmental aspects as the road conditions. According to Elvik et al. [40], the relative accident risk can be up to 2.5 times higher on a road covered with ice or snow as compared with a dry road. It is of course uncertain which condition the roads are in when the passengers are transferred, in particular when we deal with seasonal closures. For these areas though, it is most likely that the roads are covered with ice/snow if the airports are closed for the winter. Hence we present the calculated accident costs for ice-/snow-covered roads in the results table. The driving times may be affected as well, but for the main part of the winter season, there is cold weather and good snow clearance in addition to the use of winter tires so driving speeds are not severely reduced.

Accident costs are based on the calculated number of accidents and the cost of an average accident (police-registered accident including injuries with a weighted average cost according to the degree of injury, fatalities included [29]). The average accident cost equals the standard value, deducted from the NPRA's Manual V712 [29], and we do not further discuss these values. These costs do not constitute a significant part of the overall costs, and hence the overall results are not affected by this assumption.

4.5. The Cost Model for Aircraft Operations

The cost structure of an airline can be considered in different timescales such as per day, week, month, year, which is dependent on the purpose. In this project, costs per one-way flight are considered, and they are aggregated over the number of trips. As a practical approximation to these costs, Janić [41] has estimated a regression model to quantify the average costs per flight, dependent on the aircraft seating capacity and non-stop route length (Equation (2)):

$$C(n,d) = 7.934 n^{0.603} d^{0.656} \qquad (2)$$

where: $C(n,d)$ is average costs per flight in NOK; n is aircraft seating capacity; d is route length. The constant can be used for calibration.

The properties of the model seem appealing in the sense that it incorporates the scale effects of both flight length and aircraft size, and because it has proven to give a reasonable fit to the data for a selection of actual route costs. The model is therefore used in the calculations of changes in aircraft operating costs to get indications of the cost effects when assessing changes in the number of flights, stage lengths, and types of aircraft. However, this model is too crude to give detailed information for actual planning of commercial services. In such cases crew and fuel costs, age and characteristics of engines and fuselage, maintenance schedules, etc. will have to be considered.

4.6. Operators' Revenue

Restrictions for MTOW/MLW and consequently the use of smaller aircraft are assumed to result in increased air fares. In this study, we account for an increase of 20% and 50%, for scenario P1 and

P2, respectively. This increases the revenue per passenger, but on the other hand, the restrictions also result in deterred traffic (the net effect are presented in Section 6). For scenarios P3, P4, and U1, where the passengers are transferred to an adjacent airport, we assume no change in airfares per passenger.

5. Input Values, Assumptions, and Uncertainties

The values presented in Table 4 are general assumptions applicable for all four airports, specified by travel purpose (business/other). Table 5 contains airport-specific factors. The information in these two tables combined forms the basis for the CBA. The passengers' generalized travel costs are given by Equation (3):

$$GC_{ij} = travel\ time_{ij} \times P_{time} + \frac{(P_{km} \times km_{ij}) + parking\ fee}{car\ patronage} + air\ fare + shuttle\ fare \tag{3}$$

where: GC_{ij} = the total generalized travel cost; P_{time} = the value of time (VOT); $travel\ time_{ij}$ = total travel time (from origin to destination); P_{km} = the vehicle operating costs.

Table 4. Input values, for all airports and flights involved.

General Assumptions (2019 NOK, Time in hh:mm)		Business Travels	Other Travels
All Aircraft Movements during November–March Are Assumed to Be Affected in Cases of Winter Closure.			
Value of travel time (VOT), 1 h [38]		NOK 694	NOK 245
Car patronage [29]		1.2	2.34
Vehicle operating costs (socio economic costs) [29]		NOK/km 1.86	
Parking fee at the airport of origin, for 3 days on average [1]		NOK 550	
Attendance before departure, including time to park [42]		01:00	
from Oslo airport to Oslo city center.	Travel time/payable costs (transport measure)	00:18/NOK 190 (Express Train)	00:24/NOK 101 (NSB local train)
from Tromsø airport to Tromsø city center.	Travel time/payable costs (transport measure)	00:10/NOK 250 (Taxi)	00:15/NOK 100 (Express Bus)
from Local airport to Local city center.	Travel time/payable costs (transport measure)	00:15/NOK 200 (Taxi)	00:15/NOK 200 (Taxi)
Demand elasticity [2] planned change/unexpected change		−0.8/−0.2	
Cancellation disadvantage for outbound trips (U1); 15 min. reorganizing before bus—departure and 1 h extra attendance at the alternative airport		01:15	
Waiting time at the airport for returning trips (U1)		02:00	
The average cost per police-registered accident [29]		NOK 3 208 500	
Accidents on dry and bare roads/on roads covered with ice and/or snow per million vehicle km [40]		0.188/0.47	
Load factor (included in the calculation of aircraft operations costs) [3]		0.7	
Aircraft costs per minute: B737-700/800 (data from Norwegian)/90-seater [41]/39-seater [41]/19-seater [41]		NOK 500/350/200/140	

[1] The parking fees, air fares and flight times used in these calculations are average numbers based on the National Air Travel Survey, Avinor [2], prior studies, and searches on the airlines' websites. [2] The demand elasticity (assessment based on the literature cited in connection with Figure 4 is set to −0.8 (implying that a 10% increase in travel costs deter 8% of the passengers) for planned changes. For unplanned changes, the elasticity is set to −0.2 (please see Figure 2). [3] Based on historic averages, as a rough estimate.

Table 5. Input values, specific to the airports included in the case study.

Airport Specific Assumptions (2019 NOK, Time in hh:mm)		KKN (LKL)	ALF (LKL)	HVG (LKL)			VDS (VAW)		
Business travels % [42]		32.9%	37.8%	39.2%			44.3%		
Destination		OSL	OSL	OSL	TOS	Local	OSL	TOS	Local
Destination % [1]		100%	100%	32.6%	67.0%	0.4%	52.5%	44.2%	3.3%
Time to airport [2]	base case (P3, P4 [3])	00:40 (04:35)	00:30 (02:20)	00:08 (02:25)			00:20 (01:07)		
Distance to airport [2]	base case (P3, P4 [3])	42 km (327 km)	31 km (171 km)	5 km (166 km)			17 km (79 km)		
Travel time by bus to alternative airport (U1 [3])		04:45	02:30	02:35			00:55		
Flight time [4]	base case (alternative)	02:50 (02:30)	02:30 (02:30)	02:50 (02:50)	01:30 (01:05)	00:40 (01:00)	03:30 (03:15)	02:00 (02:00)	00:40 (01:00)
Air fares (NOK) business/other [4]		1725/ 1250	1725/ 1250	1100/ 900	1100/ 900	1100/ 900	1100/ 900	1100/ 900	1100/ 900
Flight length base case (Length km alternative)		1370 (1270)	1225 (1270)	1375 (1270)	305 (235)	175 (175)	1395 (1450)	420 (465)	175 (175)
Seating capacity P1, P2/P3, P4, U1		90/186	90/186	19/39	19/39	19/39	19/39	19/39	19/39

[1] "Closures" affects only the routes that are highly likely to become affected by the new ICAO regulations. Routes served by aircraft that are unaffected by these regulations at the actual airport are not included in the study. [2] Weighted average travel time and distance from the municipalities in the catchment area to the airports. The driving times are based on the official speed limits. This may be understating the driving times in really adverse weather conditions, and hence underestimating the economic costs of the proposed regulation. There are no corrective data available, however we do not consider this to have a serious impact on the conclusions. [3] The deviation between the travel time and distance in P3 and P4 compared to U1, is explained like this; for scenario U1, the bus service goes between the original airport and the alternative airport, while in scenario P3 and P4, the passengers travel directly from the centroid in the different catchment areas to the alternative airport. [4] The parking fees, air fares and flight times used in these calculations are average numbers based on the National Air Travel Survey, Avinor [2], prior studies, and searches on the airlines' websites.

VOT will vary based on whether the diverted trips to other airports/transport modes are planned or stochastic, as discussed in Section 4.

In Table 5, it is worth noting that for ALF and KKN, the only affected landings concern those that are carried out by larger jet aircraft serving the routes to Oslo.

Some Omitted Elements and Uncertainties

This study includes economics costs for the passengers, operators, and other effects on society (accident costs). However, there are some omitted elements and uncertainties, all of which we assume not to affect the results significantly.

- We have not assessed all different actions that could be performed if ICAO's regulations should be imposed because the data do not allow for this. For example, to leave passengers and/or luggage behind is highly relevant, but data are scarce.
- Passengers' wider costs of delays (e.g., from chained activity patterns) are indirectly considered through higher time costs for the increased waiting and shuttle time. We believe that the passengers' inconveniences are still calculated a bit on the lower side.
- The aircraft cost calculations have the highest uncertainty in this study, and they must be considered as indicative only. We use rough assumptions for the number of seats offered at present and scale up the departure frequency with smaller aircrafts to meet this number.
- Impacts from increased number of departures are not included. Reduced headway will, in theory, induce some traffic and hence reduce the inconvenience of higher airfares when using smaller aircrafts (scenarios P1 and P2).

- Costs of transfers/worsening of correspondence between flights are not included.
- Emissions to air from changes in aircraft fleet, number of departures, and actual routing and changes in shuttle services to/from the airports are not addressed.
- Impacts on costs for the airport owner Avinor and the ground handlers are not considered.

6. Main Results

The changes in travel distances and travel time varies between the scenarios. Table 6 shows the expected changes for each scenario and airport.

Table 6. Overview of the additional time spent and distance traveled for passengers transferred to an adjacent airport (deducted from Tables 4 and 5).

Scenario	Additional Time and Distance via the Adjacent Airports (Time in hh:mm)							
	KKN	**ALF**	**HVG**			**VDS**		
(Time/km)	OSL	OSL	OSL	TOS	Local	OSL	TOS	Local
P1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
P2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
P3	03:35/ 285 km	01:50/ 140 km	02:17/ 161km	01:52/ 161km	02:37/ 161km	00:32/ 62 km	00:47/ 62 km	01:07/ 62 km
P4	03:35/ 285 km	01:50/ 140 km	02:17/ 161 km	01:52/ 161 km	02:37/ 161 km	00:32/ 62 km	00:47/ 62 km	01:07/ 62 km
U1 departure U1 return trip	05:40 02:00	03:45 02:00	03:50 02:00	03:25 02:00	04:10 02:00	01:55 02:00	02:10 02:00	02:30 02:00

The scenarios where the passengers must be diverted to other airports (scenarios P3, P4, and U1) give significant changes in travel times and costs. The implementation of scenarios P1 and P2 is highly likely to be complicated because it demands aircraft types that may become more or less unique for these routes. In the longer run, we cannot exclude the possibility that it might become possible to combine these aircraft types with other routes but for the time being these possibilities are rare.

The main findings are summarized in Table 7. Subsequently, we assess the impacts for the passengers and airlines, based on costs of diversion to other airports, and cancellations. We base the number of aircraft movements and passengers on the winter season 2016/17. The percentage of affected landings is given in Klein-Paste [10]. We have examined this winter season with annual seasons from 2011 to 2016 and no anomalies were detected. Hence, the winter 2016/17 should represent an approximate baseline for the coming years. Expected annual growth must be taken into account if future years are going to be addressed. We take departed passengers into account as well, since diverted or cancelled landings are likely to affect the corresponding departures.

Based on the discussion in connection with Table 6 and the fact that cancellations often cannot be published well ahead, the grey-marked scenarios P3 and U1 appear to be the most relevant ones. P3 (winter closure and transfer to an adjacent airport) seems relevant because the regularity will either end close to 90% (Alta) or even way below (the three others). This raises the question of whether the winter services will remain sustainable under the new regulations. U1 (unexpected delays for the affected passengers) is the situation that the passengers and airlines normally face in cases of disrupted services. The passengers face additional waiting time and shuttle costs as well as inconveniences connected to their planned activities. The airlines face additional flight time and holding costs. The economic impacts of these scenarios are clearly the highest both in total and per passenger.

Table 7. Main findings, economic impacts (in millions NOK). 1 EUR ≈ 10 NOK.

Scenario	Airport			
	KKN	**ALF**	**HVG**	**VDS**
Scenario P1: The airport remains open during winter, but with smaller aircraft that can serve under the new ICAO friction regulations. 20% fare increase.				
Travel costs, remaining passengers	−17.4	−24.3	−0.9	−4.8
Travel costs, waiting for next departure	-	-	-	-
Travel costs, deterred passengers	−0.6	−0.8	−0.1	−0.1
Travel costs, transferred passengers	-	-	-	-
Total generalized travel costs for passengers	−18.0	−25.1	−1.0	−4.9
Accident costs [1]	n/a	n/a	n/a	n/a
Revenue loss (−) or gain, airlines	11.6	15.9	0.6	3.3
Operating costs, airlines (reduced (+) or increased)	−16.0	−15.8	−2.4	−8.5
SUM economic effects	−22.3	−24.9	−2.8	−10.1
Scenario P2: As scenario P1, but with 50% fare increase.				
Travel costs, remaining passengers	−37.2	−54.4	−2.1	−11.1
Travel costs, waiting for next departure	-	-	-	-
Travel costs, deterred passengers	−3.6	−5.2	−0.2	−0.8
Travel costs, transferred passengers	-	-	-	-
Costs for passengers	−42.8	−59.7	−2.3	−11.9
Accident costs [1]	n/a	n/a	n/a	n/a
Revenue loss (−) or gain, airlines	24.7	33.5	1.3	7.4
Operating costs, airlines (reduced (+) or increased)	−16.0	−15.8	−2.4	−8.5
SUM economic effects	-33.8	−41.7	−3.4	-13.0
Scenario P3: The airport is closed during winter, and all traffic is transferred to the nearest relevant airport, i.e., an airport can serve today's types of aircraft				
Travel costs, remaining passengers	-	-	-	-
Travel costs, waiting for next departure	-	-	-	-
Travel costs, deterred passengers	−24.2	−11.9	−0.7	−0.5
Travel costs, transferred passengers	−65.0	−65.3	−3.5	−9.1
Costs for passengers	−89.2	−77.2	−4.2	−9.6
Accident costs (increased (−))	−8.8	−8.1	−0.5	−1.3
Revenue loss (−) or gain, airlines	−34.0	−28.1	−1.4	−2.6
Operating costs, airlines (reduced (+) or increased)	4.7	−2.3	−0.5	−7.1
SUM economic effects	−127.3	−115.7	−6.6	−20.6
Scenario P4: Diversion of all affected landings to adjacent airports, under the assumption that the cancellations are published well ahead.				
Travel costs, remaining passengers	-	-	-	-
Travel costs, waiting for next departure	-	-	-	-
Travel costs, deterred passengers	−8.2	−0.7	−0.1	−0.1
Travel costs, transferred passengers	−22.1	−3.9	−0.7	−1.5
Costs for passengers	−30.3	−4.6	−0.8	−1.6
Accident costs (increased (−))	−3.0	−0.5	−0.1	−0.2

<div align="center">**Table 7.** *Cont.*</div>

Scenario	Airport			
	KKN	**ALF**	**HVG**	**VDS**
Revenue loss (−) or gain, airlines	−11.5	−1.7	−0.3	−0.4
Operating costs, airlines (reduced (+) or increased)	1.5	−0.1	0.5	−1.1
SUM economic effects	−43.3	−6.9	−0.7	−3.3
Scenario U1: Diversion of all affected landings to adjacent airports, under the assumption that the cancellations occur without notice.				
Travel costs, remaining passengers	-	-	-	-
Travel costs, waiting for next departure	−17.6	−4.5	−1.0	−3.6
Travel costs, deterred passengers	−6.4	−0.7	−0.2	−0.2
Travel costs, transferred passengers	−38.5	−6.9	−1.1	−3.4
Costs for passengers	−62.5	−12.1	−2.3	−7.2
Accident costs (increased (−))	−1.9	−0.3	−0,1	−0.1
Revenue loss (−) or gain, airlines	−3.7	−0.6	−0.1	−0.2
Operating costs, airlines (reduced (+) or increased)	−5.0	−0.6	−1.5	−3.9
SUM economic effects	−72.0	−13.4	−3.9	−11.3

[1] Changes in accident costs is be minimal in scenarios P1 and P2 because no traffic is diverted. For the other scenarios, we have used accident rates for icy/snowy roads.

The other scenarios are included to show e.g., possible impacts of using smaller aircraft. These scenarios (P1 and P2) are likely to cause significant alterations in the market structure on the supply side. The results indicate that there is a potential for a better match between the size of the market and the capacity offered, but a thorough assessment of operational changes is beyond the scope of this study.

In scenarios P3, P4, and U1, we assume that the passengers are transferred to an alternative airport. This leads to a modest increase in number of road traffic accidents. We see the highest impact for Kirkenes in scenario P3, where the airport is closed during the wintertime, and all flights are diverted to Lakselv. An accident cost of NOK 8.8 million for roads covered with ice/snow corresponds to an annual increase of 2.8 accidents/year (police reported accidents involving injuries; spanning from minor injuries to severe injuries and death), during the period November to March.

7. Discussion and Conclusions

7.1. Kirkenes Airport (KKN)

There are negative net economic effects for scenario P1 mainly because of increased passenger and airline costs. All flights KKN-OSL vv. include the same number of seats as today, serviced by a 90 seats aircraft and with increased frequency. The net economic effects for P2 compared with P1 are even more negative because of increased traffic deterrence from a 50% increase in airfares that outweighs the net increased fare revenues. As for P1, all flights KKN-OSL vv. include the same number of seats as today, serviced by a 90 seats aircraft and with increased frequency.

For scenario P3, there are negative net economic effects because of a significant increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of a time consuming transfer to LKL for all passengers to/from OSL (the flight distance to LKL is somewhat shorter than to KKN, which slightly minimize the increase in total travel time for the transferred passengers). The results for scenario P4 show a negative net economic effects even from a limited number of affected landings. This is because of a significant increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of a time-consuming transfer to LKL.

For scenario U1, there are high negative net economic effects even from a limited number of affected landings because of a significant increase in travel costs and a significant reduction in airfare revenues. This is mostly due to the inconvenience of unplanned transfer to another airport. The traffic deterrence and revenue loss are low because the elasticity of demand is expected to be lower in this unforeseen situation. Penalties connected to the unforeseen nature of the transfer, like extra waiting time and travel time (with VOT × 2), are included.

7.2. Alta Airport (ALF)

There are negative net economic effects for scenario P1 mainly because of increased passenger and airline costs. All today's flights with B737-700/800 are replaced with the same number of seats, serviced by a 90-seat aircraft and with increased frequency. The net economic effects for scenario P2 compared with P1 are even more negative because of increased traffic deterrence from a 50% increase in airfares that outweighs the net increased fare revenues. As for P1, all today's flights with B737-700/800 are replaced with the same number of seats, serviced by a 90 seats aircraft and with increased frequency.

For scenario P3, there are negative net economic effects because of a significant increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of transfer to LKL for all passengers to/from OSL. The flight distance to LKL is somewhat longer than to ALF (this inconvenience leads to a further increase of travel time for the deterred passengers). The results for scenario P4 show a negative net economic effects even from a limited number of affected landings. This is because of a significant increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of a time-consuming transfer to LKL.

For scenario U1, there are relatively high negative net economic effects even from a limited number of affected landings because of a significant increase in travel costs. This is mostly due to the inconvenience of unplanned transfer. The traffic deterrence and revenue loss are low for the same reasons as for Kirkenes Airport. Penalties connected to the unforeseen nature of the transfer, like extra waiting time and travel time (with VOT × 2), are included.

7.3. Honningsvåg Airport (HVG)

There are almost no net economic effects because of traffic deterrence from a 20% increase in airfares (scenario P1). The small negative net economic effect observed is mainly because of increased passenger and airline costs. All affected flights include the same number of seats as today, serviced by a 19-seat aircraft and with increased frequency. The net economic effects for scenario P2 compared with P1 are slightly more negative because of increased traffic deterrence from a 50% increase in airfares. As for P1, all affected flights include the same number of seats as today, serviced by a 19 seats aircraft and with increased frequency.

For scenario P3, there are negative net economic effects because of an increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of a time-consuming transfer to LKL for all passengers to/from HFT and TOS (the flight distance to LKL is somewhat shorter than to HVG, which slightly minimizes the increase in total travel time for the transferred passengers). The results for scenario P4 show a negative net economic effects even from a limited number of affected landings. This is because of an increase in travel costs and a reduction in airfare revenues, due to traffic deterrence because of a time-consuming transfer to LKL. Even if the aggregated numbers are small, there are noticeable effects for the passengers.

For scenario U1, there are relatively high negative net economic effects for each passenger, because of a significant increase in travel costs. There is a limited number of affected landings. The traffic deterrence loss occurs because of a time-consuming transfer to LKL and penalties connected to the unforeseen nature of the transfer, like extra waiting time and travel time.

7.4. Vadsø Airport (VDS)

There is a negative net economic effect because of passenger costs from a 20% increase in airfares (scenario P1). All affected flights include the same number of seats as today, serviced by a 19 seats aircraft and with increased frequency. The net economic effects for scenario P2 compared with P1 are slightly more negative because of increased traffic deterrence from a 50% increase in airfares. As for P1, all affected flights include the same number of seats as today, serviced by a 19-seat aircraft and with increased frequency.

For scenario P3, there are negative net economic effects because of an increase in travel costs and a significant reduction in airfare revenues, due to traffic deterrence because of transfer to Vardø airport (VAW) for all passengers to/from ALF and KKN (the flight distances are somewhat longer than from VDS, which slightly minimizes the increase in total travel time for the transferred passengers). In practice, some of the routes may be diverted to KKN, which means increased passenger costs but reduced airline costs. The results for scenario P4 show a negative net economic effects even from a limited number of affected landings. This is because of an increase in travel costs and a reduction in airfare revenues, due to traffic deterrence because of a transfer to VAW. In practice, some of the routes may be diverted to KKN, which means increased passenger costs but reduced airline costs.

For scenario U1, there are relatively high negative net economic effects for each passenger, because of a significant increase in travel costs. There is a limited number of affected landings. The traffic deterrence loss occurs because of transfer to VAW and penalties connected to the unforeseen nature of the transfer, like extra waiting time. Some of the routes may be diverted to KKN in this case as well, which means increased passenger costs but reduced airline costs.

7.5. Travel Cost Per Passenger

Table 8 shows the costs per passenger and the share of deterred traffic per scenario. Scenario U1 has much lower traffic deterrence than the comparable scenario P4 (a hypothetical but not very realistic situation where the delays could be announced well in advance). The reason is that we have used a much lower demand elasticity of −0.2 for U1 as compared to -0.8 for the others (please see Figure 4). In scenario U1, many trips will have already started, and hence the passengers are less sensitive because they on average are likely to be significantly more reluctant to cancelling their trip. The common denominator for the "P" scenarios is that the passengers are informed in advance about delays, cancellations, and/or diversions and hence they will on average have much more flexibility.

Table 8. Costs per passenger in NOK per one-way trip and share of deterred traffic (in %). 1 EUR ≈ 10 NOK.

	Differences in Passengers' Cost from Today's Services, per Passenger, One Way			
	KKN	**ALF**	**HVG**	**VDS**
P1	**273**/*282* (6%)	**277**/*286* (7%)	**190**/*196* (4%)	**193**/*198* (4%)
P2	**648**/*707* (16%)	**657**/*719* (17%)	**453**/*491* (11%)	**463**/*496* (11%)
P3	**1352**/*1539* (36%)	**850**/*912* (21%)	**828**/*936* (21%)	**375**/*390* (8%)
P4	**1352**/*1539* (36%)	**850**/*912* (21%)	**828**/*936* (21%)	**375**/*390* (8%)
U1	**2789**/*2828* (23%)	**2232**/*2280* (16%)	**2399**/*2481* (17%)	**1762**/*1804* (10%)

Costs for all affected passengers (*ex ante*) in bold, *remaining travelling passengers (ex post) in Italics*. (% deterred passengers in parenthesis).

Table 8 shows that the passenger inconveniences are potentially high, depending on the scenarios. Passengers at Kirkenes in particular, with a long shuttle distance to the alternative airport in Lakselv (see Figure 1), get around NOK 5600 in extra costs for a return trip if diversions on short notice occur. Even those with only around 70 kilometers to the nearest alternative airport get additional costs of over NOK 3500 for a return trip under such conditions. For a planned diversion (P3), the costs are between approximately NOK 750 and NOK 2700, respectively.

If we generalize scenario U1 to comprise all affected landings (around 500 landings in the regional and around 3800 landings in the local airport network during an average winter season), we get an estimate of up to NOK 400–450 million per year for the passenger costs only. This estimate may be on the higher side due to the fact that we have not been able to isolate the landings where the flight is on time, but with a reduced number of passengers.

7.6. Conclusions

This study has examined how a change in the regulatory framework for air transport could affect transport costs. The case in question is the ICAO State letter AN 4/1.2.26-16/19 [1] that proposed to set a higher minimum friction on runways operated during slippery conditions. This may affect operations, particularly on the northern hemisphere. Four Norwegian airports that operate under severe winter conditions are used as examples., The main contribution of the paper is to show how we can assess the systemic economic effects from a relatively simple and straightforward change in regulations concerning an important part of the transport market.

At the outset, it is likely that the changes in ICAO regulations could result in both increased delay stochasticity and the need for seasonal aircraft weight restrictions. In order to account for this, we have used an approach with scenario building where the scenarios differ between planned and unforeseen cancellations or diversions. The different scenarios are supposed to show the economic effects from policy-relevant measures that can be introduced if such regulatory changes should take place, in order to aid the decision-making process.

The results show that for scenarios P3, P4 and U1, where the passengers are transferred to an adjacent airport, the travel costs per return trip increase significantly with up to NOK 5600 if higher runway friction cause unexpected diverted traffic. For scenarios P1 and P2, continued services on the airports but with an increase in air fares from restrictions in payload and/or use of smaller aircraft leads to a more modest travel costs increase. In turn, this leads to a smaller number of deterred passengers, resulting in less severe economic effects. If the results from the most realistic scenarios are generalized to all affected flights in Norway, the annual estimate is up to NOK 400–450 million. The impacts on increased aviation safety are not taken into account. However, data on aircraft accidents in Norway do not indicate significant effects from the prosed regulatory change.

These aggregated numbers may not seem exorbitant. However, the costs are mainly borne by a limited number of airports. Some of them may have to close during winter, with severe consequences for local communities. The aggregated economic effects will be smaller if the planned aircraft movements take place, but with reduced payload. This means that lesser passengers will become affected. Therefore, we recommend using the costs per passenger (Table 8) as the most reliable estimates together with the number of affected passengers and consider the aggregated economic effects in Table 7 as estimates in the upper end.

We have assessed the effects for an average year only, based on annual data for a representative winter season, with inherent uncertainties as pointed out above. Discounting to a net present value can be made by means of traffic forecasts and real growth in factor prices for future years. This can be relevant if assessments of long-term investments like runway extensions are considered as compensatory measures.

Although these airports are typical for severe winter conditions, the findings cannot be generalized to all such contaminated airports. However, they may indicate that if the regulations should

be implemented, the economic consequences for individual airports may become severe and not economically sustainable.

7.7. Aftermath

After the report by Bråthen et al. [2], was launched, ICAO plans to postpone the implementation of the regulations (Global Reporting Format (GRF)) until November 2021. EU may postpone the implementation with up to 12 months to correspond with ICAO's implementation. In addition, the EU legislation now includes an adjustment (Specially Prepared Winter Runway (SPWR)) that allows for comparing the reported friction coefficient from the airport with the use of braking data from the aircraft. Both GRF and SPWR must be finally confirmed by an ICAO State Letter and a decision in the EU Council (both can be expected to be in place during July 2020). It is expected that SPWR may reduce the number of affected landings and the adverse economic effects significantly.

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