**Summary:**

# Cost-benefit analysis of a measure aimed at reducing the consequences of runway excursions at Tromsø Airport

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*The report presents a cost-benefit analysis (CBA) of a proposed measure of extending the runway excursion safety area (RESA) at the southern end of Tromsø Airport (Langnes). The purpose of the measure is to reduce the potential damage of runway excursion (RE) – overrun of the runway end at landing or take-off, as well as landing undershoot. There is uncertain information about the initial risk situation and about the particular changes that the measure may will provide, as RE are infrequent and Norwegian data limited. However, there is a large European data set on the specific location of planes overrunning or undershooting during a 30 years' period; which provides the basis for estimating the share of RE and undershoot cases that may be located in the constricted area of the RESA at Tromsø Airport – two missing outer rectangles that reduce the RESA width from the standard 150 m to 90 m. About 10-15% of all overrun and undershooting cases are estimated to be located in the missing rectangles, or in areas further out that would imply passing the missing rectangles. The section of RESA in the southern end of Tromsø Airport where the width is constricted to 90 m is the roof of a road tunnel. Location of an overrun plane in the missing rectangles could thus result in a plane falling down to the road. Thus, the expected level of damage due to a RE (or an undershoot) at Tromsø Airport is expected to be higher compared to the expected level of damage due to RE at airports with standard RESA width of 150 m, everything else equal. The potential damage comprises primary effects, such as damage to aircraft and passenger injuries, and secondary effects, such as delay for passengers, airlines and the airport. At Tromsø Airport there are additional potential consequences for the road traffic, damage to the road infrastructure and subsequent delay/closure. The estimated distribution of the level of damage, for different types of accidents and incidents, with associated damage costs, is based on estimates from the international literature as well as official Norwegian valuations for the transport sector. Based on the obtained information and inputs, the CBA of a measure extending the road tunnel, increasing the RESA width from 90 m to 150 m, yields a result below "break-even". The net benefit based on the main input point estimates is negative, and the benefit-cost ratio is just below one. A sensitivity analysis based on 10,000 simulations with drawings from input value intervals also yielded a negative mean net benefit value, while the mean of the simulated benefit-cost ratio was just above 0.9. Moreover, the sensitivity analysis indicated that the cost of the measure, the tunnel/RESA extension, is the major input element that could tilt the net benefit in a positive or negative direction. The simulated 90% confidence interval of the benefit cost ratio is between 0.6 and 1.3.*

## Background

The Norwegian Civil Aviation Authority has requested a cost-benefit analysis of a measure aimed at reducing the potential damage of runway excursions (RE) at Tromsø Airport (Langnes). The runway end safety area (RESA) at the southern end of Tromsø Airport, is constricted to 90 meters' width where the county road (Fv

862) between the city of Tromsø and Kvaløya passes under the RESA in a tunnel. As the standard width of RESA is 150 m, Tromsø Airport currently has "missing outer rectangles" on each side. Surpassing 45 meters to the side of the centre line, after the strip, instead of a flat area with grass or gravel (30 meters further out to each side), there is an edge (of a tunnel roof), and beneath there is a road. A side excursion beyond the strip may thus result in a plane running over the edge and falling down on the road. Thus, overrun of the runway at landing or take-off towards the south, as well as undershoot when landing towards the north, may result in more damage at Tromsø Airport compared to other airports with standard 150 m × 240 m RESA. Due to the narrowing of RESA over the road tunnel, the effective width of RESA is limited to 90 m (green area in Figure S.1), although a section further out is 150 m wide (adding the brown areas in Figure S.1).

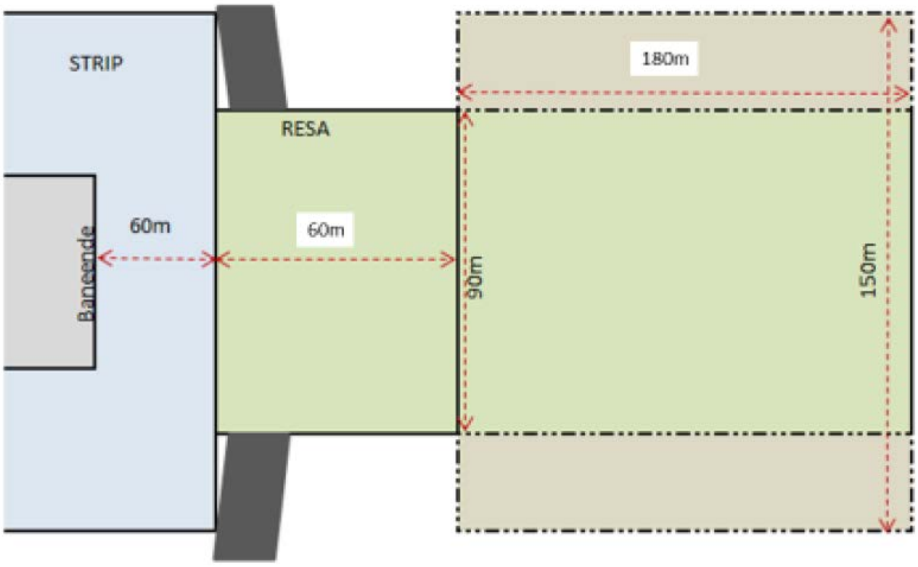


*Figure S.1: RESA in the southern end of Tromsø Airport, Langnes (for landings and departures to the south and landings to the north). The standard RESA area is 240 m × 150 m, and there is an additional 60 m × 150 m (runway) strip just after the runway end (Norw.: baneende). At Tromsø Airport the RESA consists first of a narrowed field over the Fv862 road tunnel, 60 m × 90 m (thus, there are two "missing side rectangles" of 60 m × 30 m), and then there is an outer field of 180 m × 150 m (Source: Luftfartstilsynet, 2013, with forwarded corrected figure from the CAA).*

Upon departure/landing in direction towards the south (from left to right in Figure S.1), a RE-case would mean that the plane stops after passing the runway end. Upon landing in direction towards the north (from right to left in the figure) an undershoot would mean that the plane lands before reaching the runway.

## Fundaments and assumptions for cost-benefit analysis

There will always be uncertainty about the extent of change that specific measures bring about. In our case we even have limited knowledge about the initial ("before change") situation, as RE and undershooting are infrequent events. There were only 24 registered RE events (at landing) on Norwegian airports (allowing airplanes above 5.7 tonnes), from 2001 to 2015, based on 6.2 mill. movements. Although the proposed measure, extending the width of the RESA from 90 m to 150 m, will not affect the frequency of RE (and undershooting) events, 24 RE incidents and

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accidents represent a very small number for establishing some expectancy about how the consequences are distributed. Thus, the expected change in damage distribution due to the implementation of the measure will be highly uncertain.

The point-of-departure is to apply a former analysis of airplane locations in runway overrun and undershooting incidents. The observed longitudinal and lateral distances have been modelled based on a large European data set, finding that they fitted well to a Weibull survival function (van Es et al. 2014). Thus, we applied the model parameters to estimate the (expected) relative frequency of locations in the "missing outer rectangles". We also added the locations in two triangular fields further out (the half of the brown areas in Figure S.1), as overrunning airplanes would have had to pass (theoretically) the "missing outer rectangles" to reach these outer areas (Figure S.2).

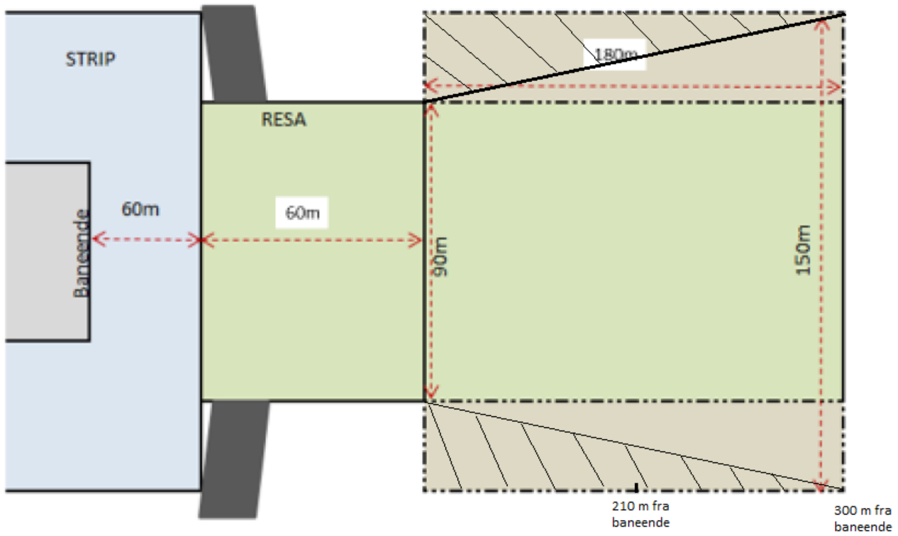


*Figure S.2: Theoretical location of an airplane in the hatched triangle areas, farther out than the "missing outer rectangles", in case of an RE, would normally imply passing the area of the "missing outer rectangles" (source: Luftfartstilsynet, 2013, with forwarded corrected figure from the CAA; own adaptations).*

It was estimated that approximately 10-15% of location points in case of overrun and undershooting would either be in the "missing outer rectangles" or in the hatched triangles further out (in RESA). The share was slightly above 15% for overrun at take-off, while it was slightly lower than 10% for undershooting. The overall distribution between accidents and incidents, 25% vs. 75%, seems reasonably robust, but the specific distribution of minor and major accidents remains more uncertain. The chosen specification of accident and incident distribution (seven levels, altogether) was largely based on international literature, which was also the case for the various damage cost estimates. The benefit estimate is given from an expected shift in the distribution of accident and incident levels, when extending the RESA at Tromsø Airport (from 240 m × 90 m) to the standard 240 m × 150 m.

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## Sensitivity analysis indicates that the cost of the measure is most decisive for the CBA results

The cost of the RESA measure at Tromsø Airport has been roughly estimated at 100 mill. NOK. E.g., Flyvbjerg et al. (2003) have shown that there is a stronger tendency to underestimate project costs in CBA than overestimating; their before-after study of CBAs showed that the major part of the post-CBA cost observations was placed within an interval from about 30% below the CBA cost estimate to about 60% above. In a sensitivity analysis, we applied a similar asymmetric interval to our cost estimate, as well as (mostly asymmetric) uncertainty intervals for the many inputs affecting the benefit estimate. Triangular distributions were assumed for the inputs (except for some of the damage costs to the road, where uniform distributions were applied).

The estimated weighted average damage cost of an RE (or undershooting) event (the average of the damage costs of all seven accident and incident levels, weighted by their expected relative frequency) is just above 9 mill. NOK at Tromsø Airport and just below 5 mill. NOK at Norwegian airports with standard RESA.

The assumed uncertainty interval for the cost of the measure is asymmetric, reflecting the stronger tendency to underestimation than overestimation. It is the assumption and potential change in this input that primarily controls the outcome of the CBA. Thus, it is the cost of the extension of the RESA at Tromsø Airport that should be addressed first, if more precise CBA estimates are to be obtained Changes in other single inputs (e.g., the increase of large and catastrophic accidents at Tromsø Airport compared to other Norwegian airports, due to a narrow RESA with an edge down to a passing road) may move the net benefit estimate about a million NOK up and down (given that the cost of measures held equal NOK 100 mill.). If several inputs affecting the estimated benefit of the measure are tilted towards their lower end, the resulting net benefit will end up considerably below zero.

The average annual net benefit based on (10,000) simulations, drawing from triangular input intervals, is below zero (close to minus 600.000 NOK). Based on "deterministic" analysis, applying "best" point estimate, the estimated net benefit is approximately minus 200.000 kr (Table S.1). The use of asymmetric input intervals in the simulation, particularly the interval for the cost of the measure (tilted towards higher values) explains the difference between the simulated and the deterministic estimates. The 90% confidence interval from the simulations (from the 5% to the 95% percentile) is equal to {-2.4 mill.;1.1 mill.}. A separate simulation of the BC ratio yielded an average of 0.92, while the deterministic BC ratio was 0.96. The 90% confidence interval from the simulations was within {0,6;1,3}.

*Table S.1: Net benefit estimates for the measure (extension of the RESA at Tromsø Airport), NOK-2015, and benefit-cost ratio – deterministic and simulated.*

| | Benefits | Costs (of measure) | Net benefit | BC ratio |
|---|---|---|---|---|
| **Deterministic (using "best" point estimates)** | *4,670,000* | *4,860,000* | *-190,000* | 0.96 |
| **Simulated (sensitivity analysis)** | | | *-580,000* | 0.92 |


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