

## Executive summary

# DEVELOPMENT OF A LANDING OVERRUN RISK INDEX



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Each year a large number of landing overruns occur worldwide. Safety statistics of commercial airline operators show that on average there is almost one landing overrun occurrence every week. Each year there are also a number of landing overruns that resulted in third party damage and injuries on the ground. To operators it is therefore interesting to know how big their overrun risk is and what possible actions could be taken to reduce this risk.

### **Description of work**

The current paper presents the development of a methodology that determines the risk of an operator of having a landing overrun in their operation. The methodology is based on the exposure that an operator has to certain landing overrun risk factors which are combined and weighted into a safety performance index.

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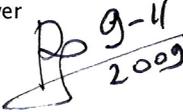
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## SUMMARY

Each year a large number of landing overruns occur worldwide. Safety statistics of commercial airline operators show that on average there is almost one landing overrun occurrence every week. Although many of these occurrences are not catastrophic still about half of all landing overruns do cause significant damage to the aircraft and/or injuries to the passengers and crew. Each year there are also a number of landing overruns that resulted in third party damage and injuries on the ground. To operators it is therefore interesting to know how big their overrun risk is and what possible actions could be taken to reduce this risk.

A study conducted by NLR-Air Transport Safety Institute showed that factors such as long landings, high on approach, excess approach speed, slippery runways, significant tailwind etc. increase the risk of a landing overrun. However, to an individual operator these factors are not very meaningful unless the exposure of the operator's fleet to these factors is taken into account. The current paper presents the development of a methodology that determines the risk of an operator of having a landing overrun in their operation. The methodology is based on the exposure that an operator has to certain landing overrun risk factors which are combined and weighted into a safety performance index. This index represents the relative risk an operator has compared to a reference condition in which all risk factors are absent. This landing overrun risk index is easy to manage and to monitor. The methodology requires a number of input parameters which partly can be obtained from standard flight data monitoring programs. The presented method is illustrated by applying it to actual data obtained from different operators. Variation of the landing overrun index by aircraft type, location, season etc are shown.

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# I INTRODUCTION

## I.1 BACKGROUND

The first official aircraft accident reported in 2008 was with a NAMC YS-11 aircraft operated by Philippine carrier Asian Spirit, which overran the runway on landing at Masbate in the central Philippines on January 2nd 2008. Since that date at least 27 other landing overrun accidents occurred in 2008 and many more incidents. Each year a large number of landing overruns occur worldwide. Safety statistics of commercial airline operators show that on average there is almost one landing overrun occurrence (varying from an accident to a minor incident) every week. Although many of these occurrences are not catastrophic still about half of all landing overruns do cause significant damage to the aircraft and/or injuries to the passengers and crew. Each year there are also a number of landing overruns that resulted in third party damage and injuries on the ground. To operators it is therefore important to know how large their overrun risk is and what possible actions could be taken to reduce this risk. Such knowledge would perfectly fit in an operator's Safety Management System. Many operators do monitor their flights using the data taken from the quick access recorder and analyse reported incidents in their fleet. Although the number of landing overruns is high, individual operators normally will have not many landing overruns in their archives to learn from. However they do have data on the factors that are known to increase the risk of a landing overrun. Currently only limited use is made of this information in managing landing overrun risk. This paper will show the development of a method to derive a risk index which will help the operators to monitor and manage their landing overrun risk.

## I.2 OBJECTIVES

A study conducted by NLR-Air Transport Safety Institute showed that factors such as long landings, high on approach, excess approach speed, slippery runways, and significant tailwind etc. increase the risk of a landing overrun [Van Es, (2005)]. However, to an individual operator these factors are not very meaningful unless the exposure of the operator's fleet to these factors is taken into account. This paper will present the development of a methodology that determines the risk of an operator of having a landing overrun in their operation. The methodology is based on the exposure that an operator has to certain landing overrun risk factors which are combined and weighted into an index. The index

represents the relative risk an operator has compared to a reference condition in which all risk factors are absent. The landing overrun risk index should be easy to manage and to monitor.

### 1.3 OVERVIEW OF THE PAPER

In section 2 the development of the method is presented. Section 3 discusses an application of the method. Conclusions and recommendations are given in section 4.

## 2 DEVELOPMENT OF THE METHOD

### 2.1 APPROACH

The methodology is based on the exposure that an operator has to certain landing overrun risk factors which are combined and weighted into an index. The method was first explored by Tauss [Tauss, (2008)] which studied the concept of the landing overrun index. This paper reflects the continuation of this work. The index represents the relative risk an operator has compared to a reference condition in which all risk factors are absent. In this case the index will have value of one. Risk index values above one would indicate an increased landing overrun risk. As the method should also account for the influence of available runway length the risk index could become less than one when for instance a landing is conducted with a large runway margin (difference between available and required runway length to stop the aircraft). Again it should be realised that a risk index of one means that the landing overrun risk is equal to the reference condition in which all risk factors are absent and that the available runway length does not affect the overrun risk in that case.

### 2.2 LANDING OVERRUN RISK FACTORS

An estimate of the risk of having a landing overrun accident with a particular risk factor present is accomplished by calculating a risk ratio [Van Es, (2005)]. This risk ratio provides insight on the association of a factor on the risk in a landing overrun accident. The risk ratio is the rate of the accident probability with the factor present over the accident probability without the factor present. The risk ratio is given by the following formula:

$$Risk\ Ratio = \frac{\left( \frac{\text{accidents with presence of a risk factor}}{\text{normal landings with presence of a risk factor}} \right)}{\left( \frac{\text{accidents without presence of a risk factor}}{\text{normal landings without presence of a risk factor}} \right)}$$

Risk ratio values greater than 1 indicate an increased level of risk due to the presence of a particular factor. A risk ratio of 4 means that the probability of accident with the risk factor present is 4 time higher than without its presence. Positive associations between a risk factor and landing overruns accidents show that a demonstrated association exists. However it does not prove causation. In [Van Es, (2005)] a number of factors that increase the risk of a landing overrun are identified and quantified using historical data. In [Van Es, (2005)] risk ratios are provided for the following factors: Non-precision approach, touching down

far beyond the threshold (long landing), excess approach speed, visual approach, significant tailwind present, high on approach, wet/flooded runway, and/or snow/ice/slush covered runway. The quantified results are shown in Table 1.

*Table 1 Landing overrun related risk factors [Van Es, (2005)]*

Landing overrun related risk factor	Risk Ratio
Non-precision approach*	25
Long landing	55
Excess approach speed	38
Visual approach*	27
Significant tailwind present	5
High on threshold	26
Wet/flooded runway	10
Snow/ice/slush covered runway	14

\*Compared to a precision approach.

The risk ratios are derived assuming that they are independent of each other. In reality this is not necessarily the case for all risk factors. For instance the landing overrun risk is much higher when a non-precision or visual approach is flown. These approach types are more likely to become unstabilised (e.g. flying too fast and too high) than precision approaches. Indeed the vast majority of overruns in which there was an excess approach speed occurred during a non-precision or visual approach (81%). Furthermore in 80% of all landing overrun accidents that were high over the threshold the approach type was non-precision or visual. Similar in 82% of all overruns in which a long landing was reported the approach type was a non-precision or visual approach. From these data it becomes clear that there is a correlation between the risk factors “Excess approach speed”, “Long landing” and “High on approach” with non-precision or visual approaches. To use the quantified factors related to non-precision or visual approaches for any kind of risk index, a correction should be made to account for this correlation and to avoid double counting of the risk factors. The risk ratios for non-precision approaches and visual approaches are reduced by 81% (average of the three percentages identified), resulting in the following new risk ratio of 5 for both non-precision approaches and visual approaches (both rounded to 5). The table with the corrected risk ratios as required for the risk index are shown in table 2.

*Table 2 Corrected landing overrun related risk factors*

<b>Landing overrun related risk factor</b>	<b>Risk Ratio</b>
Non-precision approach*	5
Long landing	55
Excess approach speed	38
Visual approach*	5
Significant tailwind present	5
High on threshold	26
Wet/flooded runway	10
Snow/ice/slush covered runway	14

Table 2 does not list the influence of the remaining runway length on the landing overrun risk. When the available runway length is much higher than the required stopping distance it seems logical that the overrun risk would become less even with the presence of many risk factors. For instance a long landing should not be a problem for an aircraft that lands on 4,000 m long runway when the aircraft needs (according to the operating manual) 800 m for a full stop. In this case the remaining runway distance to stop the aircraft is 3,200 m. Detailed analysis of some 182 landing overruns showed that as the remaining distance to stop the aircraft becomes more than approximately 1,600 m the risk of a landing overrun decreases<sup>1)</sup>. This 1,600 m seems rather high at first. However, this is the difference between the available runway length and certified landing distance required to stop the aircraft. In the previous example the 800 m landing distance is what the aircraft in theory and according to its flight certification should be able to achieve. However, in reality airline pilots do not land their aircraft as test pilots do and need more distance to stop the aircraft. The empirical relation between the remaining distance to stop the aircraft and the risk ratio is shown in Figure 1. This relation is based on the correlation of the identified 182 landing overrun occurrences with the number of landings by runway length. Note that the landing distance required is defined here without any dispatch safety factors (e.g. without the 1.67 factor on the landing distance as required by dispatch).

<sup>1)</sup> Data source: NLR-ATSI Air Safety Database.

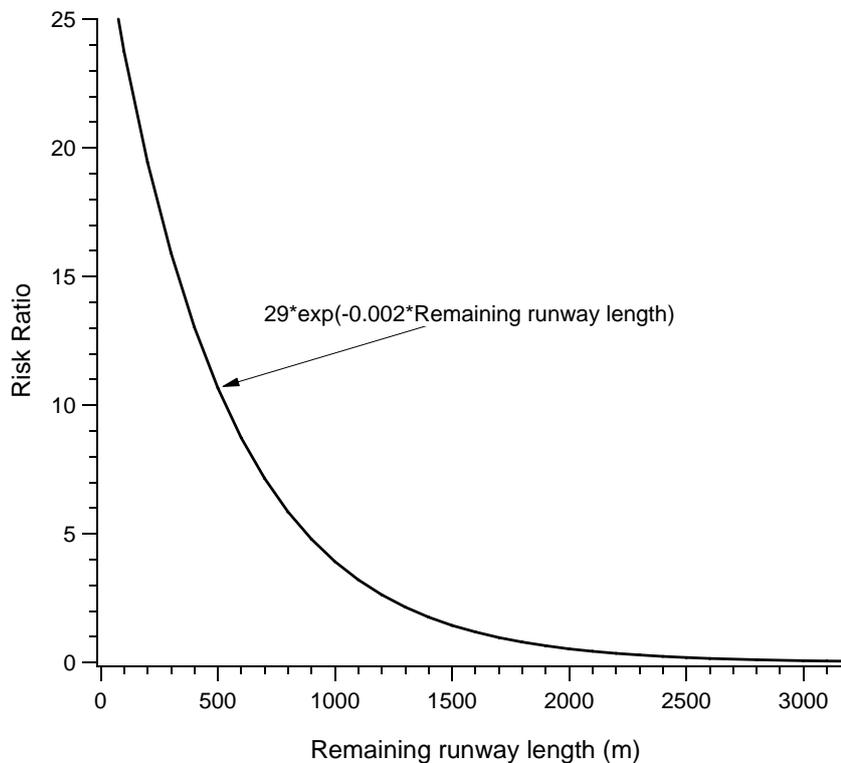


Figure 1: Influence of remaining runway on landing overrun risk

### 2.3 DESCRIPTION OF THE METHOD

The methodology is based on the exposure that an operator has to certain landing overrun risk factors which are combined and weighted into an index. These factors are presented and quantified in section 2.2. The index represents the relative risk an operator has compared to a reference condition (e.g. risk index of one). It should be realised that a risk index of one means that the landing overrun risk is equal to the reference condition in which all risk factors are absent and that the available runway length does not affect the overrun risk in that case. In a simple mathematical form the landing overrun risk index for an individual landing is given as follows:

$$LORI = (k + RR_1 + \dots + RR_i) \times RR_{remaining\ runway}$$

In which  $RR_i$  is the risk ratio associated with a certain risk factor that is present during the landing. When the risk factor is absent,  $RR_i = 0$ . In the case that all risk factors from table 2 are absent from the landing,  $k=1$ , and  $k=0$  if at least one factor is present. This is to avoid that the risk index become zero in the case that all risk factors from table 2 are absent. The parameter  $k$  has no real physical meaning.

For example an aircraft makes a localiser-only landing on a wet runway, with a significant tailwind. The required landing distance is 950 m, and the LDA is 3,200 m. The risk index is then equal to:

$$LORI = ((5)_{NPA} + (5)_{tailwind} + (10)_{wet\ rwy}) \times 29 \times EXP(-0.002 \times 2250) = 6.4$$

From a safety performance measurement point of view it is more meaningful to look at a larger set of landings and to average the risk index over these landings. The landing overrun risk index is then given by:

$$LORI = \frac{\sum (k + RR_1 + \dots + RR_i) \times RR_{remaining\ runway}}{\sum all\ landings}$$

The index can be analysed for the complete fleet, for a particular aircraft type, for a particular airport, or even a single runway. In all cases care should be taken to use the index only when a sufficient number of landings are available in order to obtain statistical meaningful results.

The methodology requires a number of input variables which can be obtained from standard flight data monitoring programs and other sources. In table 3 an overview of the input needed for the risk index model is listed including some background information of each of the variables.

Table 3; Overview of the input variables of the risk index model

Input for risk index model	Remarks/background information
Non-precision approach/ Visual approach	It is not easy to see if a landing was conducted as a non-precision approach or visual approach. However based on the used runway or on the fact that invalid glideslope data is recorded on the quick access recorder it can be accessed whether a landing was conducted as Non-precision approach/ Visual approach.
Long landing	Typically a landing is considered to be long when the distance from the threshold to the touchdown point is more than 2,300 ft. However this is not a generally accepted definition for a long landing. Some operators use different thresholds. Furthermore the algorithms used by available flight data monitoring software are often not very accurate in calculating the airborne distance leading to an overestimation of the airborne distance. See for an accurate estimate of the airborne distance using quick access recorder data the study into landing distance performance by Van Es and Van der Geest [Van Es et. al., (2006)].
Excess approach speed	An excess approach speed condition exists when the CAS at or near the threshold exceeds $V_{ref} + 20$ kts.
Significant tailwind present	A significant tailwind conditions exists whenever the tailwind at or near the threshold crossing is higher than 10 kts. This value of 10 kts. is not be related to the fact that some aircraft are certificated to land with a 15 kts. tailwind. The value of 10 kts was derived from the analysis of historical landing overruns for aircraft with both 10 and 15 kts tailwind limits. The tailwind can be calculated from the quick access recorder by subtracting the recorded ground speed and true air speed from each other.

High on threshold	An aircraft is considered to be high above the threshold when the (radio) altitude at the threshold crossing is 15 ft. above the prescribed threshold crossing height (normally the threshold crossing height is 50 ft.). The GPS recorded position could be used to determine the threshold crossing time however it should be realised that often the sampling frequency and the number digits of the quick access recorded GSP position is insufficient to do so. Being high on the threshold does not necessarily result in a long landing. Unpublished flight data show that approximately 20% of all long landings are associated with being too high on the threshold.
Wet/flooded runway or Snow/ice/slush covered runway	It is difficult to access to runway condition for historical landings. An estimate of the runway condition can be made using the METAR data at the time of the landing.
Remaining runway length	With the quick access recorded flap setting, landing weight, approach speed, tailwind, the required landing distance (without dispatch correction) can be calculated and subtracted from the landing distance available declared for the used runway.

## 3 APPLICATION OF THE METHOD

### 3.1 INTRODUCTION

To illustrate how the method could work some examples are presented in this section using real in-flight recorded data obtained for a narrow bodied jet aircraft.

A total of 14,000 landings for a narrow bodied jet aircraft are available. These landings are recorded over a 11 month period running from October 2004 until August 2005. The aircraft is operated at 24 different airports which have a large variation in runway lengths and weather conditions. The runway condition is estimated using METAR data valid for the time and date of the landing. For each recorded landing the landing overrun index is calculated.

Different types of analyses can be made using the risk index such as trend analysis by month, by airport, or by runway. In order to obtain a statistical reliable average landing overrun index, a sufficient number of landings should be used. As a rule of thumb at least 50 landings should be considered when calculating the landing overrun risk index.

### 3.2 RESULTS

In figure 2 an example is given of the monthly trend in the average landing overrun risk index for the narrow bodied jet aircraft for the period October 2004 until August 2005. The risk index appears to be higher than the average of 11 during the months April, May, and June of 2005. In this example case detailed analysis of the individual landings during these months showed that this is mainly caused by increase in the number of landings with significant tailwind and landings which are high on the threshold. Such findings could trigger an operator to formulate measure to minimise these conditions.

Normally a safety manager would like to compare a monthly trend to a target level index. Ideally one would take a value of 1 as target level for the landing overrun risk index. However, this is not always a feasible target. In the example case studied in this paper the narrow body jet aircraft is operated at airports with relatively short runways compared to the landing performance of this aircraft. This does not mean that the landings with this aircraft are unsafe, however, it means that the average risk levels are higher (although still acceptable when

considering the certification of the aircraft). Any kind of target risk level used should be based on the operational characteristics of the specific operator.

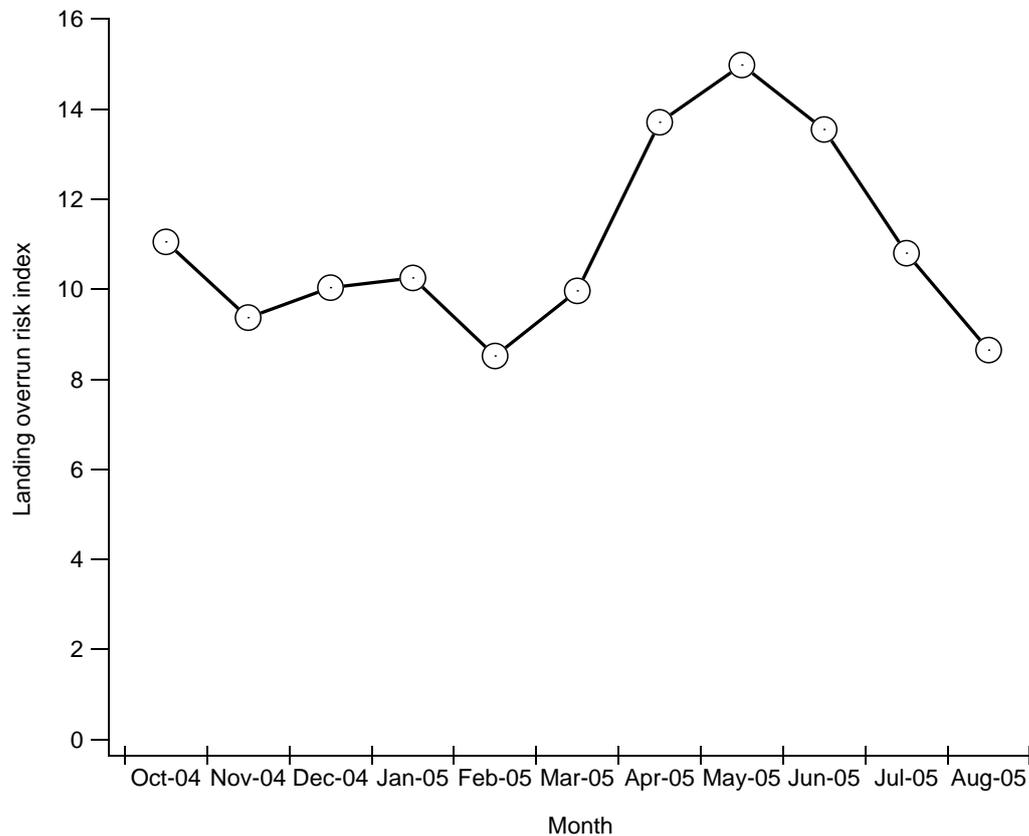


Figure 2: Example monthly trend of landing overrun index

Another example of how the landing overrun risk index can be used is shown in Figure 3 which gives the relation between the runway length and the overrun risk index. It is clearly shown that the shorter runways have a higher average landing overrun risk index. This comes as no surprise and partly follows the relation given in figure 1.

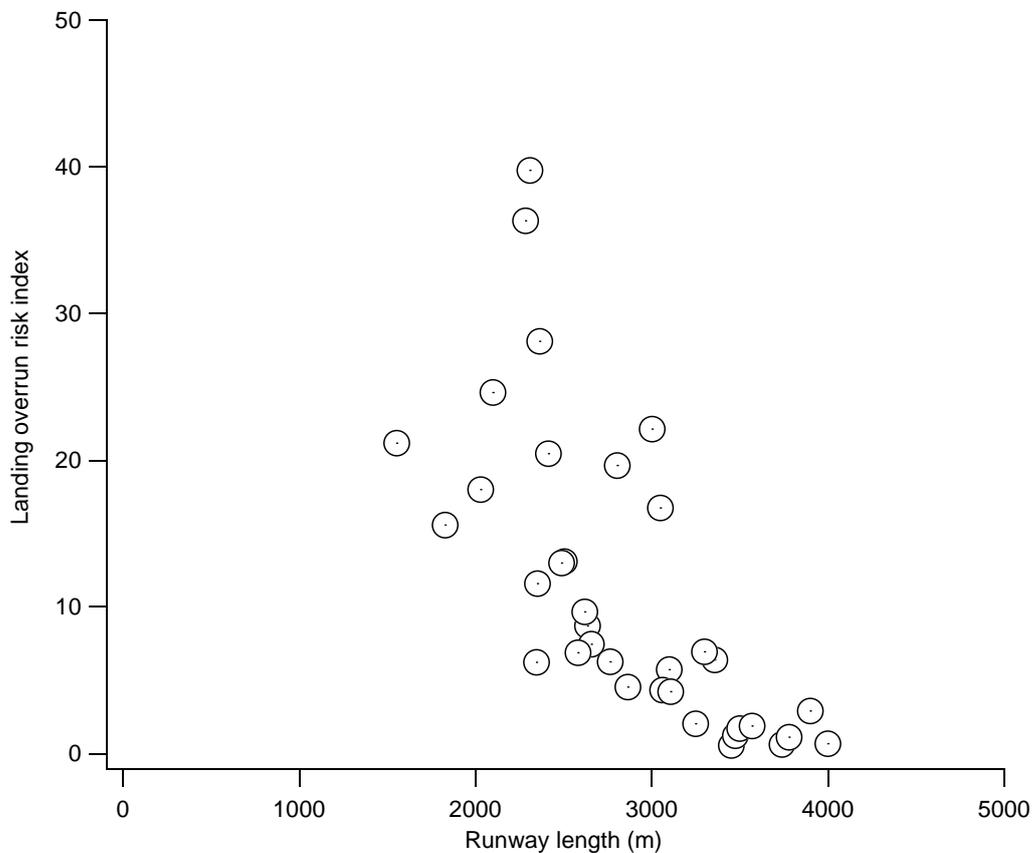


Figure 3: Relation between runway length and the overrun index

Finally another example is given in figure 4 which presents the average landing overrun index for all the individual airports in the dataset. The value of the index per airport shows a broad variation between 0.6 and 36.6. For most of the airports the risk index is higher than one. This is partly caused by the fact that the narrow body jet aircraft in the example case is mainly operated at airports with relatively short runways compared to the landing performance of this aircraft. It should be realised that a risk index of one means that the landing overrun risk is equal to the reference condition in which all risk factors are absent and the available runway length does not affect the overrun risk. Often this situation does not exist and the risk will be higher than the reference condition of one.

The high risk index value for airport A, is caused by several factors. First this airport has only one runway and a relatively high number of landings are conducted under tailwind conditions (26% of the landings versus a 12% overall average). Furthermore the average landing weight at airport A is about 10% higher than the overall average. The large number of tailwind landings combined with a higher average weight results in longer landings than the fleet average. As

the runway is not very long (2,200 m) the landing overrun risk at airport A is relatively high compared to the others. Furthermore there also appears to be a large number of long landings at this airport (6% of the landings versus a 2% overall average) which also contributes to the higher risk value for airport A. The airport with the lowest overrun index (airport X) is the airport with the longest runway (4,000 m) in the dataset. The average required landing distance for the narrow body jet aircraft at this airport is 1,400 m. This very long runway more or less neutralises the landing overrun risk despite several cases of long landings at this airport.

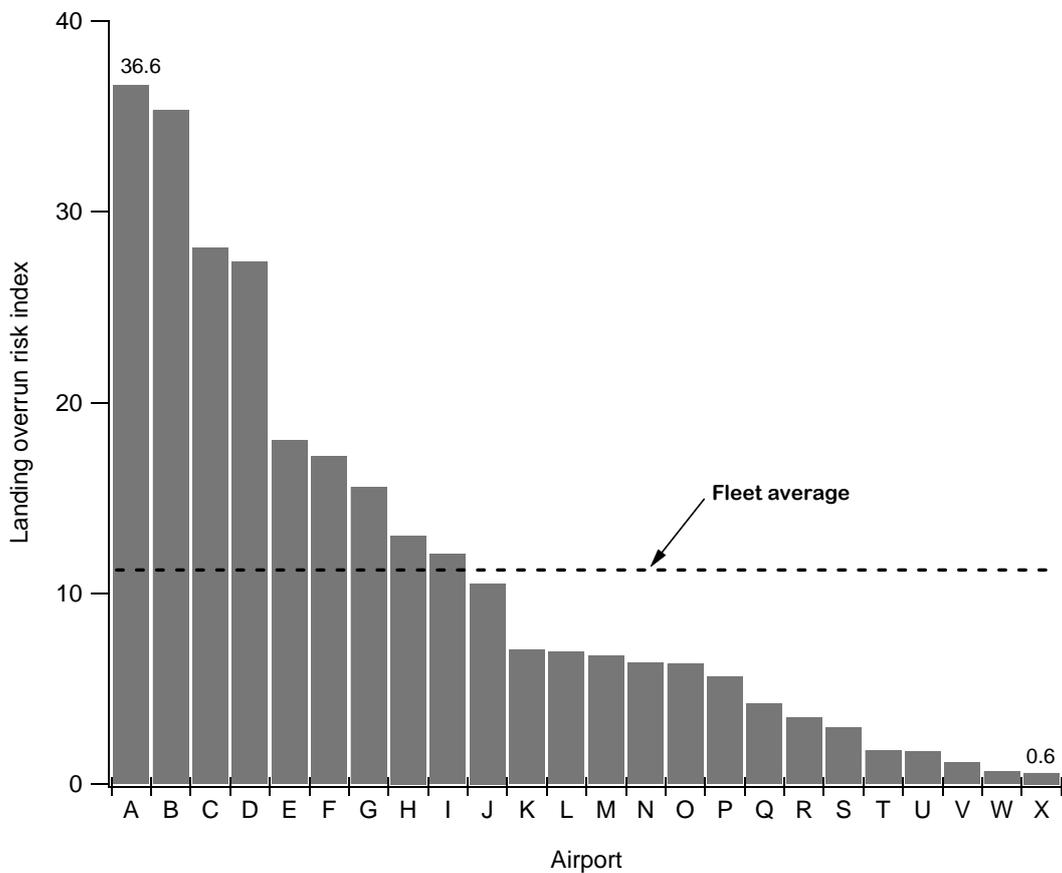


Figure 4: Average landing overrun index per airport

## 4 CONCLUSIONS AND RECOMMENDATIONS

### 4.1 CONCLUSIONS

A simple method to assess the risk of an operator of having a landing overrun in their operation is presented and discussed in this paper. Application of the method using real operational data shows that it can be used to analyse the landing overrun risk in the day-to-day operations in a meaningful way. The method could be a helpful tool to airlines that want to monitor and mitigate their landing overrun risk.

### 4.2 RECOMMENDATIONS

It is recommended to apply the method to other landing datasets to gain more experience.

## 5 REFERENCES

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