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Runway Safety NextGen

Authors

Captain Rob van Eekeren has been involved in runway safety policy development, rule making, training and implementation since 2002. His research on the future of runway safety is privately funded and aims at finding effective methods resulting in a reduction of the risks for passengers, crew and third parties on runway accidents. Dr. Stephen Wright is a Lecturer at the University of Leeds specializing in aviation and aircraft engineering. His research focus is aviation multidisciplinary, including runway excursion events, heat exchanger performance and environmental factors affecting airport operations.

Abstract

Reducing the risk of runway incursions or excursions in order to meet future aviation growth can be achieved two fold: by preventing and by limiting the level of damage. In order to reach an As Low As Reasonably Practicable (ALARP) level of runway safety is insight in the cost of runway safety events as well as in their mitigations required. Aircraft and Aerodrome operators could get this insight by combining the likelihood of future occurrences with their cumulative costs. On top of already existing prevention measures, new additional restrictions could face financial limits as indicated by the law of diminishing returns. That implies that either accepting the risk 'as is' and thus accepting higher levels of runway incursions and excursions or find cost-effective mitigations postponing the financial limits to safety. ; thus a cost-benefit approach.

A method of estimating the costs of runway related an occurrence has recently been published. Combining this method with a model capable of predicting the likelihood of runway incursions or excursions tailor-made per aircraft or aerodrome operator and their mitigations opens the possibility of a cost benefit approach. Runway incidents and accidents in the period 2015-2017 are analyzed and their costs estimated at $ 11 Billion, corrected for purchasing power. Veer-offs are shown to be by far the most costly events, followed by overruns. Runway incursion analysis has showed to be the least cost event compared with the two aforementioned events. The number and severity of veer-offs are expected to rise. The costs of future veer-offs should be weighed against the costs of prevention and the cost of reducing the levels of damage. Damage reduction is the main objective of the runway strip (RESA for overruns). It appears that the level of damage and costs rise considerably when a runway strip or RESA is inadequate or inappropriate for the moment (e.g. bearing strength).

A cost driven, flexible risk based system is recommended in order to reduce the risks and costs associated with runway excursions with emphasis on veer-offs and overruns. Concrete actions include a three step approach for aircraft and aerodrome operators.

Introduction

Major runway incursion and excursion accidents resulted (more than a decade ago) in initiatives to prevent these accidents. That resulted in the various prevention action plans and runway safety manuals. Currently, for more than ten years later since the inception and implementation of these initiatives, the results of preventing runway safety events happening should be visible. The law of diminishing returns poses financial restrictions of new additional preventive measures. It seems that most "low hanging fruits" have been

addressed already and that finding new measures becomes increasingly more difficult and costly.

In the present time, a shift in aviation safety thinking has occurred towards the ALARP safety levels. Operators should now aim at a low as reasonably practicable level (ALARP) of runway safety. This is achieved when further mitigations are either impracticable or grossly outweighed by the cost: It requires a prediction of future costs related to accidents or incidents at or near a runway and thus an estimation of the likelihood and the associated costs of occurrences. A consequence of this activity allows evaluation of the most cost-beneficial mitigations: If the mitigation costs grossly outweigh the likely future accident costs, than the risk is acceptable.

In order to further reduce the risks associated with runway related occurrences, a follow up policy needed to address these issues. This policy should be in line with the ALARP philosophy and thus compromises a cost-benefit approach.

Although preventing runway accidents is "in the blood of aviation safety," the principles may have become too challenging and costly to implement further runway incident related preventions. Also preventing should not be the sole goal, but the reduction of the risk and so the effects of an occurrence to humans should be recognised.

This effect compromises the hazard to injury, damage of equipment and property and disruption of operations. Therefore the next prevention measures the risk can be considered to include the reduced by cost effective measures (aimed at reducing the hazard of damage), reductions in potential fatalities, injuries and third party risk. Risk reduction includes minimizing the effect once a runway incursion or excursion has occurred. The most cost effective risk reduction measure should be preferred, whether that is an additional prevention system / measure or a system that reduces the level of damage.

Runway Safety NextGen

Runway Safety NextGen is a cost-benefit driven system aimed at reaching the ALARP level of runway safety.

Runway Safety NextGen identifies the current costs of runway incursions and excursions, prioritizes potential safety gains based on a cost-benefit approach, includes severity reduction as well as prevention measures as possible mitigations and allows selecting the most cost efficient mitigation.

This cost-benefit risk based system is expected to open a new line of risk reduction systems, resulting is less casualties, less injuries, reduction of the severity of damage, less effect on the operations and the third party risk. E.g. introduction of passive (and now active) safety systems in the automotive industry (seatbelts, airbags, cage construction, pedestrian protection design, road guard rails, etc.) did not prevent accidents occurring, but increased the survivability of the event and reduced the level of damage.

Overview

In order to gain an insight in the costs associated with runway incursions and excursions, the runway safety events that occurred in the period between 01-01-2015 and 01-10 2017 have been analyzed. Their associated costs have been estimated in accordance with the method provide by van Eekeren *et al.* (UDC: 625.717International Journal for Traffic and Transport Engineering, 2017, 7(3): 283 – 297).

In this (near) three-year period (see Table 1) the cost as a result from runway incursions and excursions are estimated at $ 11, 8 Billion. All costs are corrected for local purchasing power. 1082 runway damaging incursion and excursions events occurred in this time period and 208 people lost their lives.

TABLE 1: COST OF RUNWAY EVENTS BETWEEN 2015 -17. (SAFE RUNWAY GMBH)

2015-2017	Number of events	Fatalities	Total costs (Million $ PPC)
Incursions	29	0	556,5 $
Underruns	112	17	1.064,5 $
Veer-offs	607	120	7.081,1 $
Overruns	334	71	3.102,7 $

Results of runway incursions, underruns, veer-offs and overruns expressed per event type in number of events, number of fatalities and the estimated costs (Fig. 1). Veer-off's resulted in 120 fatalities and costs estimated at $7bn costs, overruns resulting in 71 fatalities and $3.1 bn, underruns resulting in 17 fatalities and $1bn costs: lastly, runway incursions reported no fatalities with $0,5 bn costs.

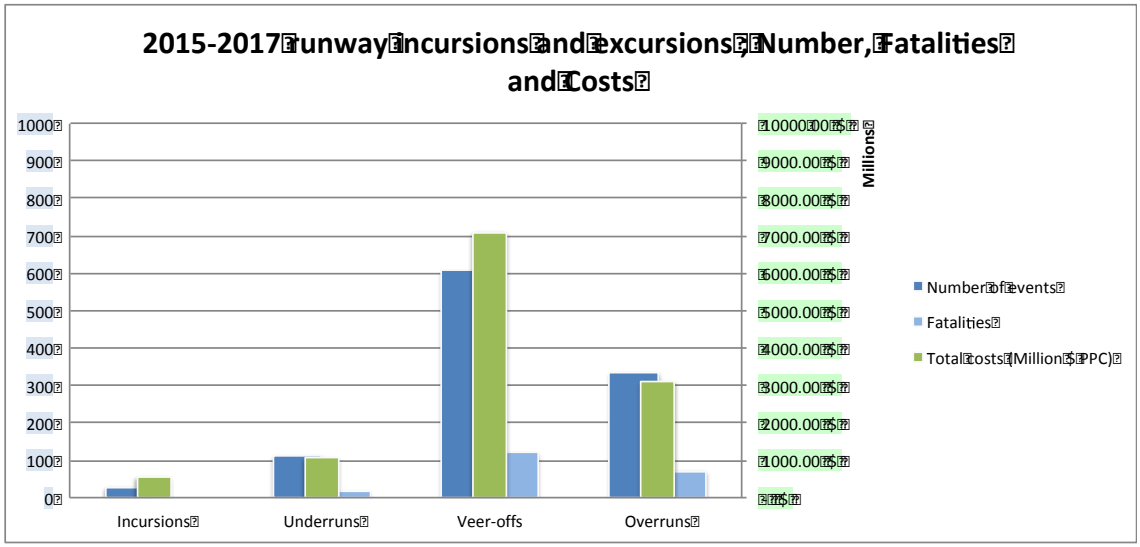

FIGURE 1: FREQUENCY, COST AND FATALITIES OF RUNWAY EVENTS 2015-17(SAFE-RUNWAY GMBH)

Runway incursions account for 5 % whilst runway excursion account for 95% of the total estimated costs (Fig. 2). 208 People lost their lives due to runway excursions in the period whilst none due to runway incursions.

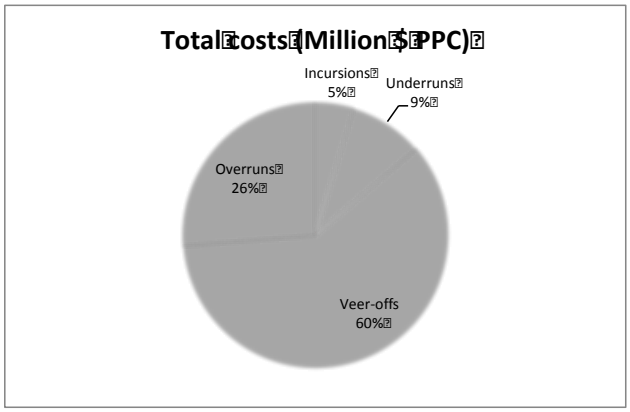

FIGURE 2: TOTAL COST OF RUNWAY EVENTS 2015-17 (SAFE-RUNWAY GMBH)

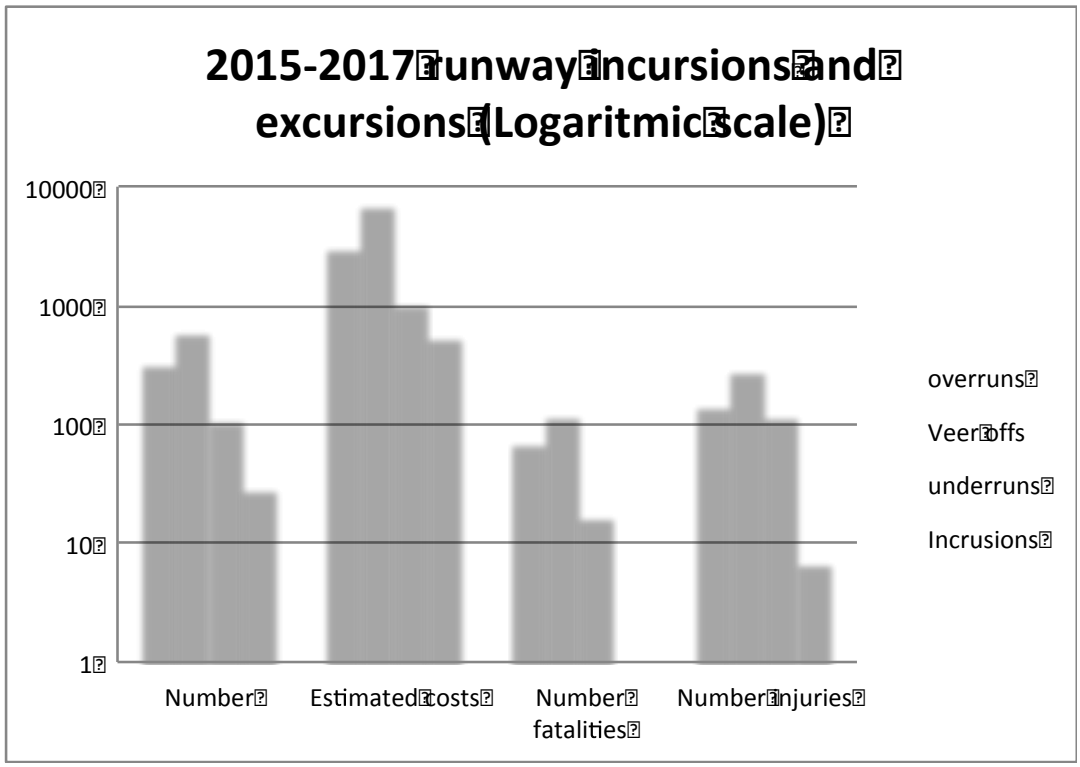

FIGURE 3: LOGARITHMIC REPRESENTATION OF RUNWAY EVENTS 2015-17 (SAFE-RUNWAY GMBH)

Figure 3 illustrates (frequency and event type) clearly, namely that runway veer-offs followed by overruns occur most frequently, resulting in the highest levels of recorded injuries and fatalities and have the by far highest associated costs. The costs, delays and injuries as a result of runway incursions are a fraction of the other three categories.

Discussion

Incursions

Since 2002, an increased the effort in preventing runway incursions has taken place. One might conclude that this was successful, even though the associated costs are nearly $ 200 Million annually. To compare the success rate of the runway incursion prevention plans, a cost

overview over a longer period (e.g. past 10 years) would be necessary. Although many low risk incursions occur (.e.g. crossing the holding line), damaging incursions seem to be rare events, as supported by the historical data.

Excursions

The same cannot be said for runway excursions (compared to incursions). Their (excursions) associated costs are estimated at $4bn per year. Preventing runway excursion has apparently not been so successful, as reflected by the financial and human costs. An overview over a 10 year period would also be useful.

Overruns

An average of 120 overruns occur yearly, with an estimated $1.3bn associated costs (All types of aircraft; All types of operation). The data suggests that general aviation suffers 90 yearly overruns with $800m costs *p.a.* . At the time of writing, the main emphasis of preventing runway overruns is focused on large commercial aircraft. In the period 2015-2017 a total of 19 ($130m p.a.) landing overruns and 3 take off overruns ($ 100m p.a.) with commercial air traffic (CAT) with a MCTOM of 45 300 kg or more having occurred. The historical data supports the view that take off related overruns are 5 times more costly as landing overruns. The conclusion is that although there is a certain public interest in this type of operation, the facts show that a focus only on landing overruns with large commercial aircraft might not be most cost effective.

Veer-offs

An average of 200 yearly veer-offs with 40 fatalities, 80 injuries and over $ 2.2bn costs occur. The yearly cost for CAT events are estimated at $ 700m. General aviation suffers 160 veer offs with $1.3bn of associated costs. It is likely that the number and costs of runway veer-offs will increase in the future due to three reasons. Firstly, the expected climate change (Puempel, 2016) will cause an increase attributed (cross-) wind events. Secondly, these will be more crosswind operations due to the combination of aviation growth and less crosswind orientated runways. Lastly, there is a tendency that aircraft manufacturers will provide lower restrictions regarding hard crosswind limits, thus safe operational decisions are passed from the manufacturer onto the aircraft operator and flight crews. Due to the expected increased number of crosswind operations, it would be imperative to include measures and systems that reduce the severity of runway excursions.

The high number and high associated costs require specific mitigations and risk reductions of runway veer offs.

Airports

Airport runway excursion risk reduction systems include the runway strip and RESA systems. The runway excursion costs and risks for humans have increased considerably, especially at those airports with an inadequate bearing strength of the runway strip (adverse weather) or non-adherence to the ICAO SARPS. On average, the annual data for HUB aerodromes observes typically 10 runway excursions ($600m); 120 events ($1.2bn) at regional aerodromes and 180 events at Municipal airports / strips ($ 330m).

Veer-offs at regional and hub aerodromes are more than twice as costly than overruns. At Municipal airports / strips the associated costs are about the same

ALARP

100% Prevention is highly unlikely; a certain rest risk remains. Also it will become increasingly more expensive to successfully implement additional prevention measures. The

ALARP level of safety will thus sooner be reached with a focus on prevention only. More emphasis is needed on increasing the survivability and reduction of the damage levels after an excursion event occurs. The actual bearing capability is based on the risk based analysis of the runway strip and RESA - taking into account the various weather types (heavy rain, snow, etc.) that is needed to effectively mitigate the cost of runway excursion associated risks.

Conclusion

Expressing runway incursions and excursions provides an excellent insight in the magnitude of these safety risks. The ALARP safety level to be achieved also requires an insight of the associated costs. It can be concluded that the risk associated with runway veer-offs and to a lesser extend also overruns require further reductions. Limits to further preventive measures provide the need for cost effective alternatives. These are likely to be find in reducing the effects / severity of a runway excursion. Contrary to controlled flight into terrain, or Mid-Air collision, ground-based accidents and events, in principle, could become 'more' survivable. Thus the first "low-hanging fruit" of risk reduction could be found in improving the runway strip and runway end safety area.

Recommendation

Runway Safety NextGen is a system where runway safety is increased though a pure cost-benefit driven approach. This will overcome expected limits posed by the law of diminishing returns in the near future. More emphasis of new measure to reduce the effects, frequency and severity of runway excursions is expected to be more cost-effective than imposing operational limits or measures, that currently imply a false sense of safety.

Aerodrome 3-step approach.

1. Step one is either full adherence to ICAO SARPS of airports of their runway strip and RESA (also in all of the local weather types) –or- the development of a new risk-based system where runway strip and RESA requirements take the local weather; prediction of the bearing capability also in adverse weather, the location of items endangering aircraft in the runway strip (e.g. ditches, trenches, sudden changes in soil (concrete, mud, grass, sand, etc.), the energy level of the incident aircraft at specific locations, fully into account for quantifying the risk of the aircraft and inhabitants.
2. Step two is an indication of the likelihood of a runway excursion, combined with the probability distribution of these occurrences along runway strip and the expected runway excursion costs per airport. This can be done in specific models capable of proving likelihood with energy level prediction of future overruns and veer-offs per major aircraft type utilizing the airport.
3. Step three will be choosing the most appropriate mitigations and their costs. If mitigations grossly outweigh the safety benefits than the risk is acceptable. If not, than the final step will be implementing the risk reduction mitigations.

Aircraft operators 3 step approach

1. Determine the likelihood of runway overruns and or veer-offs at the airports of operation and the associated costs. Costs are dependent on the expected level of damage and thus on the quality of the runway strip and RESA in preventing damage.
2. Determine appropriate mitigations and their costs. Include next to training, FDM and SOP's , cross- and tailwind limits for specific airports also the quality of the runway strip and RESA as potential mitigations.

3. Choose the most appropriate cast effective mitigation in order to meet the ALRP level of safety. If these cost outweigh grossly the safety benefit(s), accept the runway excursion risk.

ATTACHMENTS

A INCURSIONS analysis and data 2015-2017

B UNDERRUNS analysis and data 2015-2017

C VEER-OFFSanalysis and data 2015-2017

D OVERRUNSanalysis and data 2015-2017

INCURSIONSanalysis and data 2015-2017

ALL

In the period 01-01-2015 until 01-10-2017 a total of 29 incursions occurred. The total associated costs in the (almost) three-year period are estimated at 557 Million Dollar US (corrected for purchasing power). No lives were lost and 7 have been injured.

MTOM > 5700 kg

15 incursions with aircraft with a MCTOM of above 5700 kg occurred. The associated costs are estimated at $ 535 Million, and no injuries or fatalities are accounted for.

MCTOM ≤ 5700 kg

The number of incursions for light aircraft is about the same (14), with 7 injuries and also no fatalities. Total costs involved are estimated at 21 Million $.

Incursions	Number of Incursions	Estimated costs Million $ PPC	Number fatalities	Number injuries	Remarks
All types; All operators; All damage levels	29	556.5 $	0	7	
MCTOM > 5700kg					
All damage levels and types of operation	15	535.60 $	0	0	
& Damage Minor or more	7	534.0 $	0	0	
& GEN, NCC, TRA or CAT	7	534.0 $	0	0	
& Damage Substantial or Destroyed	6	522.9.0 $	0	0	
MCTOM ≤ 5700kg					
All damage levels and types of operation	14	20.9 $	0	7	
& Damage Minor or more	12	20.8 $	0	7	
& GEN, NCC, TRA or CAT	12	20.8 $	0	7	
& Damage Substantial or Destroyed	12	20.8 $	0	7	

SOURCE: SAFE RUNWAY GMBH; TABLE 2

Airports

The majority of the incursions occur at Municipal airports and strips, followed by half at the regional airports and only 2 at Hub aerodromes. The highest costs are at the Regional aerodromes. The average costs per overrun occurrence are the highest at Hub and Regional aerodromes about the same; at municipal airports considerably less.

Description	Number of **Incursions**	Estimated costs Million $ PPC	Number fatalities	Number injuries	Average cost per event
All types; All operators; All damage levels	29	556.5 $	0	7	$ 19.2 M
Airports					
HUB aerodromes	10	362.0 $	0	0	$ 36.2 M
Regional aerodromes	8	179.2 $	0	1	$ 22.4 M
Municipal Airports & strips	11	18.6. $	0	6	$ 1.7 M

SOURCE: SAFE RUNWAY GMBH; TABLE 3

UNDERRUNSanalysis and data 2015-2017

ALL

In the period 01-01-2015 until 01-10-2017 a total of 112 underruns occurred. The total associated costs in the (almost) three-year period are estimated at 1.1 Billion Dollar US (corrected for purchasing power). 17 People lost their lives and 119 have been inured due to runway underruns. Although technically an underrun might be considered as a CFIT, an accident/incident is taken as an underrun when the intention was to land the aircraft and when it contacted the area just before the runway.

MTOM > 5700 kg

16 underruns with aircraft with a MCTOM of above 5700 kg occurred. The associated costs are estimated at $ 848 Million, whilst 2 people lost their lives and 57 were injured.

MCTOM ≤ 5700 kg

The number of underruns for light aircraft is considerably higher (96) as are the number of fatalities and injuries together (15/ 62). The total costs involved are estimated at just above 216 Million $.

VEER-OFFS	Number of Underruns	Estimated costs Million $ PPC	Number fatalities	Number injuries	Remarks
All types; All operators; All damage levels	112	1 064.5 $	17	119	
MCTOM > 5700kg					
All damage levels and types of operation	16	848.0 $	2	57	
& Damage Minor or more	16	848.0 $	2	57	
& GEN, NCC, TRA or CAT	15	836.1 $	1	53	
& Damage Substantial or Destroyed	10	582.0 $	1	53	
MCTOM ≤ 5700kg					
All damage levels and types of operation	96	216.5.6 $	15	62	
& Damage Minor or more	96	216.5.6 $	15	62	
& GEN, NCC, TRA or CAT	96	216.5.6 $	15	62	
& Damage Substantial or Destroyed	87	213.4 $	15	59	

SOURCE: SAFE RUNWAY GMBH; TABLE 4

Airports

The majority of the underruns occur at Municipal airports and strips, followed by half at the regional airports and only 2 at Hub aerodromes. The highest costs are at the Regional aerodromes. The average costs per overrun occurrence are the highest at Hub and Regional aerodromes about the same; at municipal airports considerably less.

Description	Number of **Underruns**	Estimated costs Million $ PPC	Number fatalities	Number injuries	Average cost per event
All types; All operators; All damage levels	112	1 064.5 $	17	119	$ 9.5 M
Airports					
HUB aerodromes	2	64.7 $	0	0	$ 32.3 M
Regional aerodromes	27	809.7 $	2	71	$ 30 M

Municipal Airports & strips	82	179.2. $	14	44	$ 2.2 M

SOURCE: SAFE RUNWAY GMBH; TABLE 5

Aerodromes with Multi Occurrences

6 Airports had 2 or more underruns. The associated costs at these multi occurrence aerodromes are estimated at $ 20.5 Million

VEER-OFFS analysis and data 2015-2017

ALL

In the period 01-01-2015 until 01-10-2017 a total of 607 veer offs occurred. The total associated costs in the (almost) three-year period are estimated at 7.1 Billion Dollar US (corrected for purchasing power). 120 People lost their lives and 289 have been inured due to runway veer-offs.

MTOM > 5700 kg

140 veer-offs with aircraft with a MCTOM of above 5700 kg occurred. The associated costs are estimated at $ 6.1 Billion, whilst 78 people lost their lives and 79 were injured.

MCTOM ≤ 5700 kg

The number of veer-offs for light aircraft is considerably higher (467) as are the number of fatalities and injuries together (42/ 210). The total costs involved are estimated at just above 1 000 Million $.

VEER-OFFS	Number of Veer offs	Estimated costs Million $ PPC	Number fatalities	Number injuries	Remarks
All types; All operators; All damage levels	607	7 081.1	120	289	
MCTOM > 5700kg					
All damage levels and types of operation	140	6 080.8 $	78	79	
& Damage Minor or more	126	6 065.8$	78	75	
& GEN, NCC, TRA or CAT	112	5 334.8 $	67	62	
& Damage Substantial or Destroyed	73	4 302.1 $	67	60	
MCTOM ≤ 5700kg					
All damage levels and types of operation	467	1 000.3 $	42	210	
& Damage Minor or more	462	998.5 $	42	208	
& GEN, NCC, TRA or CAT	456	971.4 $	39	204	
& Damage Substantial or Destroyed	395	895.9 $	39	193	

SOURCE: SAFE RUNWAY GMBH; TABLE 6

Airports

The majority of the overruns occur at Municipal airports and strips, followed by half at the regional airports and les than 10% at Hub aerodromes. The highest costs are at the Regional aerodromes, closely followed by the Municipal/strip airports. Half these cost s occur at Hub

aerodromes. The average costs per overrun occurrence are the highest at Hub aerodromes (27M$), followed by Regional (11M$) and Municipal (4M$).

Description	Number of **Veer offs**	Estimated costs Million $ PPC	Number fatalities	Number injuries	Average cost per event
All types; All operators; All damage levels	607	7 081.1 $	120	289	9.3 M$
Airports					
HUB aerodromes	34	2 104.3 $	0	30	26.9 M$
Regional aerodromes	223	3 670.3 $	79	73	11.4 M$
Municipal Airports & strips	335	651.9 $	25	166	4.3 M$

SOURCE: SAFE RUNWAY GMBH; TABLE 7

Aerodromes with Multi Occurrences

32 Airports had 2 or more overruns and 93 airports had 2 or more veer-offs. The associated costs at these multi occurrence aerodromes are estimated at $ 782.5 Million

OVERRUNS analysis and data 2015-2017

ALL

In the period 01-01-2015 until 01-10-2017 a total of 334 overruns occurred. The total associated costs in the (almost) three-year period are estimated at $ 3.1 Billion Dollar (corrected for purchasing power). 71 People lost their lives and 147 have been inured due to runway overruns.

MTOM > 5700 kg

In the period 01-01-2015 until 01-10-2017 a total of 38 overruns occurred with civil aircraft with a maximum certified take of mass of above 5700 kg with substantial or more damage. The total associated costs in the (almost) three-year period are estimated at 1.5 Billion Dollar US. 26 people lost their lives and 18 have been inured. These costs take local purchasing power into account.

MCTOM ≤ 5700 kg

The number of overruns for light aircraft is considerably higher (203) as are the number of fatalities and injuries (44/ 128). The total costs involved are estimated at just above 500 Million $. Also corrected for local purchasing power.

OVERRUNS	Number of overruns	Estimated costs Million $ PPC	Number fatalities	Number injuries	Remarks
All types; All operators; All damage levels	334	3 102.7 $	71	147	
MCTOM > 5700kg					
All damage levels and types of operation	97	2 537.7 $	27	19	
& Damage Minor or more	76	2 469.1$	27	19	
& GEN, NCC, TRA or CAT	69	1 947.4 $	26	18	
& Damage Substantial or Destroyed	38	1 512.3 $	26	18	
MCTOM ≤ 5700kG					
All damage levels and types of operation	237	565.1 $	44	128	
& Damage Minor or more	235	564.9 $	44	128	
& GEN, NCC, TRA or CAT	233	556.3 $	43	128	
& Damage Substantial or Destroyed	203	514.2 $	39	125	

SOURCE: SAFE RUNWAY GMBH; TABLE 8

Airports

The majority of the overruns occur at Municipal airports and strips, followed by half at the regional airports and les than 10% at Hub aerodromes. The highest costs are at the Regional aerodromes, closely followed by the Municipal/strip airports. Half these cost s occur at Hub aerodromes. The average costs per overrun occurrence are the highest at Hub aerodromes (27M$), followed by Regional (11M$) and Municipal (4M$).

Description	Number of **overruns**	Estimated costs Million $ PPC	Number fatalities	Number injuries	Average cost per event
All types; All operators; All damage levels	334	3 102.7 $	71	147	9.3 M$
AIRPORTS					
HUB aerodromes	16	430.0 $	0	0	26.9 M$
Regional aerodromes	88	1 000.8 $	33	55	11.4 M$
Municipal Airports & strips	191	830.2 $	36	115	4.3 M$

SOURCE: SAFE RUNWAY GMBH; TABLE 9

Aerodromes with Multi Occurrences

32 Airports had 2 or more overruns and 93 airports had 2 or more veer-offs. The associated costs at these multi occurrence aerodromes are estimated at $ 782.5 Million.