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ADB SAFEGATE

HUMAN FACTOR ANALYSIS OF MIXING OF LED & HALOGEN AND WARM & COOL WHITE LED TECHNOLOGIES IN AGL

Executive Summary Report

March 2023

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1 TERMINOLOGY AND ACRONYMS

Acronym	Description
AGL	Airfield Ground Lighting
ALS	Approach Lighting Systems
A-SMGCS	Advanced Surface Movement Guidance & Control System
COPAC	Official College of Commercial Pilots
EFVS	Enhanced flight Vision Systems
EVS	Enhanced Vision System
GA	Go around
HAZOP	Hazard and Operability
HF	Human Factors
HRA	Human Reliability Assessment
ICAO	International Civil Aviation Organization
INECO	Engineering and Transport Economics
NVIS	Night Vision Imaging system
RE	Runway Excursion
RI	Runway Incursion
RWY	Runway
RCL	Runway Centerline Lighting System
RWE	Runway Edge Lighting System
TDZ	Touch Down Zone
TE	Taxiway Excursion
THR	Threshold Lighting System
TI	Taxiway Incursion
TOGA	Touch-down and Go Around
TWY	Taxiway
TCL	Taxiway Centre line Lighting system
TWE	Taxiway Edge Lighting system

2 REFERENCE DOCUMENTATION

Document		Reference	Version
[1]	ICAO Doc 9859 "Safety Management Manual"	ICAO 9859	4th Edition
[2]	ICAO Doc 9157 "Aerodrome Design Manual. Part 4 "Visual Aids" & Part 5 – Electrical Systems". Section 12.12	ICAO_9157	5th Edition (2021) & 2nd Edition, (2017).
[3]	ICAO Annex 14 "Aerodromes" – Vol I "Aerodrome Design and operations"- Chapter 5.3 Lights, Appendix 1, 2, Attachment A 12, 16.	ICAO_Annex14	8th Edition (July 2018)
[4]	EASA CS & GM for Aerodrome Design (2021), Chapter M	EASA_ADR-DSN	Issue 5 (2021)
[5]	FAA Advisory Circular AC 150/5340-30J: Design and Installation Details for Airport Visual Aids. FAA Order JO 6850.2B (Subject: Visual Guidance Lighting Systems).	FAA AC 150/5340-30J FAA JO 6850.2B	12/02/2018 20/08/2010
[6]	ADB-SG-INECO_Methodology Description	ADB-SG-INECO_Met.Des	Internal document
[7]	ADB-SG-INECO_System Description	ADB-SG-INECO_Sys.Des	Internal document
[8]	ADB-SG-INECO_ AGL Perception Questionnaires	ADB-SG-INECO_AGL-PQ	Internal document
[9]	ADB-SG-INECO_AGL Perception Questionnaire Development	ADB-SG-INECO_AGL-PQ.Dev	Internal document
[10]	ADB-SG-INECO_AGL Statistical Analysis	ADB-SG-INECO_Stat	Internal document
[11]	ADB-SG-INECO_AGL HF Risk Assessment	ADB-SG-INECO_HF Risk Assesssment	Internal document
[12]	ADB-SG-INECO_AGL HF Complete Report	ADB-SG-INECO_HF Complete Report	Internal document

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5 INTRODUCTION

To address some of the concerns about **mixing LED-Halogen technologies** (this interspersion is not recommended/approved[1] for installation) as well as **mixing LED Cool-Warm white lights** (it is approved for the installation) for AGL applications, ADB-SAFEGATE-sponsored research has included an assessing **Human Factor (HF)** based on visual perception to evaluate if the associated risk is acceptable or not for safety.

For this, a multidisciplinary team of experts has been created, being composed by **aeronautical engineers, aeronautical psychologists, HF experts from INECO** and **pilots from COPAC**, all with strong professional experience.

The risk assessment methodology has been prepared **considering ICAO Doc. 9859 [1]**, HF methodologies (tools as HRA and HAZOP sessions, interviews, and questionnaires).

The resultant **INECO's HF Assessment** methodology **integrates the study of the human perception in Conventional Safety Assessment Methodologies**.

The results of this study are applicable **exclusively** when comparing to **ADB Safegate LED technology**.

DISCLAIMER: The information contained in this study is provided solely for informative purposes. While reasonable effort has been made to ensure the accuracy and completeness of the contents herein, we do not accept any legal liability or responsibility for any errors, omissions, or inaccuracies contained within the study.

ADB Safegate reserves the right to modify, update, or remove any information contained in this study at any time, without prior notice.

[1] **According to ICAO** Doc. 9157 Part 5, 12.12.1 (12.12 Mixing Technologies), it is stated that "should be of the same technology" so it is not **recommended** that LED and incandescent lighting be mixed. **According to FAA** AC 150/5340-30J, 1.4 (Mixing of Light Source Technology), "LED light fixtures **must not** be interspersed with incandescent lights of the same type".

6 OBJECTIVE

The aim of this document is to **briefly describe the project development and point out the main conclusions** of the Human Factor Analysis LED & Halogen and White Cool & Warm LED Technologies Mix in AGL: AGL Human Factors Report.

The mentioned report **addresses the potential mix of Halogen & LED and Cool & Warm LED Technologies** analyzing **whether if the risks of the operations may be increased or not**, because of the mentioned mix, and **based on the Human Factor (HF) Methodology**.

7 METHOD

The HF Analysis has been carried out in the following phases:

1. Adaptation of the FARHRA Methodology for this project [6]

   The method followed is a human risk assessment (HRA) methodology adapted to the characteristics of this study [6]. For more information regarding all the activities and task performed within this study, see the HF Analysis Complete Report [12].

2. System description (ADB-SG database review) [7]

   After reviewing the specific lighting technology installed by ADB SAFEGATE in different airports [7], an initial database was made up with **50 different airports from 12 countries**, including the United States in addition to some European countries.

3. Definition of scenarios (ADB-SG database analysis & baseline scenarios selection) [7]

   The **lighting systems** in which human perception was assessed were:

   - **Approach** Lighting System (ALS)
   - **Runway Centerline** Lighting System (RCL)
   - **Runway Edge** Lighting System (RWE)
   - **Touch Down Zone** Lighting System (TDZ)
   - **Threshold** Lighting System (THR)
   - **Taxiway Edge** Lighting System (TWE) and
   - **Taxiway Centre** line Lighting System (TCL).

In order to facilitate the understanding of the classification of the lighting systems analyzed, it is necessary to explain the criteria followed. Thus, it is first necessary to distinguish which phase of flight (approach, landing or taxiing) is supported by the different lighting systems:

- **Approach:** The system in charge of providing information during this phase is the **ALS.**
- **Landing:** The systems in charge of providing information during this phase are the **THR and RWY (TDZ, centre line and edge**).
- **Taxiing:** The systems in charge of providing information during this phase are the **TWY centre line and the TWY edge** lighting systems.

Once this criteria has been established, the classification of Scenarios was carried out taking into account the following cases:

- **Same lighting system:** mixing of lights comparison within the same system.
- **Complementary lighting systems**: systems that constitute an aid in the same flight phase (approach, landing or taxiing). For example, runway centre line and runway edge are complementary lighting systems.
- **Adjacent lighting systems**: systems that constitute an aid in consecutive flight phases. For example, ALS and runway centre line are adjacent lighting systems as the first one assists the pilot, mainly, throughout the approach phase and the second one assists the pilot mainly throughout the landing phase.

The following table lists the use cases which were selected after the processing of the database from ADB-SAFEGATE by INECO.

Use case	Classification	Technology mix in lighting systems
C1	Adjacent	ALS (Halogen **white**) - the rest of the lighting systems (LED **white**)
C2	Adjacent	ALS (Halogen **white**) - RWY Centere line/Edge (LED **white**)
C3	Adjacent and complementary	ALS/RWY Edge (Halogen **white**) - RWY Centre line/ TDZ (LED **white**)
C4	Same	ALS (LED cool **white** mixed with LED warm **white** lights)
C5	Adjacent	ALS (LED warm **white**) - RWY Centre line/TDZ (LED cool **white**)
C6	Complementary	RWY Centre line (LED warm **white**) - RWY Edge (LED cool **white**)
C7	Complementary	RWY Centre line/TDZ (LED cool **white**) - RWY Edge (LED warm **white**)
C8	Same and complementary	RWY Centre line/Edge elevated/TDZ (LED cool **white**) - RWY Edge inset (LED warm **white**)
C9	No mix	All lighting systems Halogen **white**
C10	Adjacent	RWY Edge (LED cool **white**) - TWY Edge (**blue**)
C11	Same	TWY Edge (LED and halogen **blue** technology mix)
C12	Same	TWY Centre line (LED and halogen **green** technology mix)

Table 1 – Definition of use cases of Table 2.

Finally, considering the possible flight destinations of COPAC's pilots and the scenarios adequacy to risk assessment on perception, **17 final scenarios** have been selected and **17 questionnaires** were developed for this project [9] to assess the lighting particularities.

4. Development of AGL Perception Questionnaires [8] [9]

The specific **AGL Perception (HF) Questionnaires** [9] include both:

- **Observational research** of different technologies a) (LED or halogen) and b) LED lighting temperatures (cool or warm) in the same/complementary/adjacent systems (filled by pilots during approach, landing and taxiing phases).
- At the end, a **complementary expert judgement**[2] asking the pilot **whether the risk will be increased or not due to interspersion of different technologies or LED lighting temperatures in the same system in hypothetical scenarios**. This final section of the questionnaires was filled by the pilots once finished the flight operation.

5. Training to pilots

It is important to note that the **twelve pilots selected by COPAC for this study have received specific training sessions:**

- On one hand, they are used to participate in observational studies and fill questionnaires.[3]
- On the other hand, all of them **were trained by INECO** in lights hardware and photometry, HF, and visual perception issues related to the specific AGL HF Questionnaires.

6. Flight data collection period

- Data has been gathered for **3 months** (November-22, December-22, January-23) and **87 answers to questionnaires** have been collected.
- A total of **17 different questionnaires were completed by pilots**. Further information regarding the scenarios selection process and criteria, are detailed in document System Description [7] section 7.

[2] The expert judgement group is composed by pilots in command of the aircraft, as they are the only one who can judge the safety of the operation in relation to the perceived airfield lighting, as they are the principal user of the AGL.

[3] These 12 pilots are qualified observers of the observatory (COPAC-ENAIRE) issued by the Polytechnic University of Madrid (UPM).

- It is important to note that **COPAC's pilots flew 17 out of 29 scenarios that were initially proposed**. The rows in the table below show the 17 scenarios (airports) and columns represent the different use cases:

ID scenario	IATA Code	RWY	HEAD	Halogen - LED white			LED cool - LED warm white					Haglogen white	Other	Halogen - LED other colors		Number of samples collected
				C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	
1	LEMG/AGP	13 - 31	31						✓				✓			1
2	LEAL/ALC	10 - 28	10						✓							**5**
3	LEAL/ALC	10 - 28	28	✓					✓							**2**
4	LFPO/ORY	07 - 25	25				✓			✓						**11**
5	LFPO/ORY	06 - 24	06				✓		✓				✓			9
6	LFPO/ORY	06 - 24	24				✓		✓				✓			**1**
7	LFPG	09L - 27R	27R				✓			✓						**1**
8	LEPA/PMI	06L - 24R	06L						✓							3
9	LEPA/PMI	06L - 24R	24R		✓											9
10	EFHK/HEL	04R - 22L	22L			✓								✓	✓	1
11	EGCC/MAN	05L - 23R	23R		✓											1
12	EGCC/MAN	05R - 23L	05R													1
13	LEBL/BCN	02 - 20	2									✓				6
14	LEBL/BCN	06L - 24R	06L					✓			✓					1
15	LEBL/BCN	06L - 24R	24R								✓					26
16	LEMD/MAD	14L - 32R	32R									✓				8
17	KBOS/BOS	04R - 22L	22L									✓				1
TOTAL																87

Table 2 – Summary table of the 17 scenarios finally observed.

Finally, 10 airports[4] were selected to perform the analysis (Statistical and Risk Assessment). These airports were selected based on the following 3 criteria:

1) Presence of ADB-SG lighting technology,

2) COPAC's pilots possible destinations and

3) Lighting systems proximity with different technologies.

7. Statistical Analysis [10]

87 answers were collected from COPAC pilots and a Statistical Analysis [10] was performed:

- Observational research has been focused on the following aspects: **demographic data**, operational **visibility conditions, perception sensory characteristics** (glare, color, definition, intensity and so on) for **each lighting system.**
- Expert judgement has been performed on the combination in different percentages of mixing LED-Halogen technologies and LED Cool-Warm lights (Alternative Scenarios): 5%; 5% - 25%; 25% - 50%; > 50%.

[4] Málaga – Costa del Sol Airport *(**LEMG**)*, Alicante – Elche Miguel Hernández Airport *(**LEAL**)*, Josep Tarradellas Barcelona – El Prat Airport *(**LEBL**)*, Boston Logan Airport *(**KBOS**)*, Paris – Charles de Gaulle Airport *(**LFPG**)*, Adolfo Suárez Madrid – Barajas Airport *(**LEMD**)*, Paris – Orly Airport *(**LFPO**)*, Palma de Mallorca Airport *(**LEPA**)*, Manchester Airport *(**EGCC**) and* Helsinki Airport *(**EFHK**)*.

8. HF Risk Assessment [11]

   Then, the **HF Risk Assessment was conducted based on ICAO 9859**. This HF Risk Assessment enables to stablish the Risk Probability and the Risk Severity, which finally result in a Risk Tolerability for both observational research and expert judgement. In the end, all these parameters will determine whether the risk may increase or not.

The following sections (section 8 and section 9) show main findings for both, Statistical Analysis and HF Risk Assessment.

8 STATISTICAL ANALYSIS RESULTS

The distribution of the **scenarios** and the number of observations collected (14 related to LED-Halogen technologies, 60 to Cool-Warm LED and 15 to only Halogen technology) can be shown **organized according to the technology mix** as follows:

Technology/ Temperature of lights mix	Airports where it has been evaluated	Nº Airports from which data has been collected	Samples collected
Halogen – LED Samples	LEAL / ALC 28; LEPA/ PMI 24 R; EFHK/ HEL 22L; EGCC/ MAN 05R & 23R	5	14
LED Samples (LED Warm-Cool)	LEAL /ALC 10, 28; LEBL /BCN 06L, 24R; LEMG/AGP 31; LEPA/PMI 06L; LFPG/CDG 27R; LFPO/ORY 24, 25, 06	10	60
Halogen samples	KBOS/BOS 22L; LEBL/BCN 02; LEMD/MAD 32R	3	15
TOTAL	17 different runways	18[5]	89[6]

Table 3 – Distribution of data collected of scenarios.

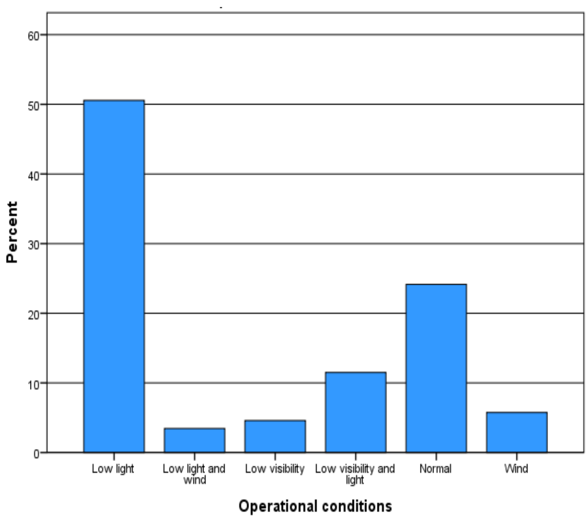
Firstly, the conclusions derived from the statistical analysis are grouped into the findings related to operational conditions of visibility, the perception of lighting system characteristics, perception of the Light System and the self-assessment of the safety risk for the mixing of lights (expert judgement).

Findings related to operational conditions of visibility:

The results were statistically crossed check with meteorology, destination, perception of lighting system characteristics and self-assessment of the safety risk of the mixing of lights.

[5] Málaga – Costa del Sol Airport ***(LEMG)***, Alicante – Elche Miguel Hernández Airport ***(LEAL)***, Josep Tarradellas Barcelona – El Prat Airport ***(LEBL)***, Boston Logan Airport ***(KB)***

[6] Please note that LEAL/ALC 28 was flown twice, which means that it has been double counted in the total number of scenarios and 4 times in the total number of samples.



- **Results** have turned to be **closely related with meteorology:** 24% of the operations took place during the day, with good operational conditions, and 65% in low light conditions.
- Low **visibility conditions appear, most of the time due to rain or fog**. No flight was operated under snow and ice conditions. **Most of the operations in low light conditions occur at night (75%)**.

Figure 1 – Frequency of operational conditions in the 87 observations.

Findings regarding the perception of lighting system characteristics, in most of the use cases where pilots perceived a variation in a sensory characteristic (change in photometric characteristics regarding to perception most of the time), meteorology conditions were adverse.

Sensory characteristics regarding the usual perception	A Halogen-LED lights mix	B Warm-Cool LED lights mix	C= B-A LED-Halogen vs Warm-Cool LED
Change in usual perception of lights	29%	31%	No significant difference
Change in light intensity	50%	14%	36%[7] greater impact in LED-Halogen
Change in scattering	0%	7%	No significant difference
Glare	21%	14%	No significant difference
Color variation	0%	10%	10% greater impact in cool-warm
Change in definition	14%	16%	No significant difference

Table 4 – Frequency of sensory characteristics where change has been detected from the usual perception in Halogen-LED and LED Cool – Warm.

[7] Please note that cases > 15% are highlighted in blue.

So, according to comparison between the two types of mixes:

- There was no significant difference between the two mixes except for the intensity of the lights (36% more of the pilots have detected change in intensity in halogen-LED mix technology than in LED warm-cool) and in color variation (10% more of the pilots have detected a variation in color in LED lighting mix compared to halogen-LED mixing.

Chi-Square *Test* was used to formulate and check the interdependence between sensory characteristics and operational conditions. The results of X^2 test are as follows:

Change in light characteristics	Pearson Chi-Square (X^2) value	*Sig.*
Habitual Perception	16,861	0,005
Brightness perception	41,897	0,000
Scattering	42,888	0,000
Glare	32,61	0,000
Color perception	5,968	0,309
Definition	42,885	0,000

Table 5 – Chi-square between light characteristics and operational conditions.

- This statistic tells us **that pilots have perceived a change in intensity, glare and definition of mixes in adjacent systems due to operational conditions**. However, there is no statistically significant association between perception of change in color and operational conditions X^2= 5,968, *p*= .309. It is important to highlight that the sample knew that they were assessing white lights.

Pilots evaluated the **white color of lights** according to the following **temperature discrete scale**. Considering 1,000K the warmest color and 10,000K the coolest color, it has been divided in scale of 1,000 by 1,000K, so **10 different colors were evaluated (from A to J)** for each system.

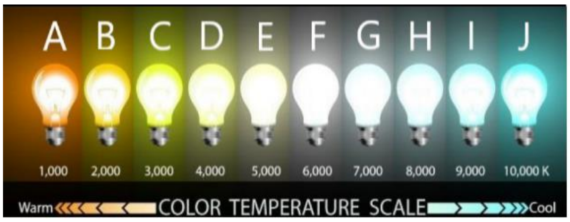


Figure 2 – Light color temperature scale.

- The distribution of color perception of the ALS along different distances shows the **predominance of warm and neutral white color** of the system perceived. Pilots perceived, in general, LED lights, as cool and halogen lights as warm).

- However, there is an evolution in function of the distance (at 3NM, 0,7NM and 0,4NM) in which lights are observed, as the pilots get closer from the ALS to the runway, they tend to perceive a much more **neutral white** color than yellowish.
- Regarding LED brightness and the light difference between warm and cool LED lights, 98% of the pilots consider that it does not affect the required safety levels.
- No uncertainty or affection in the reaction time, produced by the mix between warm and cool LED, has been reported by the 100% of the samples.

For more information regarding Transversal analysis for ALS and RWY systems and RWY TWY see Statistical Analysis.

9 AGL HF RISK ASSESSMENT RESULTS

9.1 AGL HF RISK ASSESSMENT CONCEPTS

In the following paragraphs the HF Risk Assessment will be described, however for your interest document [11] describes the assessment process in more detail.

In this study, **the hazard**[8] is considered as the sensory characteristics of the mixing of LED & Halogen or Warm & Cool LED Technologies **affecting the visual perception** of AGL.

9.1.1 SAFETY & HF RISK PROBABILITY

The probability (frequency) of its occurrence, has been defined specifically for this risk, considering the responses frequency provided by pilots. The probability description is defined in [11]:

Value	Likelihood	Meaning	Qualitative Description Quantitative Description
5	Frequent	It is expected to affect the perception of most pilots	It has occurred several times during the study, frequently, more than three quarters of responses It is expected to affect the perception of more than 75% of responses
4	Probable/occasional	It will probably affect at some point	It has occurred sometimes in this study, but infrequently, more than half of the time It is expected to affect the perception of between 50% and 75% of responses
3	Possible/remote	It could affect at some point	It has occurred rarely in this study, less than half of the time It is expected to affect the perception of between 25% and 50 % of responses
2	Improbable	Very unlikely to occur	Unlikely to affect but nevertheless has been considered as being possible It is expected to affect the perception of between 10% and 25% of responses
1	Extremely improbable	May affect only in exceptional circumstances	Almost did not occur in this study It is expected to affect the perception of less than 10% of responses

Table 6 - Probability description table.

[8] Hazards are sources of possible injury or damage, and their safety consequences are described in operational terms.

9.1.2 SAFETY & HF RISK SEVERITY

The severity assessment **has considered different possible consequences related to the hazard, taking into account the worst foreseeable situation**. a

The questions of the AGL perception questionnaire ask directly pilots to provide their opinion about potential consequences: whether mixing of lights is negatively affecting their perception (ex. glare, heterogeneous lighting, poor depth perception up to THR), safety (ex. by increasing uncertainty, reaction time or some other consequences such as performance adjustments in speed/direction controls, missed approach, GA, TOGA, RI/RE, TI/TE) or by asking them to self-assess acceptability.

The safety risk severity table was prepared in line with these questions.

Value	Severity	Meaning	Severity Description
A	Catastrophic	Accident	Aircraft / equipment destroyed.
			Multiple deaths.
B	Hazardous	Serious injury	Degradation of safety, the affectation in perception significantly influences safety.
			Major equipment damage. Serious injury.
C	Major	Serious incident	A significant reduction in safety margins, it affects pilot performance as a result of an increase in workload. RI / RE, incorrect runway alignment. Affectation in depth perception.
			Serious incident. Injury to people.
D	Minor	Operating limitations	Degrades or affects operational performance due to increased uncertainty.
			Minor incident GA/TOGA TE/TI.
E	Negligible	Few consequences	No effect on system performance or safety.

Table 7 - Severity description table.

9.1.3 SAFETY & HF RISK TOLERABILITY

Combining the two tables above, and the pilot's responses, the tolerability matrices for each of the systems are obtained, in line with ICAO Doc 9859 [1].

Safety risk		Severity				
Probability		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Table 8 - Tolerability matrix.

The following table is a summary of the safety & risk tolerability study for each lighting system.

Safety Risk Index Range	Safety Risk Index Description	Recommended Action
5A,5B,5C,4A,4B,3A	INTOLERABLE/ UNACCEPTABLE	Take immediate action to mitigate the risk or stop the activity. Perform priority safety risk mitigation to ensure additional or enhanced preventive controls are in place to bring down the safety risk index to tolerable.
5D,5E,4C,4D,4E,3B,3C,3D, 3E,2A,2B,2C,1A	TOLERABLE	It can be tolerated based on the safety risk mitigation. It may require a management decision to accept the risk.
3E,2D,2E,1B,1C,1D,1E	ACCEPTABLE	Acceptable as it is. No further safety risk mitigation required.

Table 9 - Tolerability description table.

9.2 AGL HF RISK ASSESSMENT RESULTS (BASELINE SCENARIOS)

In this section, the results of the AGL HF Risk Assessment of the **baseline scenarios** (existing lighting systems at airports) are presented. The following tables show:

- the severities vary from C to E (from Major to Negligible).
- the probability values are almost always equal to 1, except on a couple of occasions where it is 2 (1 is Extremely improbable, and 2 is Improbable),

<table>
<tr><th>Technology</th><th>System</th><th>Analysis method</th><th>System 1</th><th>System 2</th><th>Airports</th><th>Sample</th><th>Tolerability</th><th>Safety Risk Index</th></tr>
<tr><td rowspan="5">LED-Halogen</td><td rowspan="3">ALS</td><td>Adjacent system</td><td>Halogen ALS</td><td>LED RWY centre line</td><td>LEAL 28
LEPA 24R
EGCC 05R, 23R
EFHK 22L</td><td>14</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Adjacent system</td><td>Halogen ALS</td><td>LED RWY edge</td><td>LEAL 28
LEPA 24R
EGCC 05R, 23R</td><td>13</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Adjacent system</td><td>Halogen ALS</td><td>LED TDZ</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td rowspan="2">RWY CENTRELINE</td><td>Adjacent system</td><td>LED RWY centreline</td><td>Halogen ALS</td><td>LEAL 28
LEPA 24R
EGCC 05R, 23R
EFHK 22L</td><td>14</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Complementary system</td><td>LED RWY centre line</td><td>Halogen RWY edge</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td rowspan="8">LED-Halogen</td><td rowspan="3">RWY EDGE</td><td>Adjacent system</td><td>LED RWY edge</td><td>Halogen ALS</td><td>LEAL 28
LEPA 24R
EGCC 05R, 23R</td><td>13</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Complementary system</td><td>Halogen RWY edge</td><td>LED RWY centre line</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Complementary system</td><td>Halogen RWY edge</td><td>LED TDZ</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td rowspan="2">TDZ</td><td>Adjacent system</td><td>LED TDZ</td><td>Halogen ALS</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td>Complementary system</td><td>LED TDZ</td><td>Halogen RWY edge</td><td>EFHK 22L</td><td>1</td><td>Acceptable</td><td>1C,1D,1E</td></tr>
<tr><td rowspan="2">TWY</td><td>System itself</td><td>Halogen TWY centre line</td><td>LED TWY centre line</td><td rowspan="2">EFHK 22L</td><td rowspan="2">1</td><td rowspan="2">Acceptable</td><td rowspan="2">1D,1E</td></tr>
<tr><td>System itself</td><td>Halogen TWY edge</td><td>LED TWY edge</td></tr>
<tr><td>THR</td><td colspan="3">Included as a risk consequence</td><td>LEAL 28
EGCC 05R, 23R
EFHK 22L</td><td>5</td><td>Acceptable</td><td>1D</td></tr>
</table>

Table 10 - Summary table for the Halogen-LED risk assessment of the baseline scenarios.

Technology	System	Analysis method	System 1	System 2	Airports	Samples	Tolerability	Safety Risk Index
Cool-Warm LED	ALS	System itself	Cool ALS	Warm ALS	LFPO 06,24,25 LFPG 27R	22	Acceptable	1D,1E
	RWY centre line	Complementary systems	Warm RWY centre line	Cool RWY edge	LFPO 06,24 LEMG 31 LEAL 10,28 LEPA 06L	21	Acceptable	1C,1D,1E
		Complementary systems	Cool RWY centre line	Warm RWY edge	LFPO 25 LFPG 27R	12	Acceptable	1C,1D,1E
		Complementary systems	Cool RWY centre line	Inset Warm RWY edge	LEBL 06L LEBL 24R	27	Acceptable	1C,1D,1E, 2D
	RWY EDGE	Complementary systems	Cool RWY edge	Warm RWY centre line	LFPO 06,24 LEMG 31 LEAL 10,28 LEPA 06L	21	Acceptable	1C,1D,1E
		Complementary systems	Warm RWY edge	Cool RWY centre line	LFPO 25 LFPG 27R	12	Acceptable	1C,1D,1E
		Complementary systems	Warm RWY edge	Cool TDZ	LFPO 25 LFPG 27R	12	Acceptable	1C,1D,1E
		Complementary systems	Inset Warm RWY edge	Cool RWY centre line	LEBL 06L LEBL 24R	27	Acceptable	1C,1D,1E, 2D
		Complementary systems	Inset Warm edge	Cool TDZ	LEBL 06L LEBL 24R	27	Acceptable	1C,1D,1E, 2D
Cool-Warm LED	TDZ	Complementary systems	Cool TDZ	Warm RWY edge	LFPO 25 LFPG 27R	12	Acceptable	1C,1D,1E
		Complementary systems	Cool TDZ	Inset Warm RWY edge	LEBL 06L LEBL 24R	27	Acceptable	1C,1D,1E, 2D
	TWY	Complementary system	Blue TWY	Cool white RWY edge	LFPO 6, 24 LEMG 31	10	Acceptable	1D, 1E

Table 11 - Summary table for the Cool-Warm LED risk assessment of the baseline scenarios.

9.3 GLOBAL AGL HF RISK ASSESSMENT RESULTS (ALTERNATIVE SCENARIOS)

The purpose of this section is to facilitate the access to the global AGL HF Risk Assessment results of the Alternative Scenarios, based in expert judgement, in a simple way. In following sections (Section 9.4), the results will be shown for the different lighting systems.

The ranges established for the alternative scenarios are:

- LED-Halogen mix <5%.
- LED-Halogen mix 5-25%.
- LED-Halogen mix 25-50%.
- LED-Halogen mix >50%.
- LED Cool-Warm mix <5%.
- LED Cool-Warm mix 5-25%.
- LED Cool-Warm mix 25-50%.
- LED Cool-Warm mix >50%.

Summarizing, for the **LED-Halogen mixing**:

- For **low mix percentages (<5% and 5-25%)**, the **mix** is **predominantly acceptable**, so **the risk does not seem to increase.**
- **Above these percentages, the first "Unacceptable" (4.7%in 25-50%) appear, especially after 50% of the mix (22.1% of "Unacceptable"), so it cannot be assured that the risk does not increase**.

Summarizing, for the **Cool-Warm LED mixing**:

- For **low mix percentages (<5% and 5-25%), the Cool-Warm white LED mixing is almost 100% acceptable**, being still **0% unacceptable** for 25-50% mix**.**
- **For percentages above 50%, "tolerable" values reaches 55.8%. Nevertheless, the maximum percentage of "Unacceptable" is 1.2%, so it seems that the risk does not increase**.

9.3.1 LED-HALOGEN <5%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
LED-Halogen <5%	Acceptable	100%
	Tolerable	0%
	Unacceptable	0%

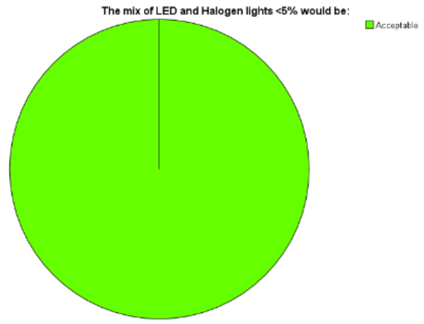


Figure 3 – Percentages for LED-Halogen <5%.

As can be seen, **100% of the pilots report that the mix would be acceptable in this percentage**.

9.3.2 LED-HALOGEN 5-25%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
LED-Halogen 5-25%	Acceptable	81,4%
	Tolerable	18,6%
	Unacceptable	0%

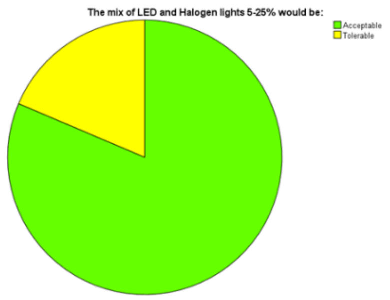


Figure 4 – Percentages for LED-Halogen 5-25%.

This time, **the presence of "Acceptable" remains high, but the presence of "Tolerable" is already detected**.

9.3.3 LED-HALOGEN 25-50%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
LED-Halogen 25-50%	Acceptable	53,5%
	Tolerable	41,9%
	Unacceptable	4,7%

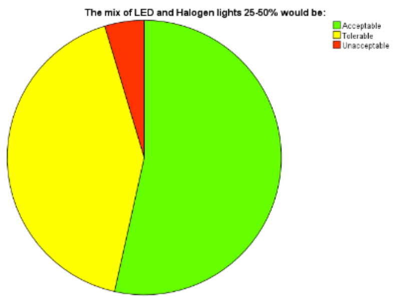


Figure 5 – Percentages for LED-Halogen 25-50%.

On this occasion, **the number of "Acceptable" and "Tolerable" responses is becoming more similar. First "Unacceptable" responses are beginning to appear**.

9.3.4 LED-HALOGEN >50%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
LED-Halogen 25-50%	Acceptable	29,1%
	Tolerable	48,8%
	Unacceptable	22,1%

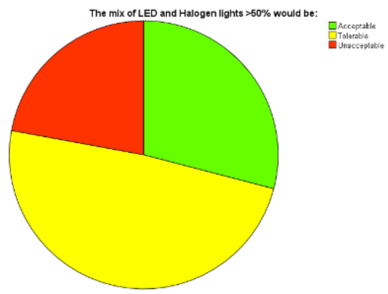


Figure 6 – Percentages for LED-Halogen >50%.

For this case the **most frequent value is "Tolerable". The presence of "Unacceptable" is already considerable, while acceptability has decreased**.

9.3.5 COOL-WARM LED <5%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
Cool-Warm LED <5%	Acceptable	100%
	Tolerable	0%
	Unacceptable	0%

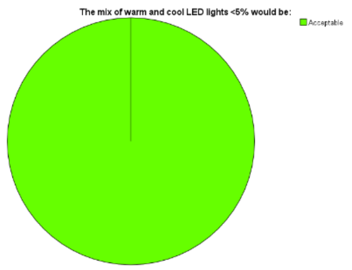


Figure 7 – Percentages for Cool-Warm LED <5%.

As in the previous item, **all reported values are "Acceptable"**.

9.3.6 COOL-WARM LED 5-25%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
Cool-Warm LED <5%	Acceptable	97,7%
	Tolerable	2,3%
	Unacceptable	0%

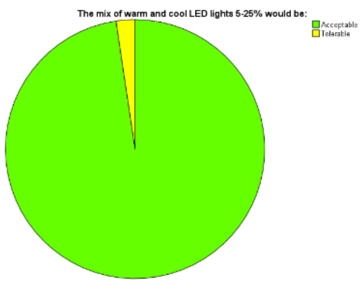


Figure 8 – Percentages for Cool-Warm LED 5-25%.

Again, **almost all values are "Acceptable"**.

9.3.7 COOL-WARM LED 25-50%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
Cool-Warm LED <5%	Acceptable	66,3%
	Tolerable	33,7%
	Unacceptable	0,0%

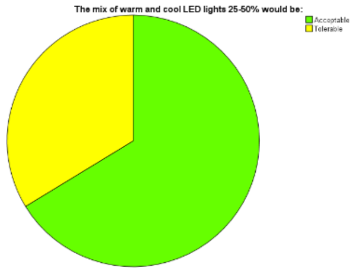


Figure 9 – Percentages for Cool-Warm LED 25-50%.

It is interesting to note that, for high values of mix such as **between 25 and 50%,** the **most frequent value is still Acceptable**, being the rest Tolerable.,

That is, **none of the pilots would consider the Cool-Warm mix LED as Unacceptable for these percentages.**

9.3.8 COOL-WARM LED >50%

The obtained results can be summarized according to the following representations:

Mix	Tolerability	Percentage
Cool-Warm LED <5%	Acceptable	43,0%
	Tolerable	55,8%
	Unacceptable	1,2%

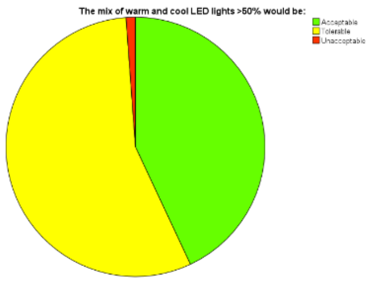


Figure 10 – Percentages for Cool-Warm LED >50%.

The most frequent value is “Tolerable” followed by “Acceptable”. **Even for the most conflicting range (>50%), only 1% of “Unacceptable” is detected.**

9.4 AGL HF RISK ASSESSMENT RESULTS BY SYSTEMS (ALTERNATIVE SCENARIOS)

In this section, the results, based in Expert Judgement, of AGL HF Risk Assessment of the **alternative scenarios by lighting systems** are presented.

Summarizing, for the **LED-Halogen mixing**:

- For **low mix percentages (<5% and 5-25%)**, the **mix** is **predominantly acceptable**, so **the risk does not seem to increase** compared with its equivalent baseline scenario, where it was classified as Acceptable.
- For **higher mix percentages (>50%)**, **there are some cases** (ALS, RWY CL, RWY Edge), where it is considered **Unacceptable** (**<25%** of the replies, being 75% of the replies "Acceptable" or "Tolerable").

On the other hand, for **the Cool-Warm white LED mix**:

- For **low mix percentages (<5% and 5-25%)**, on the same application / lighting system, the Cool-Warm white LED mixing is **almost 100% acceptable**. For **medium percentages (25-50%)**, the Cool-Warm white LED mix is **predominantly acceptable**. In these cases, the **risk does not seem to increase** compared with its equivalent baseline scenario.
- For **higher mix percentages (>50%)**, **there are some cases** (RWY CL, RWY Edge, TDZ), where it is considered **Unacceptable** (**<5%** of the replies, being 95% of the replies "Acceptable" or "Tolerable")

Technology	System	Analysis method	System 1	System 2	Airports	Samples	Expert judgment for those airports				
							Tolerability	<5%	5-25%	25-50%	>50%
LED-Halogen	ALS	Adjacent system	Halogen ALS	LED RWY centre line	LEAL 28 LEPA 24R EGCC 05R 23R EFHK 22L	14	Acceptable	100%	85,7%	50%	35,7%
							Tolerable	0%	14,3%	50%	42,8%
							Unacceptable	0%	0%	0%	21,4%
		Adjacent system	Halogen ALS	LED RWY edge	LEAL 28 LEPA 24R EGCC 05R 23R	13	Acceptable	100%	84,6%	46,2%	30,7%
							Tolerable	0%	15,4%	53,8%	46,2%
							Unacceptable	0%	0%	0%	23,1%
		Adjacent system	Halogen ALS	LED TDZ	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
	RWY CENTRE LINE	Adjacent system	LED RWY centre line	Halogen ALS	LEAL 28 LEPA 24R EGCC 05R 23R EFHK 22L	14	Acceptable	100%	85,7%	50%	35,7%
							Tolerable	0%	14,3%	50%	42,8%
							Unacceptable	0%	0%	0%	21,4%
		Complementary system	LED RWY centre line	Halogen RWY edge	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
LED-Halogen	RWY EDGE	Adjacent system	LED RWY edge	Halogen ALS	LEAL 28 LEPA 24R EGCC 05R 23R	13	Acceptable	100%	84,6%	46,2%	30,7%
							Tolerable	0%	15,4%	53,8%	46,2%
							Unacceptable	0%	0%	0%	23,1%
		Complementary system	Halogen RWY edge	LED RWY centre line	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
		Complementary system	Halogen RWY edge	LED TDZ	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
	TDZ	Adjacent system	LED TDZ	Halogen ALS	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
		Complementary system	LED TDZ	Halogen RWY edge	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
							Unacceptable	0%	0%	0%	0%
	TWY	System itself	Halogen TWY centre line	LED TWY centre line	EFHK 22L	1	Acceptable	100%	100%	100%	100%
							Tolerable	0%	0%	0%	0%
		System itself	Halogen edge	LED edge			Unacceptable	0%	0%	0%	0%
	THR	Risk consequence			LEAL 28 EGCC 05R, 23R EFHK 22L	5	Acceptable	100%	100%	86,4%	50%
							Tolerable	0%	0%	13,6%	50%
							Unacceptable	0%	0%	0%	0%

Table 12 - Summary table for the Halogen-LED risk assessment of the alternative scenarios.

Technology	System	Analysis method	System 1	System 2	Airports	Samples	Expert judgment for those airports				
							Tolerability	<5%	5-25%	25-50%	>50%
Cool-Warm white LED	ALS	System itself	Cool ALS	Warm ALS	LFPO 06,24,25 LFPG 27R	22	Acceptable	100%	100%	89,9%	54,6%
							Tolerable	0%	0%	9,1%	45,4%
							Unacceptable	0%	0%	0%	0%
	RWY centre line	Complementary systems	Warm RWY centre line	Cool RWY edge	LFPO 06,24 LEMG 31 LEAL 10,28 LEPA 06L	21	Acceptable	100%	100%	71,4%	47,6%
							Tolerable	0%	0%	28,6%	52,4%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Cool RWY centre line	Warm RWY edge	LFPO 25 LFPG 27R	12	Acceptable	100%	100%	91,7%	50%
							Tolerable	0%	0%	8,3%	50%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Cool RWY centre line	Inset Warm RWY edge	LEBL 06L LEBL 24R	27	Acceptable	100%	96,2%	46,2%	30,8%
							Tolerable	0%	3,8%	53,8%	65,4%
							Unacceptable	0%	0%	0%	3,8%
	RWY EDGE	Complementary systems	Cool RWY edge	Warm RWY centre line	LFPO 06,24 LEMG 31 LEAL 10,28 LEPA 06L	21	Acceptable	100%	100%	71,4%	47,6%
							Tolerable	0%	0%	28,6%	52,4%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Warm RWY edge	Cool RWY centre line	LFPO 25 LFPG 27R	12	Acceptable	100%	100%	91,7%	50%
							Tolerable	0%	0%	8,3%	50%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Warm RWY edge	Cool TDZ	LFPO 25 LFPG 27R	12	Acceptable	100%	100%	91,7%	50%
							Tolerable	0%	0%	8,3%	50%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Inset Warm RWY edge	Cool RWY centre line	LEBL 06L LEBL 24R	27	Acceptable	100%	96,2%	46,2%	30,8%
							Tolerable	0%	3,8%	53,8%	65,4%
							Unacceptable	0%	0%	0%	3,8%
		Complementary systems	Inset Warm RWY edge	Cool TDZ	LEBL 06L LEBL 24R	27	Acceptable	100%	96,2%	46,2%	30,8%
							Tolerable	0%	3,8%	53,8%	65,4%
							Unacceptable	0%	0%	0%	3,8%
	TDZ	Complementary systems	Cool TDZ	Warm RWY edge	LFPO 25 LFPG 27R	12	Acceptable	100%	100%	91,7%	50%
							Tolerable	0%	0%	8,3%	50%
							Unacceptable	0%	0%	0%	0%
		Complementary systems	Cool TDZ	Inset Warm RWY edge	LEBL 06L LEBL 24R	27	Acceptable	100%	96,2%	46,2%	30,8%
							Tolerable	0%	3,8%	53,8%	65,4%
							Unacceptable	0%	0%	0%	3,8%

Table 13 - Summary table for the Cool-Warm LED risk assessment of the alternative scenarios.

10 CONCLUSIONS

The conclusions of this study, at the date of the execution of this report, are based on both analyses performed:

- The **statistical analysis** of the answers provided by the pilots to the perception questionnaire and
- The **assessment of the risk** associated with the perception of mixing of lights.

Regarding the **LED & Halogen technology mix**, the responses are in the acceptable zone of the tolerability matrix, except for percentages higher than 50% in the mixing of LED-Halogen lights, a considerable number (22% of the pilots responses) of "Unacceptable" is obtained, in other cases the risk, in general predominantly, is in the acceptable (29%) and tolerable (49%) zone of the tolerability matrix.

Regarding **the LED cool & warm lighting mix**, all the results show that, in general, the risk is in the acceptable/tolerable zone of the tolerability matrix.

This means that, except for that case (higher than 50% of LED-Halogen potential mix), the mixing can be considered acceptable for the two lighting mixes assessed (the LED-halogen technology mix and in the LED cool and warm temperature lighting mix).

As it has been mentioned previously, when interspersing lights of different technologies, it would be recommendable to do it following patterns agreed among the different stakeholders.

The following table summarizes the risk assessment performed for the baseline scenario and for the alternative scenarios:

System	Baseline scenario	Alternative scenario	LED-Halogen	Cool-Warm white LED
ALS	1C,1D,1E	5%	The risk does not seem to increase	The risk does not seem to increase
		25%		
		50%		
		>50%	It cannot be affirmed that the risk does not increase	
RWY CENTRE LINE	1C,1D,1E	5%	The risk does not seem to increase	The risk does not seem to increase
		25%		
		50%		
		>50%	It cannot be affirmed that the risk does not increase	It cannot be affirmed that the risk does not increase
RWY EDGE	1C,1D,1E	5%	The risk does not seem to increase	The risk does not seem to increase
		25%		
		50%		
		>50%	It cannot be affirmed that the risk does not increase	It cannot be affirmed that the risk does not increase
TDZ	1C,1D,1E	5%	The risk does not seem to increase according to the available data[9]	The risk does not seem to increase
		25%		
		50%		It cannot be affirmed that the risk does not increase
		>50%		
TWY	1C,1D,1E	5%	The risk does not seem to increase according to the available data[9]	Other colors than white LED
		25%		
		50%		
		>50%		
THR	1C,1D,1E	5%	The risk does not seem to increase	Other colors than white LED
		25%		
		50%		
		>50%	It cannot be affirmed that the risk does not increase	

Table 14 - Risk summary for each system.

It should be considered that **this is a theoretical extrapolation that should be verified in simulator and in practice in later phases of a potential implementation**.

[9]Only 1 sample regarding this potential mix; it would be recommendable to obtain more data.

11 DISCUSSION

Understanding **how LED lighting may affect perceived brightness and color, as well as the compatibility with existing infrastructure** (traditionally based on incandescent-halogen lighting) **are important safety considerations**.

Available literature, studies, and regulations [2 & 5] related to LED, conclude that the light emitted by LEDs, and how it is perceived, may result in undesired effects to be experienced by pilots of aircrafts.

Different organizations and research groups have analyzed this topic from different points of view.

The research undertaken by INECO has not included topics such as flicker or stroboscopic effects, photometrical and luminotechnical aspects, engineering (costs, benefits, infrastructure and so on), HF issues (NVIS, EFVS or EVS) and others concerns associated with LED lighting for airfield applications and refers to the available literature for this purpose.

Since **the pilot in command of the aircraft is the only one who can judge the safety of the operation in relation to the perceived airfield lighting, INECO has addressed the study presented in this document focusing attention on the pilot and assessing the visual perception of lights in different scenarios and how they affect their senses and comprehension** and, therefore, how the pilots react to this information, specifically in regard to the concern about the possible acceptance of mixing LED-halogen technologies and warm-cool white LED lights combination.

For this study, a scientific experiment has been carried out for which a group of pilots has received training in relation to LED and halogen airfield lights hardware, photometry (candelas, color, coverage), AGL system configuration, color temperature, etc.

These pilots have flown different international airports, under different configuration scenarios and atmospheric conditions, and have answered a series of questionnaires, specifically prepared for this study.

The research undertaken by INECO has resulted in an increased knowledge of the possible acceptance of the LED-halogen and warm-cool white LED lights combination based on to the sensory perception of the pilots.

The visual perception questionnaires are made up of a maximum of 40 questions divided in 5 sections: (1st) Data Protection Management and general information, (2nd) Demographic data, (3rd) Visibility operational conditions, (4th) Perception of the different technologies in relation with the lighting system and (5th) Expert judgement. They have been used to make the corresponding conclusions about the topics on which this document is focused.

It is important to note that the answers related to sections 1st to 4th are based on “real parameters and considerations” while the ones included in section 5th are based on the “pilot judgment”. The subjectivity associated to the answers of the 5th section may affect the accuracy of the conclusions drawn.

Further, in regard with the 5th section results, and by comparing:

- the conclusions and answers based on the expert judgment and intuition of pilots who have evaluated the real mixing (both warm-cool LED lights or LED-halogen technologies) in subsystems required to be viewed simultaneously at a specific time of an operation (for example, RWY centre line and RWY edge),
- the observations based on the evaluation of adjacent and consecutive subsystems that are not required to be viewed at a specific moment of an operation (for example, ALS and TDZ),

The research suggests that the former provides greater precision than the latter. This is due to the fact that the effect and severity on the flight operation safety is different depending on whether "simultaneity of subsystems” is mandatory or not.

12 MITIGATING MEASURES/ RECOMMENDATIONS

It has been made clear throughout the document that, according to the risk analysis, **for those scenarios for which the risk is in the acceptable zone** of the tolerability matrix, **it is not necessary to establish any kind of mitigation strategies.**

However, some recommended actions are shown here below to reduce the risk for those cases where significant percentages of pilots (more than 20%) have evaluated as **Unacceptable** the situation. In particular, for the case of interspersing **more than 50%** of LED lights with halogen lights.

The following list is a **summary** of **recommended actions** proposed for the enhancement of lighting system performance taking human perception considerations into account, further information can be consulted in [11]:

1. Strategies related to **learning from experience** (expert's consultations, interviews and observation of the best **pattern** when installing mixed lights).

2. Considering the expertise of the different stakeholders (engineers, HF specialists, pilots), it should be stablished **guidelines defining the best patterns for the different lighting systems** (ALS, Runway and Taxiway) when interspersing lights.

3. Specific **flight crew training in AGL lighting systems**, lighting technologies and HF issues when performing adjustments to compensate uncertainties due to mixing.

4. Perform **simulations of scenarios** where different percentages of LED lights are interspersed with halogen lights following specific patterns.

5. **Awareness of the risk and consequences of certain tasks** (distribution of graphic information on possible negative consequences caused by incorrect perception of lights as runway incursion, damage to landing gear, etc.)

6. Safety Management System need to consider an **indicator to monitor** this human performance issue.

7. Specific **actions to improve the Safety Culture** (promotion and awareness campaigns to encourage notification of events related to an increased uncertainty due to the mixing of lights).

8. **Coordination with Regulatory bodies**, establishment of promotion processes, working groups and expert committees for consultations/informative meetings about the gradual implementation of LED in AGL systems.

9. Development of specific **mitigating measures** for reducing potentially safety events to provide additional protection during future test phase of mixing of LED and halogen.

10. Development of a system that allows **monitoring relevant failures** of interspersed lights (hardware).

11. Increase the investment on technology and innovation to facilitate the preventive maintenance of AGL lights revision of classical **maintenance programs** according to the mixing of technology (different timeline)

12. Introduction of a **new hazard taxonomy** within the category "SA & sensory events" within Hazard Taxonomies.

13. Foresee the **mixing of lights in the Aerodromes design**.

14. Establishment of a **technical support team** for the efficient resolution of doubts/incidents during **early phases of implementation**.

15. Dissemination of **Lessons Learned** in training or awareness campaigns.

16. Further research in the **Photometry** characteristics affection in the pilot perception.

13 FURTHER DEVELOPMENTS

Once LED is part of the aviation industry, and in order to facilitate the "green" objectives, ADB-SG is leading the development of studies helping airports operators to integrate the LED technology within the AGL.

INECO has conducted this Human Factors research to get a better understanding of how LED lighting and white LED color affect the pilot's recognition of AGL from the safety point of view.

Proposed further research trends regarding the current investigation are as follows:

- The questionnaires used in the present research have been developed in the mother tongue of the pilots who have participated in the experiment. **It is proposed to translate all the questionnaires into English** -by an official translator thus eliminating any bias caused by language defects- **to open up scientific research to more groups of experts**.

- It is recommended to **prepare drawings** in which the **mixing of lights is illustrated** at <5%; 5% - 25%; 25% - 50%; > 50%. These ones would be carried out by a group of experts (engineers, HF specialists, pilots) who would make their inferences about the safety and would propose the best patterns for interleaving of lights. In this way common criteria would be defined by the group.

- It is recommended to develop a **flight simulation study** through one of the leading companies in the sector to simulate scenarios such as those analyzed in this study.

- It is recommended **to carry out actual tests** in Airports in operation **interspersing LED lights within halogen lighting systems**, with **percentages and patterns** as described in previous points.

- It is suggested to **build a simulated airport runway and taxiway in a laboratory to scale the size**, orientation, configuration, and photometric parameters to develop samples and predict patterns of acceptance regarding the mixing of LED and halogen lights as well as cool-warm white lights.

- **Regulation** “FAA. AC150/5340-30J. Section 1.4.” and “ICAO. Doc9157. Part 5. Section 12.12” makes an exception to the mixing of lights in approach lighting systems and taxiway. It is proposed to carry out an analysis of the incidents that have occurred up today to conclude whether the permitted mixing of lights has had any impact on the safety analyses (any identification of events related to this issue) or not.

- It is suggested to **research the available literature on the use of light-emitting diodes** (LEDs) for airfield lighting applications from the visual perception point of view and related documents and articles.

- It is proposed to **convene and participate in Human Factor committees**, where the regulators are present (EASA, FAA, ICAO, etc.), to joints efforts to make easier the interspersion of LED lighting in a variety of airfield lighting applications.