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RESEARCH, SAFETY ALGORITHMS, AND OPERATIONAL PROCEDURES OF AIRPORT MAINTENANCE

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ABSTRACT

With the current development plan, Mostar Airport has initiated a series of renovation and modernization initiatives aimed at enhancing operational efficiency, increasing traffic throughput and improving maintenance standards. This strategic approach is based on adherence to newly enacted legislative prerequisites, specialized education, and innovative security algorithms. Specific airport solutions from scientific research projects were confirmed by professionals and specialists through the Intelligent Systems Course at the Electrical Engineering Department of the Zagreb University of Applied Sciences and promoted as confirmed optimization algorithms in practice at airports. This paper presents the effects of scientific research on determining the state of intensity of airport unit lights, which were applied in the rationalization of the specific projects on the section of the airport light system at Mostar Airport. The planned replacement of one section of the existing edge lights of the airport taxiways by installing new ones, based on empirical confirmation, led to the decision for revitalization, which was also used for the creation of operational maintenance procedures.

Keywords: *air traffic safety, optimization algorithms, operational procedures,*

1. INTRODUCTION

Specific examples of airport maintenance involve assessing the condition of airport lighting, a subject that has undergone various tests and research conducted over many years at the Electrical Engineering Department of the Zagreb University of Applied Sciences (ELO TVZ).
In the Intelligent Systems Course, a total of 15 graduate theses were dedicated to the issue of airport lighting. In the pursuit of maintaining specialized airport systems, a legislative and theoretical foundation has been established through the application of intelligent design principles and continuous monitoring. Databases and knowledge bases have been created through processing. Drawing on scientific international experiences from airports with lighting systems, the specificities have been identified, and a framework for rational maintenance has been established. Equipment manufacturers must meet legislative requirements, lincluding the light intensity of each lighting fixture in airport lighting signalization systems. During operation, the airport operator must ensure that these systems are functioning within legislative limits. This is achieved through predictive maintenance.

2. LEGISLATION & RESEARCH

Air traffic safety at European airports is regulated by the European Union Aviation Safety Agency (EASA) [1]. Globally, legislative continuity is maintained by International Civil Aviation Organization (ICAO) [2], and on the national level by state aviation agencies. Numerous specialized projects in the field of airport lighting systems have been conducted in collaboration with airport maintenance specialists, confirming legislative compliance [3-5].

The individual light sources of the airport lighting system and their maintenance methods are legislatively defined through an Isocandela diagram [1-2]. This diagram depicts ellipses of equal light intensity symmetrically positioned around common vertical and horizontal axes.
It is prescribed for each type of airport lighting fixtures in the lighting signal system. The minimum

permitted light intensities, calculated as the average intensity of the main beam, are determined by identifying the grid points within the perimeter of the ellipse representing the main beam. The average value is the arithmetic mean of light intensity measured at all considered grid points. Ensuring that the average intensity never falls below 50% of the declared manufacturer's value is critical requirement for proper maintenance. This stipulation has presenteda challenge for ongoing scientific research, particularly in the realm of predictive maintenance.

Predictive maintenance is a strategy based on predictive analytics aimed at preventing equipment or system failures or degradation [6-7]. This type of maintenance relies on state information determined by statistical parameters available in databases and knowledge bases in an Expert System Model (ESM) [8]. Predictive maintenance identifies maintenance needs by monitoring indicators that signal a drop in device or system performance. Condition-based maintenance relies on real-time parameter monitoring during operation. The results obtained through analytical and mathematical processing and comparisons, determine how maintenance is carried out [9].

3. BASES FOR THE DEVELOPMENT OF PREDICTIVE MAINTENANCE

At the ELO TVZ, professional and scientific research related focused on the continuous evaluation of airport lighting through operational parameters has been ongoing for over a decade [10-14]. Various types of tests and measurements, including laboratory, field, and workshop tests, are conducted to assess the condition of airport lighting intensity. Operational results are consistently collected, monitored, and analyzed at Croatian airports, such as Brač Airport (AP BWK) and Rijeka Airport (AP RJK), as well as international airports in the surrounding region, including Sarajevo Airport (AP SJJ) and Mostar Airport (AP OMO). These activities encompass:

- Specialized measurements of the intensity of individual light sources of airport lighting fixtures.
- Laboratory testing for the development of operability enhancement studies.
- Research investigations conducted by students in their master's theses on the topic of airport lighting.
- Field tests for the development of platform lighting projects.
- Practical workshop and on-site confirmation tests of lighting intensity.
- Airport Flight Check recording after the renovation of a section of the airport lighting system.

3.1. SPECIALIST MEASUREMENTS

Specialized measurements of the intensity of unit light sources at airports are professionally conducted using a mobile system for field testing called the Photometric Measurement System (PMS) [15-16]. Measurement sensors and computers are integrated and connected within the vehicle to an intelligent agent system linked to the Global Positioning System (GPS).

Computer equipment with application software supports processes and creates the test and measurement protocol. The processed data provides real-time insight into the quality of the light signaling system as a whole and for each light source (Figure 1).

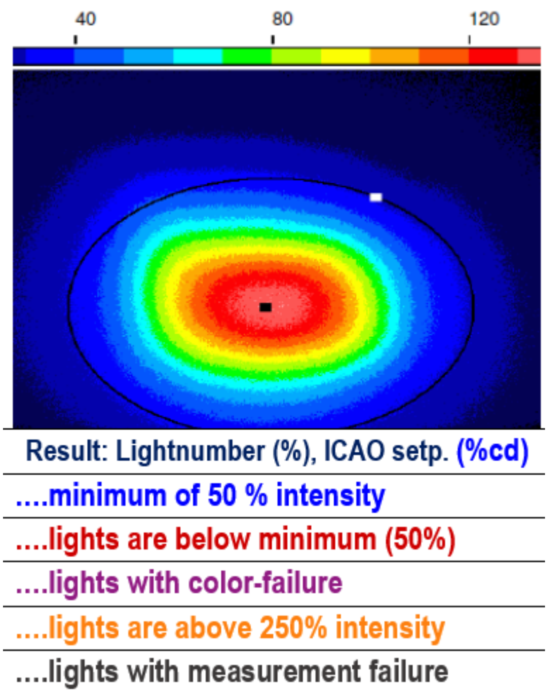

Figure 1 *Isocandela diagram and parameters of the PMS test protocol*

From the results of the measured average intensity for different types of airport lights, several conclusions can be drawn: a) dependence of intensity on horizontal and vertical orientation; b) dependence of intensity on light type; c) range of intensity percentage for new and in-service light sources.

3.2. LABORATORY TESTS

Empirical data from research and development projects related to airport lighting have led to the formulation of a hypothesis centered on an Image Based Lighting (IBL model) [8]. IBL comprises lighting techniques that do not rely on analytical light sources but analyze a single large light source. This model is applicable to airport lighting systems, which, in practical terms are a truly unique entity. Image-based lighting can be considered a more precise representation of airport signaling lights, approximated by Global Illumination (GI). GI is the airport lighting plane that assists pilots during approach and landing at the airport.

Based on these foundations, continuous exercises and specialized training are conducted at the ELO TVZ in the elective course IS, which includes laboratory experiments. In a specially equipped laboratory, the light sources of individual airport lights are examined to simulate their operational conditions at the airport (Figure 2).

Figure 2 *Laboratory model of the ALS – Practicum-Electrical Engineering Department of the Zagreb University of Applied Sciences*

3.3. AIRPORT TERRAIN TESTS

In parallel with laboratory experiments, data collection, research, and measurements have been conducted at airports. To assess the state of airport lighting intensity in specialized projects and for maintenance purposes, the following conclusions have been drawn:

1. Light Loss Factor (LLF): This factor represents the degradation of effective light output due to aging and contamination.

2. Distinguishing between light source loss and luminaire intensity loss: It is crucial to differentiate between the loss of light from the source itself and the loss of intensity from the luminaire.

3. Computer procedures treat light loss and maintenance factors equally.

4. Calculating factors through computer simulation and analogy: This approach aligns with legislation and relevant research [9].

5. Modeling and formulating maintenance parameters for airport lighting: The theory is further confirmed through the development of factors such as LLF, Lumen Depreciation Factor (LDF), and Luminaire Maintenance Factor (LMF) [17].

LLF is associated with luminaire maintenance and is linked to LMF. LDF is described by two critical parameters:

a) ***Lumen (lm)***: It is the unit of measurement for luminous flux emitted by a light source in a solid angle of one steradian, with luminous intensity in all directions of one candela (cd). In other words, 1 lm = 1 cd·sr.

b) ***Depreciation***: Depreciation is the process of degrading the value of certain parameters in comparison to other parameters under specific influences. In the context of light intensity, it represents the measure of degradation in which certain parameters are maintained but not balanced. The loss of light from airport lighting fixtures is influenced by environmental pollution. Air pollution consists of suspended particles ranging in size from 2.5 to 10 micrometers (PM2.5-PM10). Empirical confirmation of this specific pollution has been achieved through research conducted at the locations of AP SJJ and AP BWK [18]. Legislative regulations prescribe and implement pollution level measurement programs within the national network. Indicators from relevant research and assessments of their impact on airport lighting intensity have been supplemented with the effect of "sandblasting" damage to airport lights (Figure 3).

Figure 3 *Confirmation of the sandblasting effect of the airport lights at the airports in Libya [13]*

This effect is a result of the pressure from jet aircraft operations at the airport or strong winds. The effect has been confirmed through field tests in Libya at airports near oil fields [19]. The research and testing have revealed a reduction in lighting intensity on the same lighting fixture at AP SJJ after one winter season (from October 1 to May 31) by 13%, while at AP BWK it amounted to 5% after two years.

3.4. WORKSHOP CONFIRMATORY TESTS

Operational procedures for maintenance developed through implemented projects, ongoing operations, and conducted testing, are of equal importance to specialized PMS measurements [5]. These procedures are used to assess the functionality and relative condition of lighting intensity in new and old light sources using a prototype portable testing device. Workshop testing involves the use of a constant current transformer rated at 6.6A, meaning that the lighting fixture is connected in an operational state appropriate for the V degree of intensity (Figure 4).

Figure 4 *Prototype device for workshop testing the intensity of airport lighting AP BWK [5]*

The measurement procedure for testing a lighting fixture with a prototype, comprising a cover housing, a tube, and a fixed luxmeter sensor, involves placing the test lighting fixture inside the cover housing. This setup simulates a dark chamber, eliminating reflections and providing a more accurate assessment of the light radiation associated with the light source and the lighting fixture. After obtaining the workshop reference value of a new light source, field verification is sonducted [5]. Algorithmic processing of laboratory measurements at ELO TVZ has previously determined reference relative intensity relationships of a real light source in an actual lighting fixture. This information is subsequently confirmed in real operational conditions through field testing at the airport (Figure 5).

Figure 5 *Prototype device for testing the intensity of an airport lighting system [5]*

Table 1 provides laboratory tests and measurements, including calculations of relative lux values for new light sources compared to field tests for lights in operation.

Table 1 *Overview of the relative ratio of intensity in laboratory and terrain tests [5]*

Intensity Level/ Current (A)	Terrain (Lx)	Labos (Lx)	Relative Ratio (%)	Error, Device Class
V/6,6	4350	5120	+17,70%	±0,5 /±1
IV/5,2	1431	1696	+18,52%	±0,5 /±1
III/4,1	285	348	+22%	±1/±5
II/3,4	80,9	98	+21,14%	±1/±5
I/2,8	16,9	20	+18,34%	±0,5 /±5

3.5. FLIGHT CHECK RECORDING

Flight Check [3-4] is a procedure in which the condition of the complete airport lighting signalization is assessed by capturing aerial images. These recordings not only display the overall state of intensity but also identify individual malfunctioning lights within the lighting contours, including Runway (RWY), Taxiway (TWY), platform, or approach lights. This process allows for the identification of the number and positions of malfunctioning lights, serving as a basis for predictive maintenance modeling. The results of aerial recordings of the airport lighting signalization system illustrate the state of the lighting plane (contours) during the night at end/threshold and approach light (Figure 6).

Figure 6 *Airport Lighting System AP OMO, (intensity level III – end/threshold and approach light) [17]*

4. RESEARCH AND APPLICATION RESULTS

The hypothesis, chosen parameters, crucial associations, and their interconnections used to assess the state of lighting intensity can be consolidated into three intricate indicators:

1. Lighting Fixture Characteristics: This includes aspects such as the light source, structural design, and optical performance of the lighting fixture.

2. Local Atmospheric Pollution and External Influences: This category involves relevant and empirical data related to local atmospheric pollution and external factors.

3. Maintenance Interval: This factor determines the maintenance schedule for the lighting system.

From the available maintenance databases created through research and practice, the relationships among these parameters have been established using two extreme examples: AP BWK (without) and AP SJJ (with) reference extreme conditions, where the most significant influence is exerted by the surrounding aggressive atmospheric pollution. The quality of lighting undeniably depends on the quality of the light source and the lighting fixture, where not only the light characteristics but also the quality of optics and housing play a role. These influences have been detailed through simulation in a supermodel and confirmed through relationships among parameters with heuristic evidence [20] (Table 2).

Table 2 *Description of the relationship between parameters associated with value entry*

Relationships between parameters (R)	Pollution - Aggressive Atmosphere / Light fixture - Reduce Luminous Flux.
Values of pollution parameters (PM)	Heuristic level of pollution based on the measured
Values of the lights parameters (IP)	Heuristic inference about different types of lights
Values of maintenance parameters (M)	Heuristic and mathematical calculation for the maintenance period

Utilizing the overarching model and the comprehensive understanding of the interactions and relationships among parameters, maintenance interval functions, and maintenance factors have been generated for specific lighting fixtures at specific airports under determined pollution levels [6-7] (Table 3).

Table 3 *Function of maintenance intervals and maintenance factors for lighting fixtures pollution*

LMF - Luminaire Maintenance Factor			
Maintenance period	High pollution	Medium pollution	Low pollution
12	0,79 - 0,91	0,90 - 0,92	0,92 - 0,94
18	0,67 - 0,90	0,88 - 0,91	0,91 - 0,93
24	0,54 - 0,88	0,86 - 0,89	0,90 - 0,92
36	0,46 - 0,83	0,82 - 0,87	0,88 - 0,91

For halogen light sources in airport lighting fixtures during their exploitation period (Table 4), illustrates the calculated loss of initial light intensity.

Table 4 *Parameters of light fixtures of the light system with a halogen light source*

PARAMETERS OF LIGHT FIXTURES	VALUES
Intensity at the end of the exploitation life	94% - 82%
Intensity at half of the exploitation life	97% - 89%
Intensity after 40% of the exploitation life	98% - 90%
Lifetime of exploitation	2.000 - 5.000h
Expected number of activations	≥ 8.000

4.1. FEATURES OF INDIVIDUAL LIGHT SOURCES

The intensity of light emitted by each lighting fixture in the airport lighting signalization system primarily depends on the quality of its housing and optical components. Each lighting fixture is designed with a specific Ingress Protection (IP rating), which is the first crucial parameter that categorizes the quality of the lighting fixture into three levels: A) Low = IP2X, B) Medium = IP5X, and C) High = IP6X. The quality of the structural design is reflected in the light loss factor or the maintenance factor of the lighting fixture. The elaboration of these factors is addressed through the parameters of lighting fixture characteristics, local atmospheric pollution, and maintenance intervals.

The second important parameter is the type of light source used in each lighting fixture. An analysis and conclusion regarding the types of light sources have been conducted in [6-7]. In specific examples provided in [3-5] for halogen light sources, which are the most common at airports, the lifespan is depicted (Table 4), and is dependent on the connection voltage.

The airport lighting signalization system is connected in a series circuit where the intensity changes in five degrees, from 3%, 10%, 30%, 50%, to 100%, by altering the current. The system, and consequently each lighting fixture, operates at the highest level of intensity with 100% current at a minimum. This contributes to prolonging the lifespan of airport lights, a fact confirmed during operational use [6-7].

4.2. FEATURES OF MAINTENANCE

The maintenance of visual aids and electrical systems, as regulated by the EU Delegated Regulation ADR. OPS. C. 015, mandates that:

• The airport establishes and implements maintenance programs to ensure the proper functionality of electrical systems and the individual lights in the airport lighting signalization system. The electrical power supply must guarantee safety, and the lighting system must ensure aircraft navigation.

• Maintenance systems aim to ensure that during any operational period, all approach and USS (runway) lights are operational (for a Category I airport, at least 85% of all lights). The Precision Approach Path Indicator (PAPI) system must be 100% functional, meaning that all angle of descent indicator units must be in working order [20]. Throughout the system, it is not permissible for two consecutive lights (adjacent to each other) to be inoperative.

Predictive maintenance programs encompass: A) proper inspections and checks of individual elements of each system and the system as a whole, and B) maintaining transparent records of relevant maintenance activities according to: a) maintenance schedules, b) planned maintenance activities, c) operational procedures for carrying out such activities, and d) legislative and inspection requirements. Predictive maintenance monitoring and assessing the operational condition of airport systems for air traffic safety improvement are enhanced by optimization algorithms [21]. They involve: a) levels of serviceability, b) goal definition, c) maintenance performance, and d) guidelines for the development of preventive maintenance programs (ICAO 9137).

4.3. APPLICATION PARADIGMS AT MOSTAR AIRPORT

Numerous renovation and modernization projects have been initiated at Mostar Airport (AP OMO) to streamline operations, increase traffic, and improve maintenance [22-23]. The success of individual projects, based on the new legislation, is confirmed through the acceptance of specific airport requirements. The configuration of maneuvering areas, especially the TWY at AP OMO, regarding lighting signalization is more demanding (Figure 7).

Figure 7 *Aerial view of Mostar Airport*

All new projects developed for AP OMO include a recommendation for predictive maintenance of specialized airport systems, which involves detailed and continuous monitoring [24-26]. Using their own databases and knowledge bases, characteristic parameters for the application of rational maintenance algorithms for airport lighting systems are confirmed. For example, the edge lights of the airport TWY have received confirmation of satisfactory light source intensity (Figure 8).

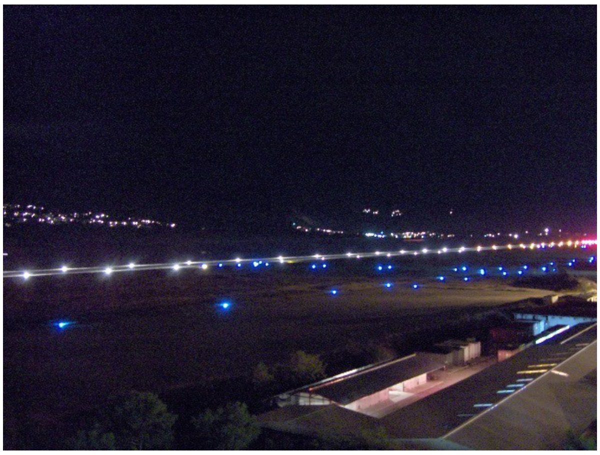

Figure 8 *Flight check of the airport lighting system*

The elaboration presented in this paper, with practical application at AP OMO, was carried out on the guidelines of airport predictive maintenance [20]. The results of the performed revitalization of airport lights at AP BWK indicated the confirmed quality of structural solutions, including the edge light of TWY at AP OMO (Figure 9).

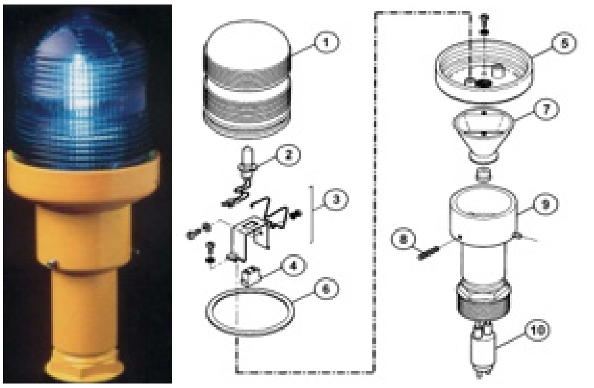

Figure 9 *Taxiway edgelight at Mostar Airport*

5. CONCLUSION

This paper presents the experiences gained through the implementation of numerous projects, published scientific papers, and airport maintenance. The algorithms created based on knowledge and databases of airport lighting systems effectively indicate the characteristics and efficiency of individual equipment, systems, and subsystems, which are applied effectively for pre-planned maintenance tasks, new projects, and plans. Determining the state of the average intensity of individual sources of airport lights is just one area of airport maintenance for which laboratory, workshop, and field tests have been conducted, parallel to measurements by the Photometric Measurement System. Empirical and mathematical analyses have determined the relative intensity values for specific examples of airport lights, in none of which the average intensity fell below 50% of the specified legislative limit. Real intensity reduction of lighting fixtures with halogen light sources at the end of their operational life averages less than 30%. Within this amount, the reduction in intensity of the halogen light source itself ranges from 6% to 18%. The reduction due to the lighting fixture itself, depending on operational and maintenance factors, ranges from 24% to 12%. These insights provide the foundation for the guidelines of airport predictive maintenance, which, in the case of Mostar Airport, propose the rationalization by revitalizing a section of the lighting system, as opposed to acquiring new equipment. The contribution of the work is in the confirmation that the state of light intensity can be established by measuring the relative amount of light intensity of each light source in the manner presented. The contribution of the work is in the confirmation that the state of light intensity can be established by measuring the relative amount of light intensity of each light source in the manner presented.

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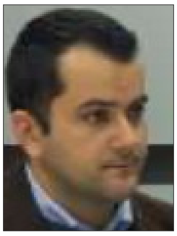

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