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ANALYSIS OF MOTION DATA OF A SELECTED VEHICLE IN THE OPERATIONAL AREA BASED ON THE EXAMPLE OF JOHN PAUL II KRAKOW-BALICE INTERNATIONAL AIRPORT

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SUMMARY

Weather conditions are a key factor influencing the operational activities of airports. Phenomena that limit visibility, strong winds or a contaminated runway are the main causes of delays, diversions of aircraft to other airports, and even cancellations of flight operations, which in turn may have negative impact on the entire air transport system. Constantly changing meteorological conditions require numerous adjustments to increase infrastructure availability and flight preparations, presenting challenges for airports in maintaining smooth operations and for the entities that use them. This article analyzes how the inspection route of the Duty Officer at Kraków John Paul II International Airport changes depending on varying weather conditions. The analysis covers the routes taken during each hour of the vehicles' operation. Particular attention is paid to the analysis of unfavorable weather conditions such as rainfall, storm activity, and snowfall.

Keywords—runway, inspection, runway friction, airport

1. INTRODUCTION

The airport is one of the fundamental elements of air transport, serving as the start or end point of a flight. Modern commercial and military aircraft are highly complex machines, making them very sensitive to external factors, particularly those that can cause mechanical damage. Airport surfaces, even though they are dedicated to aircraft movement, can pose direct and indirect threats. The greatest risk occurs on the runway due to the high speed of movement, high engine rotational speed, and the associated phenomenon of suction, as well as the obvious transition between taxiing and flight mode. Therefore, ensuring the continuous usability of the surface is crucial, i.e. maintaining its parameters at a level that guarantees safe flight operations under all conditions. Surface parameters include its integrity, the level of friction between the surface and aircraft wheels, the clarity of markings, and cleanliness. Maintaining proper infrastructure parameters is a complex process influenced by many external factors, such as weather conditions and fatigue processes accompanying operation. These processes are often prolonged over time and predictable only to a limited extent. Thanks to technical improvement, digital systems that assist in predicting certain phenomena are being implemented. There is also visible progress in materials engineering, thanks to which mixtures that ensure longer safe operation periods are obtained. However, due to the requirement to maintain the highest safety standards, ongoing surface supervision by trained personnel is irreplaceable. Unfortunately, particularly at airports with a high volume of operations, the basic challenge is performing the most accurate inspection of airport surface as possible. The priority of air traffic over road traffic and regulations requiring TWR controllers to maintain appropriate separations between runway users force the maximization of the use of the available time to perform the inspection. The limited amount of time forces vehicle drivers to increase speed, which reduces the accuracy of the inspection. The key in such cases is conducting inspections in a manner that maximizes the potential for identifying potential anomalies.

Modern airports operate in compliance with specific standards and regulations. Those are created at various levels, based on frameworks established by international organizations. In 2014, the European Union Aviation Safety Agency (EASA) issued Regulation (EU) No 139/2014 titled “Easy Access Rules for Aerodromes” to streamline regulations across member countries. This regulation was a key step in harmonizing airport certification requirements across Europe, with the aim of increasing the level of safety, efficiency and uniformity throughout the aviation sector.

The article addresses the issue of airport surface inspections, particularly the runway, with a division into movement areas, taking into account the work characteristics of the service in question. The movement of the Duty Officer at Kraków-Balice Airport (EPKK/KRK) was analyzed.

The primary service responsible for the proper functioning of the airport is the Airport Duty Officer. The scope of their inspection is the broadest, and only this service can formally/officially exclude individual elements of infrastructure or even the entire airport from use in the event of irregularities. They move throughout the airport, reporting the condition of the maneuvering area and aprons to TWR Controllers. The Duty Officer also assesses the conditions on the runway as part of the implementation of the GRF (Global Reporting Format) regulations. The GRF regulations respond to the need to provide flight crews with standardized and useful information regarding the impact of weather conditions on airport surfaces.

2. AIRPORT INSPECTION

Surfaces such as runways, taxiways, and aprons are crucial for minimizing risks to aircraft and ensuring the safe, efficient, and economical operation of an airport. As such, they represent a significant capital investment that must be maintained in appropriate condition for the particular requirements of flight operations. Airport surfaces are complex structural systems, and their performance depends on numerous variables, including the unique combination of aviation operations, the materials they are made from, and the conditions under which they operate. The simplest and most effective way to keep these surfaces in good condition is through inspection and maintenance procedures. One of the characteristic features of airports is the large area they cover. Therefore, the use of vehicles is essential to carry out the inspection.

Inspection is the primary method for ongoing verification of the condition of surfaces, accompanying facilities, and even the activity and population of wildlife within the airport vicinity. Additionally, it provides better insight into identifying nearby air obstacles. International regulations (Annex 14) and the ICAO's Doc 9137 "Airport Services Manual" as well as their European counterpart issued by EASA (Regulation (EU) 139/2014), agree on certain minima to be verified, which include:

- Runway(s),
- Taxiways,
- Aprons,
- Grass Surfaces,
- Water drainage and collection systems,
- Lightning systems.

These are mostly critical / essential elements for the flight or its successful completion. The detailed scope will depend on the complexity of the infrastructure, so, in simple terms, it can be assumed that it is proportional to the size and importance (tasks performed) of the airport. The basic division of any airport is into the maneuvering area and the apron. The maneuvering area is the part of the airport, excluding aprons, intended for the takeoff, landing, and taxiing of aircraft (*Fig. 1*)

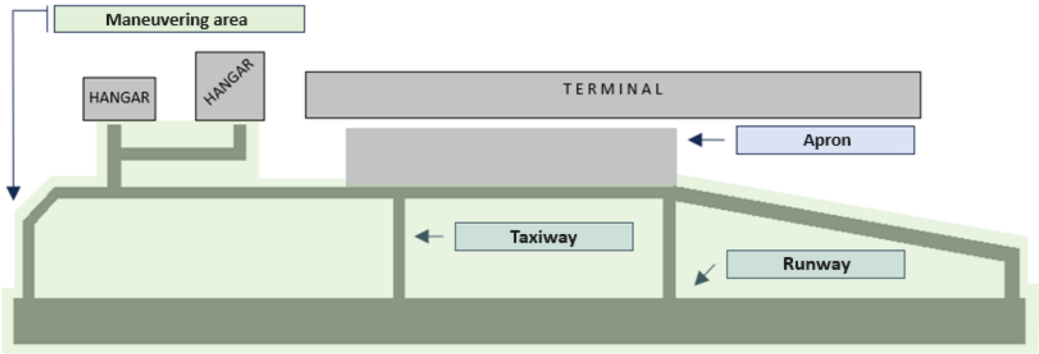

Fig. 1. Schematic layout of an airport indicating the maneuvering area (source: own materials)

Regardless of the status of the airport, work performed there should be carried out by qualified personnel who, in addition to being knowledgeable about their specific tasks, should also be trained in areas such as airport navigation and topography. According to recommendations, access to the airport's maneuvering area should be restricted (EASA 139/2014) exclusively to services responsible for ensuring operational suitability and safety.

2.1. ELEMENTS SUBJECT TO VERIFICATION DURING INSPECTION

The basic element subject to inspection at large commercial airports is the artificial surfaces on which aircraft operate, with particular emphasis on the runway. During their inspection, attention should be paid to:

- The overall cleanliness of the surface with regard to objects that, if sucked in, may cause damage, e.g., to the propulsion system (FOD). (Journal of Laws 2014 item 1420)

FOD - (Foreign Object Debris) - Sources of FOD can include human activities, damaged infrastructure, or the natural environment. These may also be devices and machines moving around the airport (AC 150/5210-24A, 2024), such as.:

  - Objects left after maintenance work,
  - Loose fragments of the surface that have detached,
  - Animal remains left after collisions,
  - Screws, pins, etc.

- Cracks, holes, and bulges in the surface,
- Damage to the navigation light fixtures,
- Clarity of horizontal markings,
- Condition of stormwater drains,
- Runway thresholds - looking for signs of too early touchdown or overrun.

There is a significant correlation between safety and weather conditions not only in the air but also on the ground. Boeing, during studies conducted between 2003-2010 on runway excursions, determined that approximately 90% of incidents occurred when the runway was in a condition other than dry, and that they are often initiated by more than one factor (Jenkins M, Aaron R.F. Jr., 2012).

Due to this, when the following conditions occur:

- Snow in various forms,

- Slush,
- Hoarfrost,
- Ice,
- Water.

The Duty Officer must assess the condition of the surface according to the Global Reporting Format (GRF). For this purpose, it is necessary to drive onto the runway, often giving priority to the driver. The elements that need to be recognized, divided into thirds, are:

- Coverage extent,
- Type of coverage,
- Layer thickness.

Based on these variables and in relation to air temperature, Runway Condition Code (RWY CC) is generated, which contributes to the aircraft configuration performed by pilots (ICAO, 2019).

In addition to artificial surfaces, the grassy area adjacent to them is also important, where attention should be paid to:

- Terrain integrity - depressions, surface integrity (especially in area closely adjacent to the artificial surface),
- Grass height, especially in terms of covering the lighting aids,
- Traces of aircraft excursion,
- Condition of vertical signs (their readability, efficiency of illumination),
- Animal clusters,
- FOD elements,
- Wind indicators.

On the apron, the inspection involves verifying the integrity of the surface, checking the condition of markings, and equally importantly, inspecting for the presence of FOD. In this case, FOD poses a threat not only to aircraft but also to passengers and ground staff.

2.2. THE ISSUE OF CONDUCTING INSPECTIONS

Due to the unpredictability of potential anomalies occurring on and near airport surfaces, inspections should ideally be conducted continuously. The likelihood of their occurrence increases with the number of flight operations and applies to each element. Additionally, it's important to note that airports cover vast areas where local geological and meteorological conditions may exist, such as areas of faster surface freezing or longer-lasting moisture. Aviation regulations stipulate a minimum number of inspections based on the airport code or often also indicate periods when inspections should be performed. ICAO recommendations include a minimum of four runway inspections:

- At dawn - detailed inspection of the runway (minimum 2 passes, 15 minutes),
- Before noon,
- Afternoon,
- After dusk - includes inspection of lights (ICAO Doc 9137, 1983).

For taxiways and aprons, ICAO does not indicate a minimum number, but only suggests daily inspection. Grass surfaces, if not used by aircraft, according to ICAO, should be inspected with a frequency that allows for the detection of damage and other irregularities. In this case, the regulations are very general. Regulations issued by EASA make the minimum number of control passes dependent on the reference code of the runway (EASA, 2023). The airport reference code is a two-character designation consisting of a number and a letter used to verify the relationship between the technical conditions of the airport and the characteristics of the aircraft. Simplifying, EASA makes the frequency of inspections dependent on the size of the aircraft using the infrastructure. The situation is more complex in the case of military aircraft, to which EASA and ICAO regulations do not apply. Military aviation follows its own regulations, which are only partially consistent with civilian ones. Military aircraft, are not large due to the shape and size of the wings, and thanks to the afterburner, they do not perform particularly long takeoff rolls. However, due to the often low air intakes, they require very clean surfaces. Unlike ICAO and EASA, regulations within the jurisdiction of the UK Civil Aviation Authority require the airport operator to inspect the maneuvering area at least twice a day (UK CAA, 2017). The legal regulations presented, regardless of the region in which they apply, emphasize the necessity of regular inspections of airport surfaces. Differences occur in terms of the "baseline" value, i.e., the minimum number of inspections. However, there is consensus that this number should be proportional to the quantity and type of flight operations. As mentioned at the beginning, most often as the number of operations performed at the airport increases, the number of minutes to perform an inspection decreases. The lack of time must be compensated by increasing the speed of movement or, if the infrastructure allows, inspection with breaks is practiced. This means that personnel conducting inspections must withdraw, in consultation with TWR, to a safe distance for the time of take-off or landing. If it is necessary to withdraw, the inspection personnel must remember precisely where they left off to resume accurately. Otherwise, there is a risk of overlooking parts of the surface. In order to improve orientation, concrete surfaces can be marked with small-sized plate numbers at the edge (*Fig. 2*).

Fig. 2.Example of marking plates (source: own materials)

Orientation in rows is significantly easier because there are several to a dozen or so, depending on the spacing of the expansion joints. To avoid mistakes, rows can be labeled with letters. At airports where smooth withdrawal is not possible, the speed of inspection must be increased, which negatively affects its accuracy. By increasing the speed, the possibility of seeing, for example, small FOD - broken screws, nuts, etc. decreases. Additionally, the field of vision narrows (Doori J., Sukhan L. & Yubu L., 2014). Without a doubt, human capabilities, particularly vision quality, play a crucial role in this case. The negative effect is intensified in conditions that limit visibility (fog, rain) or during evening and nighttime hours. Difficulties in detecting potential issues may also occur when driving while facing the sun.

In the case of aircraft aprons, the scope of inspection is very similar. The exception is that at larger airports, it is not possible for the apron to be completely free of aircraft. Therefore, apron inspection must take into account air traffic. On and around the apron, there are usually many more potential sources of FOD. This is due to the large number of people and vehicles moving around, as well as the proximity of various accompanying facilities (cargo warehouses, hangars, etc.).

Conducting proper inspections of airport surfaces requires staff to have a good understanding of the area in terms of topography and characteristic points, also in relation to meteorological conditions. The inspection process should be planned in such a way as to minimize the impact on air operations and the workload of controllers. The Human Factor aspect and the human capabilities associated with it are equally important. For this reason, personnel carrying out inspections should also be in good health (good eyesight, the ability to focus in unfavorable conditions such as noise and stress).

3. ANALYSIS OF THE MOVEMENT OF SELECTED VEHICLES AT THE KRAKOW-BALICE AIRPORT

3.1. CHARACTERISTICS OF KRAKOW-BALICE AIRPORT

Inspection is a complex process that is crucial for the safety of flight operations. Its effects can be observed in specific instances, e.g. in the form of detecting FOD, or on a broader scale, such as identifying the progressive weakening of the surface leading to crumbling. Each airport has its own unique characteristics resulting from its location, exposure to varying meteorological conditions, the materials and technology used in its construction, and the size of the operating aircraft.

Krakow-Balice Airport (EPKK/KRK) is the largest regional airport in Poland, handling over 62,000 operations annually (2023). It has a single concrete runway, designated 07/25, and measuring 2550x60m. The runway reference code is 4D. Parallel to the runway is the Bravo taxiway of the same length, with five connecting taxiways (Alpha, Charlie, Delta, Echo, Foxtrot), though only four are available for aircraft (A, C, D, F). All taxiways are made of concrete, except for TWY D, which is made of asphalt. The EPKK airport is shared with the 8th Airlift Base of Polish Airforce. The aircraft apron, currently under expansion, can accommodate up to 25 code C aircraft and is subject to coordination (Dmochowski P., Lewandowska K., 2022). Ultimately, this value is to be 32 stands. The layout is compact, with numerous internal taxiways, requiring for constant and mandatory assistance from The Marshallers. They support TWR/GND Controllers and significantly increase the safety level of taxiing on the apron. The largest regularly operating aircraft is the Boeing 787-900 (code E). Due to the runway's condition, takeoffs and landings with excessive loads (exceeding PCN - RWY 52) require additional surface inspection after each of these operations.

Fig. 3. U Layout and Naming of EPKK Airport Infrastructure (source: www.openstreetmap.com)

The main direction for take-offs and landings is 25, which is directly related to the prevailing wind direction in this region. The ratio is approximately 70/30 in favor of the wind blowing from west to east. Due to this, inspections should be carried out "against the flow," i.e. from direction 07 to direction 25. Direction 25 is supported with ILS CAT I precision approaches.

3.2. CRITERIA

The Duty Officer's (DO) vehicle was selected for traffic analysis based on its operational areas and the type of work performed. The movement of this vehicle is observed at all times of the day and night and in all weather conditions, following the guidelines outlined in Chapter 2. Data aggregation was managed by a specialized device equipped with GPS and GPRS modules for data transfer. Recorded movement data include time, GPS coordinates, and direction and speed of movement. The source of meteorological data was METAR messages for EPKK airport, published every 30 minutes.

3.3. INSPECTION UNDER SELECTED METEOROGICAL CONDITIONS

Traffic data, as mentioned in Chapter 3.2, was visualized using a Python script. To improve orientation, segments corresponding to the EPKK airport infrastructure were added. Due to the date of measurement data, traffic corresponds to the infrastructure layout from June 2022.

Fig**.** 4 shows a randomly selected route of the DO vehicle under standard conditions. Meteorological conditions corresponding to CAVOK and favorable to the driver were assumed as standard conditions, i.e. with good visibility and sunlight and in the absence of weather phenomena and precipitation (Table 1**Error! Reference source not found.**).

Fig. 4. Standard route of the Duty Officer vehicle under CAVOK conditions (source: own work)

Table 1 METAR reports for EPKK airport during the inspection conducted under CAVOK conditions (source: own materials)

2022-06-29 11:00:00	METAR EPKK 291100Z 07004KT 030V160 CAVOK 28/18 Q1016=
2022-06-29 11:30:00	METAR EPKK 291130Z 10004KT 030V150 CAVOK 29/19 Q1016=
2022-06-29 12:00:00	METAR EPKK 291200Z 10004KT 050V170 9999 FEW046 29/18 Q1016=

The inspection starts from the vicinity of the terminal building, then the vehicle leaves the apron heading via TWY B to TWY F. After receiving permission to occupy the runway, a control drive was carried out without any visible changes in direction. It should therefore be concluded that the prevailing conditions favored the ability to detect potential anomalies by the driver. The collected traffic data shows that a standard inspection of the EPKK airport covers a distance of 8 to 11 km and is carried out at an average speed of 43 km/h.

Fig. 5 shows the route in stormy conditions with recorded rainfall (Table 2). The recorded track differs noticeably from the route under standard conditions. The inspection route is significantly more extensive within the apron area and also on the runway. The route across the apron corresponds to the layout of technical fields where handling equipment is located. Their control results from recorded cases when unsecured equipment moved spontaneously as a result of strong wind, usually accompanying the activity of storm cells. The visible multiplication of passages in Third A and the irregular sinusoidal shape aim to increase the area visually inspected. Heavy rainfall accompanying storms can create water puddles, potentially contributing to runway excursion incidents. The image also shows the passage to TWY D resulting from the need to clear the runway for an aircraft landing or taking off at that time. The length of the inspection is closely related to the duration of the storm, especially the rainfall. During this period, the Duty Officer reports to the TWR Controller the conditions on the runway, focusing on the extent and depth of water. The average vehicle speed recorded at that time was 21 km/h. The passage across the apron occurred at an average speed of below 5 km/h and accounted for 31% of the total distance. The examined distance during stormy conditions ranged from 9 to 12 km.

Fig. 5.Route of the Duty Officer’s vehicle during stormy conditions (source: own work)

Table 2 METAR reports for EPKK airport during the inspection conducted in stormy conditions (source: own materials)

2022-07-08 19:00:00	METAR EPKK 081900Z 24005KT 9999 SCT040TCU SCT057 15/14 Q1023=
2022-07-08 19:30:00	METAR EPKK 081930Z 29007KT 8000 -TSRA SCT027CB SCT043 15/14 Q1023 RESHRA=
2022-07-08 20:00:00	METAR EPKK 082000Z 25005KT 9999 FEW036CB SCT065 15/14 Q1023 RESHRA=

Fig. 6 shows the route of the Duty Officer's vehicle during snowfall (Table 3). The need to ensure proper traction on the surface makes the graph almost unreadable. This is due to the multiple passes across the entire width of the runway. During snowfall, TWR controllers give priority to inspecting the runway. This is dictated by safety considerations, as the Duty Officer must verify and report the condition of the entire length of the runway before it is made available to aircraft. During the presented inspection, 12 kilometers were traveled solely on the runway, which corresponds to five full lengths. The average speed during this inspection was 26 km/h.

Fig. 6. Route of the Duty Officer's vehicle during snowfall (source: own work)

Table 3 METAR reports for EPKK airport during the snowfall inspection (source: own materials)

2022-01-06 18:00:00	METAR EPKK 061800Z 26013KT 3500 SHSN FEW005 SCT014CB BKN023 M01/M04 Q1016=
2022-01-06 18:30:00	METAR EPKK 061830Z 28009KT 9999 -SHSN FEW004 SCT012CB BKN025 M02/M03 Q1017 RESHSN=
2022-01-06 19:00:00	METAR EPKK 061900Z 27012KT 9999 FEW012 BKN026 M01/M05 Q1017=

Table 4 presents the speeds and distances covered under the specified weather conditions. Significant differences are observed primarily in the vehicle's speed of movement for conditions other than CAVOK. In the case of snowfall, an increase in the distance covered can also be observed, especially on the runway.

Table 4 Summary of measurement data for selected weather conditions (source: own materials)

	Diatance [km]	Average speed[km/h]	Distance on runway [km]
CAVOK	8,5 - 10	48	2.5
Storm	9 - 12	29	3
Snowfall	16 - 19	26	12

4. DISCUSSION AND SUMMARY

The observations listed in Table 4 confirm the dependence of DO vehicle route parameters on weather conditions. It should be noted that the staff performing inspections are subject to time constraints due to air traffic limitations. It happens that during unfavorable weather conditions, airplanes perform a holding procedure, consuming a limited amount of fuel. Extended holding may force aircraft with low fuel reserves to divert to alternate airports. Awareness of this situation may put some pressure on inspection personnel. Therefore, purely theoretical concepts have been developed to assign different levels of significance to individual parts of the runway, with the aim of reducing inspection times..

Concept 1: Each element of the runway is equally important, as any other (Fig. 11). This means that inspection should be carried out at every possible location. To perform a thorough inspection of each element, one would need to travel in a so-called "snake" pattern, which is rarely feasible under real conditions. The index created by this variant is the average value of observation strength across all squares; it is also the simplest and least informative index because it does not discriminate the place of observation. This means that an observation made at the corner of the runway is equally important as one made in the middle. However, it allows one to conclude the extent to which a large undistinguished area has been covered by observations.

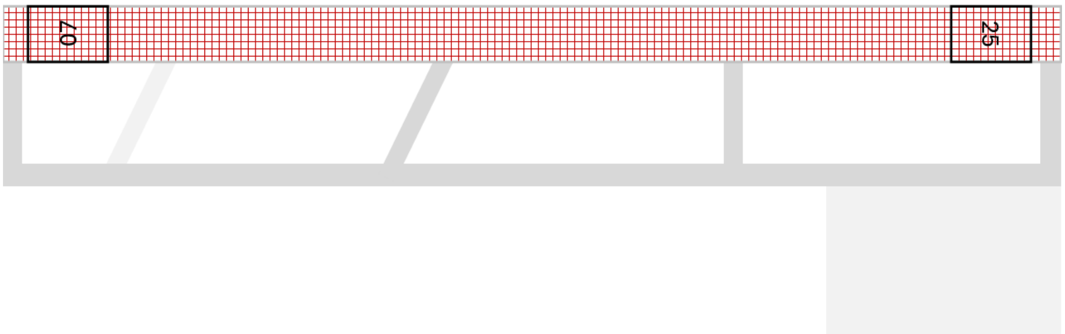

Fig. 7. Areas requiring particular attention as per Concept 1 (source: own work)

Concept 2: It is assumed that certain areas are more critical than others, where most of the surface inspection concerns directly frequented areas, i.e. the aircraft lands correctly on the runway axis, at the aiming point, executes the rollout in the center, and exits onto a selected taxiway. An area of 20 meters in width was adopted for analysis purposes. This value takes into account aircraft with Code E (14 meters main landing gear spacing) with a deviation of 3 meters on each side. Concept 2 considers the possibility of exiting onto all available taxiways, which requires additional consideration for both directions of the runway (Fig. 12). Narrowing the area of significance assumes that in the event of FOD, the risk will be greatest in the middle of the runway. In the context of maintaining adhesion, it assumes the need for the highest value also in the narrowing.

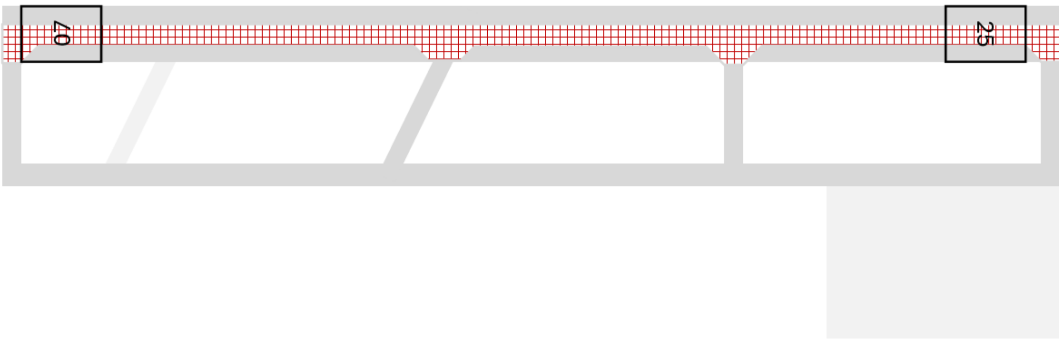

Fig. 8. Concept 2 for direction 07/25 (source: own work)

Concept 3: The basis of the assumptions is Concept 2, additionally assuming the expansion of the area of increased significance. The widening takes into account the possibility of aircraft deviations in the touchdown zone and the need for additional verification of the surface condition on the final section of the runway (Fig. 13). Additional verification is dictated by the need to decelerate the aircraft to a very low speed. In both cases, increasing the level of importance is related to traction.

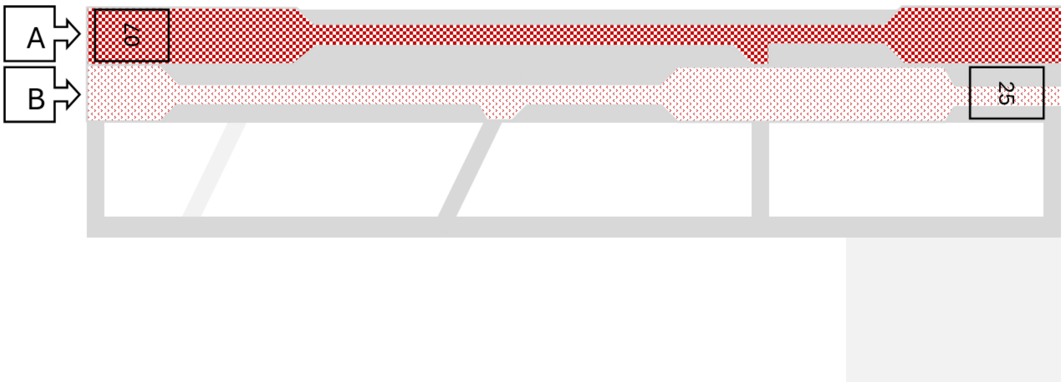

Fig. 9. Concept 3 for direction 07 (A) and direction 25 (B) (source: own work)

Inspecting the runway surface is a highly important and responsible task. It should be carried out by thoroughly trained and, above all, experienced staff familiar with the local airport conditions. The adopted concepts regarding the runway have been compared with actual inspection routes under specific weather conditions. Only concept 1 fully complies with regulations, treating each element of the runway equally in terms of inspection requirements. It also corresponds to the presented inspection route. The attention to every part of the surface is particularly visible in the event of rainfall, which reduces friction. The remaining concepts are purely theoretical, assuming scenarios in which landings are exemplary, without any deviations. This applies similarly to the presence of potential Foreign Object Debris, assuming it follows the exact main wheel gear span. Of course, these assumptions are somewhat valid. However, due to the numerous factors affecting the landing process, they should only be considered as research elements at this stage. They cannot be used to assert boldly that certain sections of the runway are more or less important in terms of control and maintenance.

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