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APPLICATION OF CAUSAL ANALYSIS OF DISRUPTIONS AND THE FUNCTIONAL RESONANCE ANALYSIS METHOD (FRAM) IN ANALYZING THE RISK OF THE BAGGAGE PROCESS

Summary. Following the events related to the pandemic and the war in Ukraine, increasing air traffic also increases turnaround agents' activity at airports. Turnaround operations are among the critical activities performed at airports, which must be characterized by punctuality and accuracy of the elementary handling operations. Lack of punctuality in ground handling causes delays in air traffic. On the other hand, a lack of accuracy can also cause disruptions that can turn into aviation incidents. Achieving punctuality and accuracy in aircraft handling is possible by minimizing the resulting disruptions during such handling. The safety management system (SMS) assumes activities to reduce the causes of potential incidents. In the turnaround process, the human factor, the technical aspect, and compliance with existing procedures are significant. The authors have extensively analyzed the disruptions arising during ground handling, learning its causes and effects, which will help avoid adverse events. Occurring disruptions can cause delays in the execution of flight operations but can also cause aviation incidents. Therefore, the authors focused on ground-handling disruptions that can cause adverse aviation incidents. The article presents the interference analysis results as

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an Ishikawa diagram. Using the FRAM method, an analysis of possible disruptions during the baggage handling process was carried out.

Keywords: turnaround operations, baggage operations, disruptions, threats, FRAM method, Ishikawa diagram, air transport safety

1. INTRODUCTION

Air transport safety is a priority, which is why, among other things, the SMS (Safety Management System) was created. The SMS encompasses the entire structure of the approach to managing risk and ensuring the effectiveness of its control by all aviation entities. It includes systematically developing risk management procedures, practices, and standards. The SMS is a systematic and systematic approach to safety management, including the necessary: organizational structure, responsibilities, duties, policies, and procedures. It enables aviation operators to continuously improve safety levels through threat identification, data collection, analysis, and risk assessment [15]. The implementation and maintenance of SMS is currently a prerequisite for any aviation organization, such as airports, air traffic service providers, air carriers, and aviation service organizations [20].

This approach also applies to aircraft ground handling at the airport, as it is a potential area for incidents and aviation accidents and disturbances contributing to them. Many challenges can be distinguished in ensuring air traffic safety during aircraft ground handling. Such activities include:

- avoiding collisions between aircraft and other traffic participants at airports,
- ensuring that aircraft are not damaged, for example, by foreign objects left in maneuvering areas,
- ensure that aircraft are safely parked and docked,
- minimizing the risk of damage to aircraft on the stand and in other parts of the airport,
- implementation of the correct process of loading and unloading aircraft (cargo and baggage, including dangerous goods);
- proper use of aircraft handling equipment, especially those in direct contact with the aircraft.

In the literature, the disruption aspect is analyzed in different contexts. The authors [30] analyzed the effects of unexpected events in magnitude and duration, which directly impacted the airside zone. Fundamentally, the authors point out the importance of studying disruptions involving ground personnel, as this affects the timely completion of ground handling.

The human factor is one of the most important aspects contributing to disruptions. The level of training [25], experience, and handling of a turnaround agent employee's difficult situations affect the entire process's safety. The human factor is an important element in terms of an organization's safety culture (safety culture) [24]. This concept includes elements such as good team communication, supervisors' responsibility for safety, and the work environment, which can appropriately reward employees' reporting of dangerous situations that directly affect safety [34].

Disruptions can cause delays or collisions in air traffic, seriously affecting aviation accidents. The authors [10] pursued the work of researchers, indicating that many incidents and accidents at the airport involve GSE (Ground Support Equipment) operators. Such incidents can have various causes, but undoubtedly one is human error, which can also result from training. With expert knowledge and fuzzy sets, the authors showed that GSE operator training is key to minimizing adverse events.

According to SMS, proactive thinking aimed at preventing air traffic incidents is essential. The authors' motivation was to analyze disruptions in the context of proactive action in air traffic using the Ichikawa diagram. This tool, used in various research areas [3], allows for cause-and-effect analysis. In the opinion of the authors of this paper, such activities should begin with analyzing emerging disturbances that may contribute to the threats of an event turning into an aviation incident or accident

2. A LITARTURE REVIEW

This paper contributes to the literature by analyzing how disruptions identified during turnaround operations affect the delays that occur but, more importantly, what impact they can have on air traffic safety threats.

Airports are evaluated in terms of throughput, defined as the maximum number of aircraft operations (take-offs and landings) in a given unit of time with acceptable delays, consistent with air traffic conditions, and uninterrupted handling of passengers and cargo. Uninterrupted passenger and baggage handling can be achieved by minimizing disruptions and delays during such handling. As the number of flight operations increases, so does delay. Delay issues are analyzed in the literature, and their causes vary. Airport capacity constraints can cause delays during peak hours with increased air traffic. In Europe, capacity constraints and air traffic control (ATC) system personnel are also causes of delays [7]. The authors focused on demonstrating that airline dominance at destination airports is a significant driver in explaining delays of arriving aircraft. They also noted that unfavourable weather conditions, strikes, and air traffic control regulations can be important contributors to delays.

Airlines are using a variety of measures to minimize delays. Such measures can be related to increasing the number of aircraft, using faster and larger aircraft, increasing the speed of delayed flights, hiring more staff and crew, and adjusting the schedule of their flights to reduce the propagation of delays. Important ground handling agent activity measures include increasing baggage handling personnel and reducing check-in times [4, 8].

Many authors have analyzed delays to explain the reasons for them in the context of the entry of low-cost airlines into the market and airline mergers in the US market [13, 14]. Such analyses have also been conducted for European airports [5, 23]. The authors analyzed whether a greater presence of low-cost airlines at the base airport reduces arrival delays. The analysis was based on 100 European airports between 2011 and 2012, and the authors deduced that low-cost airlines contribute to reducing delays for all aircraft landing at an airport. Many works have also analyzed the European market [31]. The authors studied a group of European airports between 2000 and 2004. They showed that airport concentration is a significant determinant of delays. Another study [6] examined 40 European airports in 2015-2016. The authors showed that airlines operating in a hub-and-spoke structure are ineffective in solving problems and reducing the propagation of delays.

Severe and extreme meteorological conditions can be one of the causes of the resulting disruptions, resulting in flight delays, cancellations of these flights, or diversions to other airports [2, 9]. The authors concluded from their research that poor meteorological conditions depend on the type and intensity of the event. Large airports, acting as hubs, show longer delays as a result of adverse meteorological conditions.

According to annual reports prepared by EUROCONTROL related to the primary sources of delays, the “airline” category is a large group of causes. This category includes such subcategories as aircraft handling, baggage handling, or cargo and mail handling, among others

[11]. Delays in this category specifically refer to delays related to ground handling. This can refer to the cumulative time from individual categories such as passengers and baggage, cargo and mail, ramp handling, and aircraft maintenance. These data show that the average departure delay for all causes per flight in Q2 2022 was 13.5 minutes. The reactionary delay contributed the most to the average delay per flight at 8.9 minutes (fig. 1).

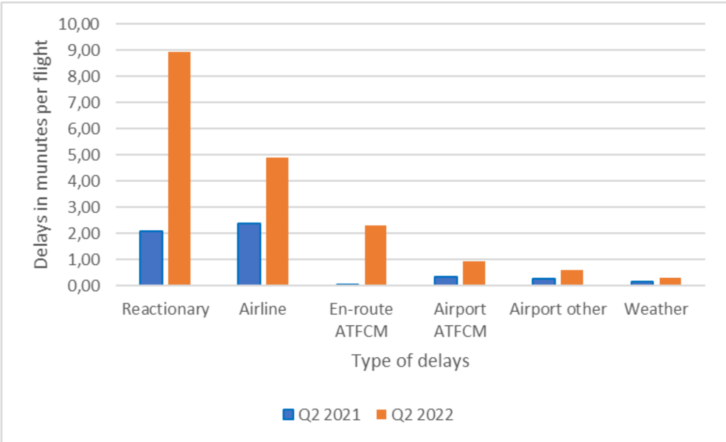

Fig. 1. The reactionary and other delays

These delays impact costs for air carriers [21] and air traffic's fluidity at the airport. Delays can also be related to the taxi time for aircraft to perform take-off operations, which tends to increase as congestion associated with aircraft arrivals increases [26].

The authors of the publication [18] have done a lot of research in the area of aircraft turnaround. They focused on creating a simulation model to support the operation of a ground-handling agent. To implement it, the FlexSim environment was used. This simulation-based software is used to optimize the implemented processes in the aviation industry, for example. The simulation model allowed for analyzing the logistical processes carried out during aircraft ground handling. The authors analyzed the degree of GSE utilization. In addition, FlexSim software allowed its dynamic allocation concerning specific aircraft while considering their mutual compatibility. As a result, the developed model made it possible to optimize the studied process. It is worth noting that the model assumed a deterministic duration of the given activities. This was done based on specific publications. In the implementation of aircraft maintenance, the fire department and crew replacement assistance were omitted. The paper's authors, created a simulation model of ground handling of selected aircraft (categorized by range) in the Simio package. The model's results showed the times of total ground handling, the activities causing delays indicated, and the percentage of critical paths in the simulations performed. The experiments made it possible to identify the critical path of ground handling, which was the path containing the unloading and loading of baggage.

Researchers are also addressing the topic of the ground-handling process in terms of safety. The creator of this work [12] focused on the role of the human factor in aviation, which is a critical element for the safety of flight operations. In the paper, he presented the development of the SHELL and BowTie concepts (they propose solutions to minimize the risk of aviation incidents) by introducing a method of testing the aptitude of airport personnel. It is implemented using a specialized system "Polipsychograph". This system designs and implements psychological tasks that test a person's mental, cognitive, and motor abilities. The results obtained are used to assess the professional capabilities of future employees. The paper contains the results of tests conducted on ground service personnel. Among other things, the research showed that an employee's predispositions depend on the quality of the work assigned to him. The paper's authors [19] focused on operational safety issues in the aircraft ground handling process. Ground handling is a critical phase from the perspective of operational safety. The available data shows that during the execution of the ground handling process, a large number of incidents result in damage to the aircraft. As a result, the execution of subsequent processes is slowed down, or the aircraft is taken out of flight, causing long delays and costs for the airline. For a new approach to safety management in aviation entities, the method for risk analysis is STAMP [2880]. It offers a different approach to operational safety, treating failure as a control error. With the knowledge and experience of the researchers', improved processes were modelled according to publicly available sources. A list of potential deviations is added to processes or individual activities.

The cause of delays during ground handling is various types of disruptions, defined as disturbances that disrupt the proper course of the process being carried out. Disruptions largely occur during passenger handling [32 80]. They occur during the process of passenger and baggage handling, e.g., late check-in, excessive ticket sales, incorrect or late catering, etc. On the other hand, during the execution of the aircraft ground handling process, disruptions may relate to handling activities, e.g., late delivery of GSE equipment, misuse of GSE equipment resulting in damage to the aircraft, lack of personnel during loading or unloading processes, lack or failure of loading equipment, misreading of baggage loading instructions, as well as disruptions related to the preparation of the necessary documentation prior to the execution of take-off operations (incorrect or late delivery of documentation related to weight and balance). Airports seek to increase their capacity (throughput), and air carriers seek to minimize aircraft turnaround times. The priority of any airport is to optimize the duration of the aircraft handling process while reducing the occurrence of disruptions that potentially cause delays and safety threats. Achieving this goal must be linked to analyzing the maintenance activities carried out at parking areas and determining the punctual execution of aircraft take-off operations. Even though delays occur as a result of disruptions, no division of disruptions has been created, nor has any categorization of them been proposed. Using the FRAM method, the authors identified disruptions using an Ishikawa diagram and conducted a risk analysis of the baggage handling process.

2.1. Work concept

The research area is the aircraft ground handling process, during which disturbances potentially lead to delays and aviation incidents, which will be analyzed in the following research work. The focus was on conducting a thorough analysis of one particular stage of the ground handling process: baggage handling. The authors analyzed the disruptions occurring using an Ishikawa diagram. The FRAM method was chosen, discussed, and characterized to conduct a risk analysis of the baggage handling process. The FRAM method is widely used in research and analysis [27].

The authors of the current research work built a model based on the FRAM method, which reflected the baggage handling process and was used to obtain variants. Each of them describes a potentially occurring situation during which a disturbance arose. By introducing variations in functions that mimic the occurrence of disruptions, it was possible to obtain multiple scenarios. The obtained variants were analyzed in terms of the harmfulness of the occurrence of each disruption. Such action made it possible to illustrate the spectrum of possibilities for the occurrence of disturbances and locate the source of their occurrence. This is also related to obtaining knowledge that can help reduce the occurrence of interference during aircraft ground handling. In addition, ranking the obtained scenarios, due to the harmful effects of potential disruptions, will allow attention to the most sensitive areas of the baggage handling process, which may involve the introduction of increased controls and training to reduce the occurrence of such situations. Identifying factors that cause disruptions can be used to minimize their occurrence, for example, by levelling or eliminating their impact.

Performing an analysis of baggage handling using the FRAM method made it possible to illustrate the scale of the potential for disruption. In addition, it made it possible to identify specific baggage handling activities, the erroneous implementation of which can result in the most severe disruptions. Showing the consequences of disruptions can help assess their harmfulness to the timely implementation of the ground handling process, which directly translates into the occurrence of delays and security threats.

3. CHARACTERISTICS OF GROUND HANDLING/TURNAROUND OPERATIONS

The handling agent performs services based on assigned service categories and uses its resources, equipment, and airport infrastructure. How individual aircraft are handled depends on the ground handling agent's standards, the manufacturer's recommendations for a particular aircraft model, and the contract details between the handling agent and the air carrier it serves. Ground Support Equipment is used to handle aircraft that load catering, mail, baggage, other cargo, and passengers [16].

The ground support process refers to activities performed during aircraft stops at stands. Coordination of turnaround operations begins with learning basic information related to the aircraft being serviced. The next stage is the creation of instructions for unloading the aircraft. It is created based on the received dispatches containing detailed information about the transported cargo (including special, e.g., dangerous). The next stage is the implementation of activities in preparation for the restoration of full operational readiness of the aircraft and the exchange of cargo and passengers. The established special operational supervision service is responsible for controlling and enforcing the performed maintenance activities on the apron. The ready and completed personnel and the equipment prepared in advance await the aircraft's arrival.

After performing landing operations at the airport, the aircraft heads to the designated parking area. It follows the “Follow me” vehicle. When the aircraft approaches the stand, the “Follow me” vehicle abandons its guidance in favour of an electronic guidance system. Wing walkers assist aircraft docking. These ground staff's job is to keep an eye on the aircraft and its surroundings to avoid collisions. Another activity is the connection of the aircraft sleeve or providing passenger stairs so that passengers can disembark. In the case where the aircraft is docked at the contact station, its passengers, when disembarking, go directly to the passenger terminal building. Connection of the GPU, or ground power unit, also takes place. If necessary, ground-based air-conditioning units can be used [1].

At the same time, the luggage racks are opened, and, based on special instructions, the process of unloading the luggage begins. Handling employees, using dedicated lifting platforms, lower the containers onto the slab. Belt loaders, loaders, or forklifts are used to handle the baggage. Once the aircraft's baggage hatches are unloaded, they are reloaded with new containers and luggage. They are placed according to previously developed instructions. The process of loading the aircraft is carried out according to the instructions of the loading planner, the so-called loadmaster.

At the same time, the service work of mechanics is also underway. An inspection of the aircraft is carried out. If damage is detected and located, the mechanics' task is to eliminate it. In the case of damage that cannot be eliminated quickly, further preparation of this aircraft for flight is abandoned. In its place, another aircraft is substituted or a decision is made to wait for another flight.

In summary, the scope of ground handling services includes:

- locking the aircraft using special equipment,
- providing a ground power source for the GPU and ASU starting the engine,
- enabling communications between the aircraft (crew) and the cruise coordinator,
- loading and unloading of the aircraft including the provision of appropriate stairs for both passengers and crew,
- owning and operating cargo platforms intended for baggage and cargo,
- enabling and supervising the process of moving the aircraft on the tarmac (towing, pushing, taxiing),
- de-icing of the aircraft,
- refueling and refueling process,
- ensuring the protection of the aircraft from unauthorized intrusion and from damage.

Aircraft ground handling is a complex organizational, technical, and operational process. It contains numerous interconnections and interdependencies between processes with a series-parallel structure along with alternative paths. GSE equipment operators must comply with the rules of vehicle traffic at airports, which are regulated by law. This mainly refers to the fact that traffic priority over vehicles and vehicles towing aircraft is given to landing, taking off, and taxiing aircraft. In addition, moving vehicles are required to give way to vehicles towing aircraft. It follows that vehicles moving within an airport, according to the regulations, must always give way to aircraft moving within it. In addition, their drivers must comply with the regulations in force at the airport (in the form of horizontal and vertical signs or speed limits, among others). Regardless of the regulations, all vehicles, aircraft, and vehicles towing aircraft should obey the instructions issued by the relevant airport control authority. Elementary activities occurring during ground handling are shown in fig. 2.

3.1. Identification of disruptions during turnaround operations

Disruption is a circumstance resulting from a violation of the established order during some activity, process, or event. From the point of view of aircraft ground handling, the key aspect is time. Thus, disruption is a violation of the established order of the implementation of activities, processes, procedures, etc., which can negatively impact the timely implementation of aircraft ground handling and the safety of the execution of flight operations [29]. Time pressure resulting from the need to perform and complete an activity promptly can cause errors that affect the resulting disruptions. In general, disruptions at an airport affect the operational efficiency of the airport. They can cause delays or diversion of flight operations to other airports. Such a situation is very disadvantageous for airlines generating economic losses and social impacts for aviation institutions, i.e., airport managers, airlines, and passengers [17].

Disruption has been analyzed in different contexts in several scientific studies and is still an important research area. The authors [0] analyzed a specific disruption event and assessed the a-posteriori effects. Another important aspect is estimating the economic impact caused by airport closures.

It should also be noted that disruptions are also associated with additional fuel consumption and an increase in local and global atmospheric pollution, which directly impacts the environment through the emission of harmful substances [29].

Turnaround operations have been analyzed in detail regarding the disruptions that occur, shown in fig. 2. The diagram directly relates to all activities that are used in the implementation of ground handling and all ground handling personnel and has been supplemented with potential interferences.

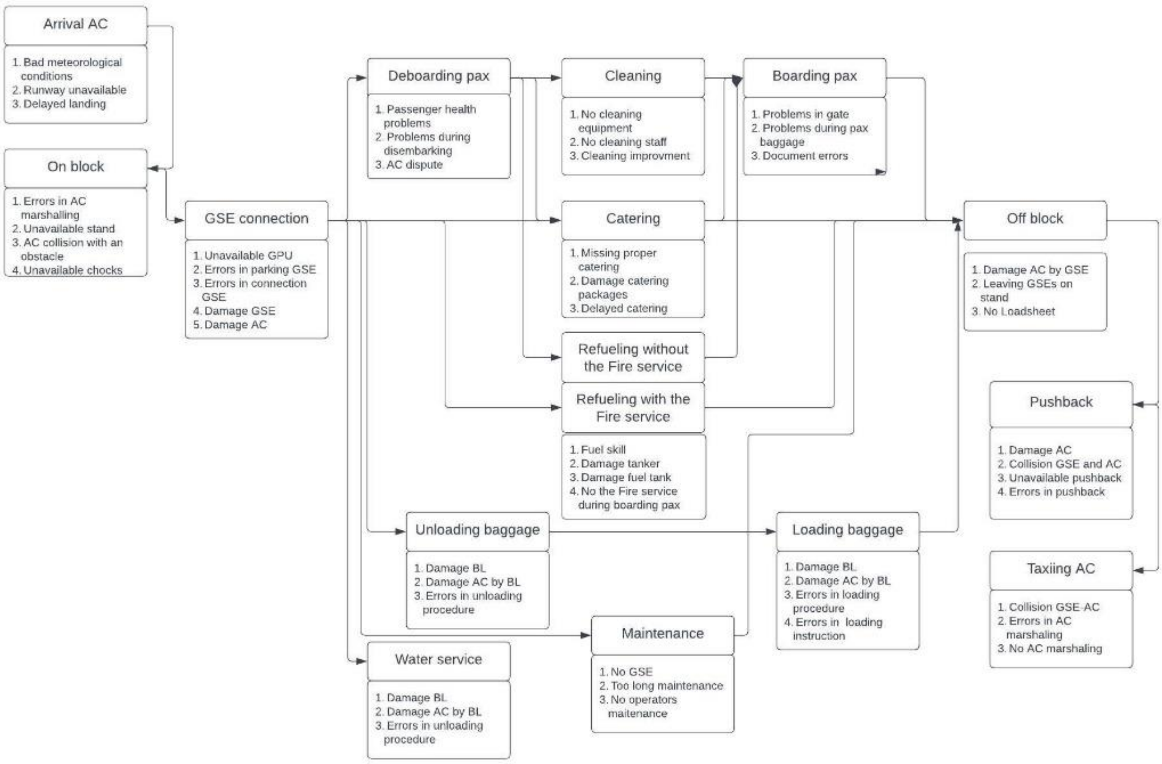

Fig. 2. Scheme of aircraft turnaround operations with disruptions

There are many measures to minimize the disruptions that have occurred in the form of procedures that are activated during the occurrence of situations that violate safety rules leading, for example, to damage to the aircraft. In addition, during the occurrence of disruptions, the movement of GSE equipment and ground handling personnel under the aircraft should be kept to a minimum. A joint disruption affecting the timely execution of ground handling is the need to identify baggage due to the fact that a passenger has not checked in for a flight and the baggage must be removed from the aircraft's hold. This activity usually determines the moment when ground handling is completed at the staging area. The operational supervisor or the aircraft commander makes the decision to identify baggage. The on-time performance of aircraft takeoff operations is also significantly affected by the aircraft's arrival time from the previous flight. Cruise flight delays can result from a variety of causes and disruptive factors, among which are:

– dynamic changes in the flight schedule,
– changes in aircraft rotations,

- on-time performance-related unpunctuality - later or earlier departure or arrival based on schedule time,
- delays and/or errors related to the implementation of turnaround processes,
- threat situations,
- inadequate meteorological conditions,
- deficiencies or errors in operational data and information,
- aircraft malfunctions,
  failures of equipment and operational infrastructure resources.

3.2. Identification of disruptions using the Ishikawa diagram

The purpose of an Ishikawa diagram is to identify the possible causes of a particular problem, which is complex and multifaceted. An Ishikawa diagram is called a fishbone diagram or a cause-and-effect diagram. The diagram makes it possible to identify the potential causes of a problem. A general diagram identifying disturbances was created (fig. 3) to illustrate the application of the Ishikawa diagram in aircraft ground handling.

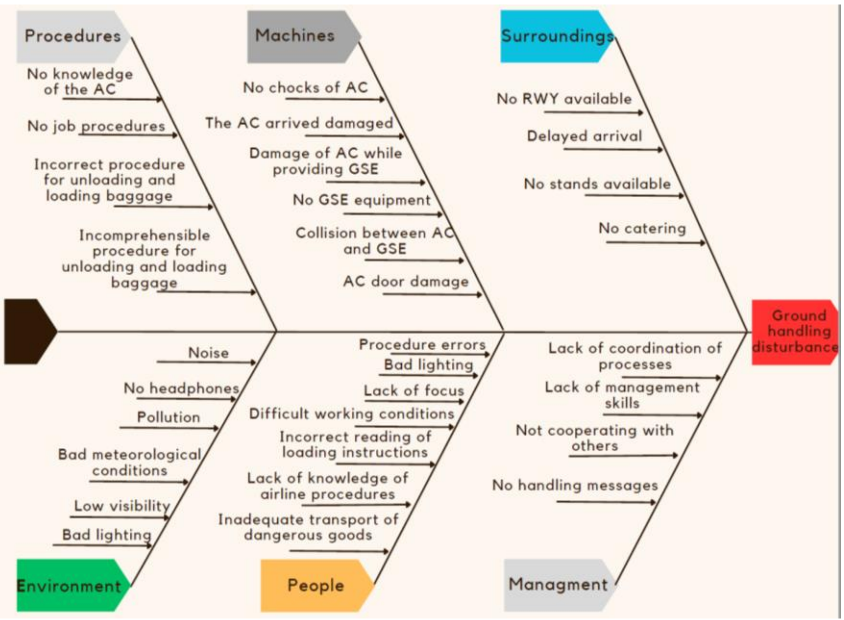

Fig. 3. Ishikawa diagram with disruptions

To accurately analyze the problem, which is the problem of the emergence of interference during ground handling, the various branches were described, namely procedures, machinery, environment, environment, people, and management. The analysis shows that the human factor is the largest contributor. In many situations, it can be related to the lack of adequate training and knowledge of ground handlers. During the analysis, the baggage handling problem came up with all branches. This is an elementary activity, which usually determines when the ground handling is completed. The process of baggage handling involves many factors, including lack of or ignorance of the proper procedures, lack of proper equipment to handle these bags, lack of knowledge of the procedures of the air carrier being handled, and lack of or inadequate communication between the person coordinating the entire ground handling process and those handling the unloading and loading of baggage. Since this process appeared most frequently and can cause the most disruption, this area was selected for further analysis.

3.3. Analysis of baggage process using the method FRAM

The authors choose the FRAM method to identify disruptions during baggage handling. This is a method for analyzing functional resonance, defined as a detected signal that results from independent interactions of multiple signals with normal variability [35]. As a result of functional variability, there is a possibility of obtaining such a result that creates hazards (the main causes of such variability are, for example, people and technology). In air traffic, these can be incidents, so the FRAM method is also used in this field. The FRAM method is characterized by four fundamental principles [27]:

- the principle of balance of successes and failures - the successes and failures associated with the implementation of the process are equivalent to each other, and thus that different effects can arise from identical causes,
- the principle of approximate adjustment - employees are constantly adapting conditions to the activities being carried out, and this is done in an approximate manner,
- the principle of emergency operation - failure cannot be planned; it is a condition that arose unexpectedly,
- the principle of functional resonance - the superimposition of multiple signals in an unexpected way, is the cause of the emergence of an emergency situation.

The FRAM method is a network that is represented by identified system functions and the relationships between them. The FRAM functions are represented by six parameters (aspects) and connect to each other linearly. Fig. 4 shows a graphical FRAM model of the implementation of the baggage handling process. This particular stage of the baggage handling process was chosen because its correct implementation is affected by a number of factors that can be a potential source of disruption.

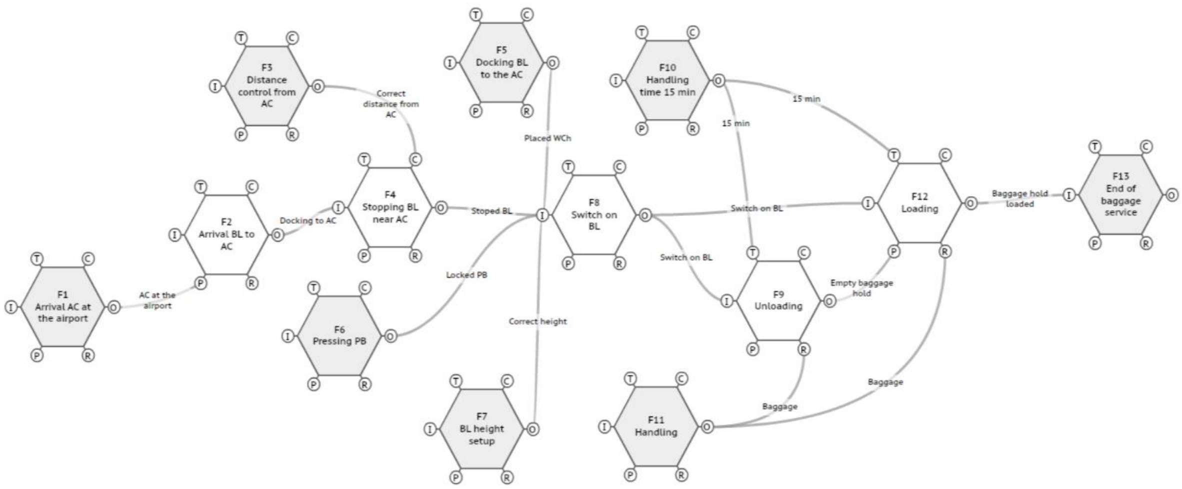

Fig. 4. Model FRAM – realization of baggage process

The model was created on the basis of data containing the times of the various stages of ground handling of an Airbus A320 aircraft with a rotation time of about fifty-five minutes, while the execution time of the unloading and loading processes is about fifteen minutes each [1]. In creating the model, the focus was on the conveyor belt vehicle and its access to the aircraft, and the unloading and loading process with a time condition was taken into account. The influence of weather conditions was ignored. This model was created to analyze the baggage handling process under disruption conditions. The introduction of the variability of functions (disruptions) made it possible to create a number of potentially undesirable events (variants). The analysis of these situations aimed to prioritize and determine the degree of harmfulness of individual disruptions (irregularities). The first stage of the analysis using the FRAM method is presented in Table 1. The characterized and described functions, which represent the course of the baggage handling process and their parameters, are placed there. Next to each function, their connections are also given. Thirteen functions are listed in Table 1, of which the largest number of connections is the F8 function (turning on the loader belt). It has four connections to the "I" parameter and two connections to the "O" parameter.

Tab. 1

Characteristics of the functions of the FRAM model

No	Function F	Input I	Output O	Precondition P	Resources R	Control C	Time T
F1	Arrival AC	-	AC at airport	-	-	-	-
F2	Arrival BL to AC	-	Arrival to AC	AC at airport	-	-	-
F3	Distance control from AC	-	Correct distance from AC	-	-	-	-
F4	Docking BL to AC	Docking to AC	Stopping BL	-	-	Correct distance from AC	-
F5	WCh setup	-	Placed WCh	-	-	-	-
F6	Pressing PB	-	Locked PB	-	-	-	-
F7	BL height setup	-	Correct height BL	-	-	-	-
F8	Switch on BL	Correct activities	BL working	-	-	-	-
F9	Unloading	Switch on BL	Empty baggage hold	-	Baggage	-	15
F10	Handling time 15 min	-	15 min	-	-	-	-
F11	Handling	-	Baggage	-	-	-	-
F12	Loading	Swith on BL	Baggage hold loaded	-	Baggage	-	15
F13	End of baggage service	Baggage hold loaded	-	-	-	-	-

AC – aircraft; BL – belt loader; PB – parking brake; WCh – wheel chock

Table 2 describes the possible variability of the function. It considers situations possible during the implementation of the baggage handling process. The most examples of function variability were noted for functions F3 and F4.

Tab. 2

Examples of the variability of selected functions

Function F	**Variability V**	**Description**
F3	F3V0	Correct distance from AC
	F3V1	Incorrect distance from AC
	F3V2	No control
F4	F4V0	BL stops in correct distance from AC
	F4V1	BL stops in incorrect distance from AC
	F4V2	BL will not stop at AC
F5	F5V0	WChs set under the AC wheels
	F5V1	WChs not set under the AC wheels
F6	F6V0	PB locked
	F6V1	PB not locked
F7	F7V0	Correct height BL
	F7V1	Incorrect height BL (too low, too high)
F8	F8V0	BL running correctly
	F8V1	BL running incorrectly
F9	F9V0	Correct unloading
	F9V1	Incorrect unloading
F10	F10V0	Handling time less than or equal to 15 minutes
	F10V1	Handling time time longer than 15 minutes
F12	F12V0	Correct loading
	F12V1	Incorrect loading

Tables 3-6 show the variability of functions in various possible configurations, making creating variants possible. At a later stage, this will allow consideration of the impact of each function's variability on the next function's variability.

Tab. 3

Impact of the variability of the F3 function on the output of the F4 function

Function F	**Input I**	**Control C**	**Time T**	**Output O**	**Variant**
F4	Output F2	F3V1	-	F4V1	W1
	Output F2	F3V2	-	F4V3	W2

Tab. 4
Impact of the variability of the F4, F5, F6, F7 functions on the output of the F8 function

Function F	**Input I**	**Output O**	**Variant**
F8	outputs	F8V1	W3
	F4V0		
	F5V0		
	F6V0		
	F7V1		
	outputs	F8V1	W5
	F4V0		
	F5V0		
	F6V1		
	F7V1		
	Outputs	F8V1	W6
	F4V0		
	F5V1		
	F6V0		
	F7V0		
	outputs	F8V1	W8
	F4V0		
	F5V1		
	F6V1		
	F7V0		
	outputs	F8V1	W12
	F4V1		
	F5V0		
	F6V1		
	F6V0		
	outputs	F8V1	W15
	F4V1		
	F5V1		
	F6V0		
	F6V1		
	outputs	F8V1	W16
	F4V1		
	F5V1		
	F6V1		
	F6V0		
	outputs	F8V1	W18
	F4V2		
	F5V0		
	F6V0		
	F6V0		
	outputs	F8V1	W25

	F4V2		
	F5V1		
	F6V1		
	F6V1		

Tab. 5

Impact of the variability of the F8 and F10 functions on the output of the F9 function

Function F	**Input I**	**Time T**	**Output O**	**Variant**
F9	Input F8V0	F10V 1	F9V1	W26
	Input F8V1	F10V 0	F9V1	W27
	Input F8V1	F10V 1	F9V1	W28

Tab. 6

Impact of the variability of the F8, F9 and F10 functions on the output of the F12 function

Function F	**Input I**	**Precondition P**	**Time T**	**Output O**	**Variant**
F12	F8V0	F9V0	F10V1	F12V1	W29
	F8V0	F9V1	F10V0	F12V1	W30
	F8V0	F9V1	F10V1	F12V1	W31
	F8V1	F9V0	F10V0	F12V1	W32
	F8V1	F9V0	F10V1	F12V1	W33
	F8V1	F9V1	F10V0	F12V1	W34
	F8V1	F9V1	F10V1	F12V1	W35

3.4. Analysis results

Tables 3-6 were created on the basis of the functions that are most relevant to the occurrence of disruption. The result of the resulting tables is thirty-five variants. The first table deals with a belt loader vehicle arriving at the aircraft. Correct parking of a vehicle with a belt loader at the aircraft occurs when the functions F3 and F4 variances take the value V0. The remaining variants (W1, W2) are related to incorrect parking. Variant W1 refers to the inappropriate distance separating the parked vehicle with the belt loader from the aircraft (parking too close or too far away). In contrast, such a disruption can be quickly removed and thus return to the correct implementation of baggage handling. Special attention should be paid to variant W2, in which the belt loader vehicle fails to stop and hits the aircraft. Such a disruption can cause the most damage (and long delays), not only in the form of damage to the vehicle and the aircraft, but can also cause damage to the health of ground handling personnel. Tab. 4 is related to the inclusion of the belt loader. As a result of the variability of the function, 23 variants have been created, which provide for the incorrect activation of the belt loader. Correct activation of the loader belt occurs only if the function variables F4, F5, F6, F7 take the value V0, that is, the vehicle with the loader belt is properly parked, chocks are placed under the wheels, the parking brake is applied, and the loader belt is set to the correct height. If any of the function variables goes to a state other than V0, it means that the loader belt is started incorrectly.

The most harmful variants are those in which the loader belt vehicle fails to stop in front of the aircraft and hits it. There are eight such variants (from W18 to W25). The second most dangerous variants are those involving unapplied parking brakes and the absence of chocks under the wheels of the loader belt vehicle, and there are four of them (W8, W9, W16, W17). This threatens the possibility of the vehicle moving during the implementation of baggage handling which can result in damage to the vehicle, the aircraft and can endanger the lives of personnel. Next in order are those variants in which the parking brake is not applied, but the chocks are substituted (W4, W5, W12, W13). These are also dangerous examples of variants that can cause major disruptions. The next ranked variants are W15, W14, W11, W10, in which the variables of function F5 and F7 are not as important as the variable V1 of function F4, which relates to the fact that the vehicle stops at an inappropriate distance from the AC. The penultimate variants are W3 and W7, which are related to the inadequate height of the loader belt. This can cause problems during the retrieval of luggage from the belt, which is associated with the creation of disruptions and subsequent delays. The last variant is W6, which lacks chocks under the wheels. This is the least of the problems, as the parking brake is applied, preventing the vehicle from moving independently. Table 5 describes the unloading process. Correct unloading occurs only if functions F8 and F10's variability takes the value V0. If any function takes a variation other than V0, the implementation of the unloading process is incorrect. The worst variant is W28, in which the loader belt was incorrectly switched on, and the unloading execution time exceeded 15 minutes. This variant generates the greatest disruptions and, as a result, the greatest delays. In Table 6 on loading, more variants were proposed than in Table 5. This is due to the fact that for the loading function, an initial condition was added, i.e. a correctly executed unloading process (luggage hatch unloaded). Otherwise, the loading process cannot start. In addition, the loading function is regulated by the time parameter T (15 minutes). Considering the above, the worst variants are W31 and W35, in which the unloading was carried out incorrectly and the execution time is more than 15 minutes. The subsequent variants are W30 and W34, in which the unloading procedure was carried out incorrectly. The next variants are W29 and W33, in which the execution time for loading takes more than 15 minutes. The last variant is W32, in which the loader belt was switched on incorrectly. Of the scenarios presented, this is the least harmful disruption.

In summary, all the variants of function variability that have arisen that can contribute to the greatest damage are those related to functions F3, F4 and F6. They concern the loader belt vehicle and the parking brake. If the loader belt fails to stop or its parking brake is not applied, the aircraft will be impacted. Such situations generate the most severe disruptions. They have the greatest impact on the timely execution of the baggage handling process and the entire ground handling process. In the worst-case scenario, health or life may be lost in addition to the destruction of the vehicle and aircraft. Such situations are unacceptable and should be especially avoided.

4. SUMMARY AND CONCLUSIONS

The analysis carried out using the FRAM method (in FRAM Model Visualiser Pro) made it possible to visualize the range of possibilities for interference during the baggage handling process. The description of the proposed function variants and their analysis led to the creation of dozens of scenarios that showed the scale of the possibility of potential disruptions and their harmfulness. The results of the analysis focused attention on the process elements whose improper implementation generates disruptions. They were ranked in terms of the harmfulness of the effects. By harmfulness of effects is meant monetary and health losses. Such data, properly presented, can contribute to offsetting the occurrence of disruptions by increasing employee awareness. It should be noted that the selected process is one of many stages of aircraft ground handling, so the number of opportunities for interference in the entire ground handling process is very large. Therefore, it is necessary to take measures to negate the formation of interference. The proposed process for identifying disruptions and analyzing the baggage handling model contributed to identifying factors affecting the timeliness of operations. With such knowledge, awareness and understanding of the problem of disruptions can be realistically increased. Reducing the frequency of their occurrence will primarily increase the safety of passengers and staff and the airport's capacity. The range of services provided by ground handling is very wide.

Although considered ancillary to the complex aviation operations conducted, ground handling at airports is the backbone of air transport operations. The quality and standard of ground services provided by various airport entities directly affect the safety of all air operations, hence the care and meticulousness associated with the selection of ground handling agents. The obtained scenarios prove that the key factor influencing the occurrence of disruptions is the human factor. Despite the existence of detailed procedures, all potential disruptions are the responsibility of personnel. Therefore, in such situations, one suggestion for improving safety and eliminating future occurrences is to emphasize periodic training to help systematize actions in accordance with the procedures in place. The training will also help raise awareness of the actions performed during the activities.

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