



**The Role of Artificial Intelligence in Improving the
Operational Efficiency of Baggage Handling Systems in
International Airports in Saudi Arabia**

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1. Introduction

Airports function as highly complex operational environments. They require the integration and interplay of multiple systems for the central tasks of managing the movement of people, planes, and bags. One of the critical systems for operational efficiency and service quality and ensuring that people are not delayed in boarding or experiencing high levels of lost luggage, is the Baggage Handling System (BHS). In addition to dealing with the operational challenges and constraints, global air travel has been expanding for the past two or more decades and is putting increasing pressure on airports to develop, implement, and justify the use of advanced technology solutions for managing baggage flow.

Artificial intelligence (AI) is predicted to play a dominant role in the transformation of the aviation industry. AI technologies have the potential to be the most powerful tools in the planning and automation of operational functions in BHS. AI technologies can facilitate accurate and timely predictive maintenance and intelligent automated monitoring and real-time data analytics for operational performance and system disruptions.

The implementation of Saudi Vision 2030 and the overall expansion in the Kingdom of Saudi Arabia's Aviation sector has influenced the rapid development of the Kingdom's international airports. The vision aims for Saudi Arabia to become a global logistics and transportation hub that connects three continents. Consequently, this has caused a rise in the volume of air traffic at the Kingdom's international airports, specifically at the King Abdulaziz International Airport in Jeddah, King Khalid International Airport in Riyadh, and King Fahd International Airport in Dammam. As a result, the improvement of airport operational systems, specifically for the handling of baggage, has become an operational priority for airport management.

The airport baggage handling systems (BHS) are a crucial component of the logistical systems of an airport. The systems facilitate the flow of luggage by moving and sorting luggage from the check-in counters to the airplane holds then from the holds to the claim. The systems are made of several components such as belts, bar code scanners, sensors, sorters, and monitors, all of which are interconnected. The efficiency of a given BHS is directly related to the operations of an airport, the punctuality of flights, and the satisfaction of customers (Kazda & Caves, 2015).

Predictive maintenance is one of the most important applications of artificial intelligence in baggage handling systems. AI algorithms help to predict maintenance and repair needs by examining operational data from the motors and sensors used in handling equipment. These systems also help to analyze and understand the patterns of breakdowns. AI predictive maintenance systems identify equipment failure and suggest repair tasks ahead of time. Such predictive maintenance strategies help to decrease the frequency of sudden equipment breakdowns and increase the reliability of the entire system (Lee, Bagheri, & Kao, 2015).

Artificial intelligence (AI) can also be integrated into baggage documentation to overcome challenges associated with those systems, as well as respond to specific issues within a given airport environment, such as improving the reliability of baggage handling equipment, minimizing operational disruptions, optimizing the efficiency of equipment, and enhancing the capability of automated systems to support real-time decision-making.

In this regard, it is crucial to recognize the implications of AI technologies for operational improvements within baggage handling systems. This will facilitate the digital transformation of the aviation sector and the sustainable operation of airports in Saudi Arabia.

2. Problem Statement

Unplanned equipment failures, and interruptions, in the system, are further challenges in the baggage handling systems. Issues with conveyor belts, sensors, and the large scale baggage backlog (congestion) can greatly impede the operation of an airport, and cause delays in the takeoff of planes. Many airport baggage handling systems rely on reactive maintenance. This type of maintenance is done after a piece of equipment fails. This type of maintenance increases the amount of time the equipment is not operational, and can be greater for the entire airport (Lee et al., 2015).

Predictive maintenance, intelligent routing of baggage, automation of anomaly detection, and real-time data analytics are just some of the many attributes Artificial Intelligence (AI) technologies are capable of to tackle the above-mentioned challenges. AI systems are capable of processing enormous quantities of data produced by operational systems, baggage handling systems, and tracking systems which means airports are able to predict and adjust operational systems before issues arise (Russell & Norvig, 2021).

Saudi Arabia is rapidly expanding its aviation industry in conjunction with its Vision 2030 strategy. This will allow the Kingdom to become the world's leading aviation and logistics center. Major international airports in Saudi Arabia—namely King Abdulaziz International Airport, King Khalid International Airport, and King Fahd International Airport—are expanding their passenger and operational capacity. Per the Saudi aviation strategy, it is projected the Kingdom will be able to accommodate an annual throughput (aka passenger processing) of 330 million by the year 2030. This will be operationally demanding to the degree that it will be overwhelming to Saudi Arabia's airports, specifically to the Kingdom's systems' abilities to handle and process baggage (GACA, 2022).

Most studies focus on (1) passenger experiences, (2) security of airports, and (3) operational efficiencies of airlines. Very few studies focus on the operational efficiency of

baggage logistics and the use of AI. With this in mind, there is an obvious deficit of the operational efficiencies of BHS systems and the AI technologies of such systems at Saudi Arabia's international airports.

Hence, this study aims to explore the impact of Artificial Intelligence on the operational efficiency of baggage handling systems, in international airports in Saudi Arabia. More specifically, the research aims to understand the extent AI-based technologies aids in predictive maintenance, accuracy of baggage tracking, reduction of system downtime, and operational performance of airports.

3. Research Objectives

The purpose of this study is to analyze how Artificial Intelligence (AI) can enhance efficiency within the baggage handling systems at Saudi Arabian international airports. To achieve this goal, the study intends to achieve the following specific objectives:

1. Assess the operational design and quality of performance of Saudi Arabian international airports' baggage handling systems.
2. Determine the primary operational difficulties and deficiencies of the baggage handling systems within airports.
3. Examine how AI influences the enhancement of various facets of baggage handling processes (predictive maintenance, smart routing, and automated supervision).
4. Determine the aim of AI technologies on the primary measures of operational efficiency, such as system dependability, the time involved in processing baggage, and the precision of tracking baggage.
5. Assess the impact of AI technologies on the efficiency and operational systems of airport baggage handling systems.\

6. Provide guidance to the airport authorities and policymakers in Saudi Arabia on the areas of improvement to be focused on in the existing systems of incorporation of AI technologies in baggage handling systems.

4. Research Questions

Considering the research problem and objectives, the study proposes the following questions:

- 1- How do baggage handling systems in international airports in Saudi Arabia operate at the moment?
- 2- What are some operational challenges that impact how baggage handling systems operate in airports?
- 3- In what ways can operational efficiency of baggage handling systems be improved by the use of artificial intelligence?
- 4- What are some ways artificial intelligence can improve the accuracy and reliability of operations in regards to the tracking of baggage?
- 5- In what ways can the use of artificial intelligence decrease the frequency and duration of downtime and disruptions of systems within baggage handling networks?
- 6- What are some possible reasons or challenges that come with using or including artificial intelligence in the systems that are used to handle baggage at airports in Saudi Arabia?

5. Research Hypotheses

Considering the objectives of this research and the theory that is related to it, the following hypotheses are proposed:

H1: The use of artificial intelligence in systems that handle baggage in international airports is expected to have major positive changes in how efficient the systems operate.

H2: The use of artificial intelligence that is based on predictive analytics has been proven to decrease the frequency and duration of downtime in systems that handle baggage.

H3: The use of artificial intelligence in systems that handle baggage in airports is expected to improve the accuracy of tracking baggage by a significant amount.

H4: The use of artificial intelligence that is based on the principles of automation has been shown to improve the reliability of baggage handling systems.

H5: The use of artificial intelligence is expected to improve the accuracy and reliability of operations in regards to the tracking of baggage.

6. Significance of the Study

The significance of the study comes from the value it adds to both theory and practice in the aviation industry. This study is particularly important from the perspective of airport operational management and the digital transformation of the airports.

This research contributes to the literature concerning the integration of artificial intelligence technologies in airport operational management and logistics. The last few years have seen a rise in scholarly interest in the application of artificial intelligence in aviation. For example, there have been numerous studies focused on the optimization of flight scheduling, predictive safety management, and the management of passenger flows (Davenport & Ronanki, 2018; Russell & Norvig, 2021). However, the literature on artificial intelligence in aviation is scarce, despite the numerous studies on the application of AI in aviation, and none of them have focused on the role of artificial intelligence in enhancing the efficiency of the operations within the baggage handling system at airports. Airport baggage handling operations are a vital logistical aspect of the airport's overall operational performance, and yet, the literature on the digital transformation of airports is silent on them. Thus, this study attempts to address the literature gap on the application of artificial

intelligence to the operational performance of baggage handling systems in international airports.

The study also aims to address a gap within airport logistics by applying elements of artificial intelligence, operational efficiency, and airport systems. The study also proposes a framework for analyzing the impact of artificial intelligence on the performance of baggage handling systems, thereby contributing to the body of knowledge on the digital transformation of logistics and operations within the airport ecosystem.

From a practical standpoint, the results of the study are of relevance to airport managers, aviation policymakers, and operational technology innovators, and provide the underlying theory for increased airport operational efficiency. This study examines the opportunities presented by artificial intelligence, including predictive maintenance, automated monitoring, and intelligent baggage routing to provide airport managers with actionable insights to enhance the reliability and operational performance of airport systems (Lee et al., 2015).

Within this framework, AI technology's potential to automate and optimize baggage handling systems is invaluable to the ongoing digital metamorphosis of Saudi Arabia's aviation industry. The productivity of airports as well as the quality of service provided to passengers is significantly enhanced by the incorporation of AI technologies, which serve to minimize unplanned service interruptions. Therefore, this study's findings may guide Saudi Arabia's airport and aviation authorities, and serve to integrate and optimize AI technologies at airports, thus supporting the backward integration of the Kingdom's aviation industry.

6.1. Definition of Terms

This section aims to present an unambiguous definition for some of the principal terms for use in the context of the present study.

- Artificial Intelligence (AI)

Artificial Intelligence (AI) refers to the ability of a computer, or a computer-controlled robot, to perform tasks usually done by humans. Such tasks comprise capturing, learning, and analyzing data and making decisions to use that data to make predictions. In this regard, AI incorporates a wide range of technology that includes, but is not limited to, algorithm based machine learning, deep learning, and data analytics (Russell & Norvig, 2021).

- Baggage Handling System (BHS)

An example of a baggage handling system is an airport baggage handling system. Such a system is an example of an integrated system of both mechanical and digital elements, and is utilized to transport, sort and track the baggage of passengers. The system is used to track luggage from the check-in counters to the loading areas of the aircraft, and from the aircraft to the baggage claim area. Almost all systems rely on conveyor belt, bar code, and sensor based and sorting and monitoring systems to ensure that adequate and prompt processing of luggage is done to ensure efficient operations of airports (Kazda & Caves, 2015).

- Operational Efficiency

Operational efficiency involves the ability of a system or organization to implement an effective system to carry out its functions while decreasing resources, time, and operational costs. In instances of operational efficiency of the airport baggage handling system, operational efficiency might involve quick, precise, dependable, and cost-effective servicing of the baggage processing systems.

- Predictive Maintenance

Predictive maintenance involve a maintenance approach based on data analytics and systems, and artificial intelligence to track the system, and predict probable failures before they occur. Predictive maintenance allows the system to identify malfunction signs before

and avert unforeseen breakdowns while enhancing the operational reliability of the system (Lee, et al., 2015).

- Baggage Tracking

Baggage tracking involves the monitoring of movement and location of the passenger baggage in airport handling systems. Tracking systems are designed to enhance accuracy and lessen the likelihood of luggage being misplaced or routed to the wrong destination.

Barcodes, RFID systems, and artificial intelligence-based computer vision have been adopted to enhance tracking accuracy (SITA, 2023).

- Airport Operational Systems

Airport operational systems include various technologies and components that enable the effective functioning of airports and include passenger processing systems, security screening systems, and aircraft ground handling systems, as well as systems for the handling of baggage and air traffic control. Operational systems work together for the optimized functioning of airports.

6.2. Thesis structure

This thesis adopts a layout typical of academic research in aviation management, operations management, and information systems. It comprises various chapters aimed at investigating the impact of artificial intelligence on the operational efficiency of baggage handling systems at international airports in Saudi Arabia. Each chapter covers a distinct element of the research, starting with the background to the research and concluding with the final recommendations.

The thesis begins with preliminary pages with important information about the study. These sections include a title page which displays the thesis title, researcher, academic institution and supervisor's name. Then, a declaration is made to confirm the originality of the research. Some preliminary pages include a dedication and/or a set of acknowledgments in

which the researcher thanks individuals and/or institutions that helped them complete the study. Additionally, the thesis contains an abstract that summarizes the research problem, objectives, methodology and main results of the study. The preliminary pages of the thesis include a table of contents that lists all sections and subsections in the thesis, as well as lists of tables, lists of figures, and a glossary of abbreviations.

Chapter one presents the introduction to the study. The chapter presents the general context around the topic of study and justifies the need to study the influence of the artificial intelligence technology on the operations of baggage handling systems at airports. The chapter also identifies the research problem by stating the operational issues of baggage handling systems at airports. Additionally, the chapter presents the study's aims and objectives, the research questions and hypotheses that the study seeks to answer. To further enhance the understanding of the readers, the chapter discusses the significance of the study to both the academic and the practice. Lastly, the chapter presents the scope and limitations of the study and clarifies the definitions of the study's key terms.

The second chapter centers on the literature review, which highlights existing research on the application of artificial intelligence within aviation, the digital transformation of airports, and systems pertaining to baggage handling. Furthermore, this chapter addresses the pertinent theories and articulates the integration of artificial intelligence within airport systems and logistics. Moreover, it reviews past literature on operational efficiency, predictive maintenance, intelligent baggage tracking, and airport management systems. The chapter wraps up by discussing the literature on this subject and devising the conceptual framework to be utilized throughout this research.

The third chapter articulates the research methodology implemented to carry out the study. This chapter describes the research design and the overarching strategy undertaken regarding the collection and analysis of the data. It also specifies the sample frame of the

study as well as the sampling method employed. Furthermore, this chapter elaborates on the data collection tool, which is a structured questionnaire constructed to determine the correlation between artificial intelligence systems and operational efficiency within systems of baggage handling. This chapter outlines the steps taken to assure the validity and consistency of the research tool and describes the quantitative analysis employed on the data collected. Chapter four details the findings from the conducted data analysis. The chapter opens with the response rate along with the demographic profile(s) of the research participants. Following that, the chapter provides the descriptive statistical analysis from the collected data along with the reliability tests that measure the consistency of the measurement scales employed in the questionnaire. The chapter details the correlation and regression analyses that examine the relationship(s) between the AI applications and the operational efficiency metrics in the BHS (baggage handling systems) before concluding with the results of the hypothesis tests and the rest of the critical statistical results from the study.

Chapter five will discuss the study results in relation to the research study objectives and the existing literature from chapter two. This chapter attempts to offer an interpretation to the statistical results and demonstrates how the findings help in understanding the role of AI in BHS operational improvements and contrast the results of this study with previous studies in the field of aviation management and airport operations.

The last chapter of the study contains the study's conclusions and recommendations. This chapter restates the study's findings and contributions to both the airline industry and academia. This chapter touches on recommendations for airport authorities and policymakers for the adoption of machine learning practices to the baggage handling system. This chapter also mentions study limitations and identifies areas related to artificial intelligence and operational efficiency of airports where further study is needed.

Included in the thesis are the references cited in the study, formatted in APA style. The last part of the thesis contains appendices with related materials to the study, including the interview questions, statistical data, and all study-related documents.

7. Literature Review

7.1. Artificial Intelligence in the Aviation Sector

The incorporation of artificial intelligence into the aviation sector eclipses all prior attempts at technological advancements. AI fosters operational superiority, bolstered safety, and the optimization of resources, as well as aids in decision making in complex aviation environments. Artificial intelligence, as defined by Russell and Norvig (2021), perform tasks that would normally require human thinking by means of a computer system. These tasks include, but are not limited to, decision making through the analysis and evaluation of available data, and problem solving of a predictive and analytical nature.

The various operational areas AI is applied to within the aviation sector include, but are not restricted to, flight scheduling, management of air traffic, predictive system maintenance, system security, and the management of services offered to customers at various airports. The operational processes of AI in aviation are a function of the data available, which is a result of the operational systems that are embedded into the aircraft, the airport, and the technology employed to process the passengers, as expressed by Davenport and Ronaki (2018).

The artificial intelligence operational systems of airports also foster the emergence of smart airports, which utilize various digital technologies for better operational integration and enhanced passenger experience. The smart airport concepts revolve around artificial intelligence, extensive data analytics, and automation to construct a more adaptable and efficient airport ecosystem.

7.2. Baggage Handling Systems in Airports

Baggage handling systems represent one of the most important logistical infrastructures within the airport ecosystem. These systems are responsible for the movement of passenger baggage from check-in points to the aircraft loading bays and from the arriving aircraft to the baggage reclaim areas. A baggage handling system is made up of a series of interlinked components, including conveyor belts, x-ray scanners, sorting machines, and various sensors and control systems (Kazda & Caves, 2015).

The baggage handling systems main purpose ? Is bag identification by baggage tracking, routing, sorting, And tracking. When checking in, some systems recognize bags by their identification tags. Tags define how systems track bags and how the routes are directed to the appropriate planes. After checking in, bags are moved to a conveyor belt system and are directed to the right flights.

With the baggage handling system, monitoring system operational problems is cumbersome. Operational problems are an area airport management is trying to use advanced technology to improve (Schwarz, 2021).

7.3. Artificial Intelligence in Baggage Handling Systems

Artificial Intelligence technologies can greatly improve the efficiency and reliability in the BHS. Some example AI applications include predictive maintenance, intelligent tracking, automated system monitoring, and decision making support.

Intelligent tracking is an equally important AI application in the BHS. Computer vision technology empowered by AI is capable of automatically identifying the movement of bags in the conveyor system in an airport and even can detect in real time if a bag is wrongly routed. These systems enhance the accuracy of tracking and the number of bags that are lost is significantly decreased.

Automated monitoring systems that utilize Artificial Intelligence are capable of identifying operational anomalies in baggage handling systems. For example, machine learning models can detect, and learn, deviations in baggage flow, identify congestion of the conveyor belt systems, and disrupt the flow of operational teams. Such abilities enhance the operational response capability of the airport, and, in turn, reduce the downtime of the systems.

7.4. Predictive Maintenance in Airport Systems

One of the most noteworthy uses of artificial intelligence in both the industrial and transport sectors is predictive maintenance. Predictive maintenance is becoming increasingly useful in airport settings because of the need to constantly operate and maintain infrastructural systems in an airport setting safely and efficiently. Baggage handling systems contain both electronic and mechanical components such as conveyor belts, motors, sensors, and sorters. Therefore, a failure in any of these components will hinder operational processes, create delays, and increase maintenance costs.

In airport systems, the predictive maintenance of systems and processes is still in its infancy. Systems such as reactive maintenance and scheduled maintenance have traditionally been implemented. Where reactive maintenance is concerned, systems are repaired once they have failed whereas scheduled maintenance entails the consistent maintenance of systems at intervals determined in advance. Both of these systems, however, have weaknesses such as creating unanticipated operational system failures or creating maintenance tasks that in the end are counterproductive and increase operational costs. In providing a solution to such problems, predictive maintenance uses artificial intelligence to evaluate operating systems and forecast the likelihood of system failure (Lee et al., 2015).

The implementation of predictive maintenance systems enables the use of certain technologies like artificial intelligence, machine learning, and data analytics, which allow the

system to analyze the data collected from sensors embedded in baggage handling equipment. The sensors track various parameters for the equipment, such as temperature, vibrations, and activity of the motors. The presence of artificial intelligence and machine learning allows the systems to recognize and analyze data trends and provide predictive alerts for equipment degradation or failure. This allows maintenance to be performed before system failure, minimizing downtime, and maximizing operational reliability.

The evidence shows that operational effectiveness in the airport industry can be improved with the use of predictive maintenance systems in equipment breakdown prevention and less maintenance costs. As predictive maintenance systems identify system anomalies and allow maintenance teams to take preventative actions, AI-based systems have been shown to eliminate downtime due to maintenance (Davenport & Ronanki, 2018). Because of this, predictive maintenance has emerged as one of the most important aspects of the ongoing digital transformation in aviation.

7.5. Intelligent Baggage Tracking Technologies

An essential component of airport logistics systems is effective baggage tracking. Tracking is imperative for effective movement of passenger luggage from check-in stations to boarding, and from arriving flights to baggage claim. Poor tracking can result in misplaced, delayed, or lost luggage, negatively impacting the experience of the customers and the operations of the airline.

Inefficient tracking systems that use barcode technologies are common in traditional tracking systems. At check-in, passengers are given barcode tags that contain information about the passenger and the flight. Automated scanners are used in baggage conveyor systems to read barcodes and direct bags to the appropriate aircraft. Although tracking systems have increased the precision of baggage handling, they are limited in handling the varying

complexities of airport systems where scanning may skip tags or the tags may become damaged (SITA, 2023).

Airports that invest in advanced technology for tracking baggage obtain operational gains and have improved the incidence of misdirected baggage within their airport as reported in the SITA Baggage IT Insights report (SITA, 2023). Therefore, intelligent baggage tracking systems are now a vital component of the logistics management systems of modern airports.

7.6. Operational Efficiency in Airport Management

Managing airports involves a high degree of complexity in a time-sensitive manner and operational efficiency remains the primary goal. To achieve this goal, the different systems that are involved in the management of the airports including the passenger processing systems, baggage systems, aircraft ground operations, and air traffic management systems must all work together. A lag in one system will invariably lead to delays in operational performance of the airport as a whole.

Airport operational efficiency can be measured using various key performance indicators, such as time taken to process bags, reliability of the system, accuracy of tracking components, and total operational costs. When assessing operational efficiency, it should be noted that the purpose of baggage handling is to ensure that bags are transported quickly and accurately throughout the airport system while not causing delays to the flight schedules.

The use of certain Artificial Intelligence (AI) technologies can improve operational efficiencies at airports. AI technologies allow for empirical decision-making (i.e. using facts, statistics, and data) and automated process oversight. AI can pick out the inefficiencies in the operational data pulled from different airport systems, redistribute resources, and improve process interactions (Russell & Norvig, 2021).

AI-enabled constructive systems can make recommendations regarding optimal routes for bags based on the number of bags and the number of people at the airport. These systems can also be used to anticipate demand, so that people won't get stuck in baggage handling systems. AI also improves operational efficiencies at airports in coordination and process design.

AI can also detect and report any process system disruptions or irregular processing in a timely manner, which helps airport operators mitigate any operational impacts. This is essential in airports that have a lot of passengers. Even the smallest delays can be very disruptive.

7.7. Previous Studies

Kazda and Caves (2015) have analyzed the operational framework of airport systems and pointed out the crucial role of airport performance of an efficient baggage handling system. Their study indicated that handling baggage is inefficient and an operational challenge that multiple airports face. They claim more technology is needed for baggage handling systems to become more reliable and operationally less disruptive.

SITA (2023) analyzed the prevailing trends and technological advancements in the management of baggage in airports. The study found that airports that utilized advanced baggage tracking technology such as RFID and AI real-time monitoring recorded a low rate of baggage mishandling. The study also found that the use of advanced digital technologies in airports improved operational efficiency and effectiveness and increased passenger satisfaction.

Schwarz (2021) studied airport logistics and stressed the need to combine advanced technology and baggage systems monitoring. The researcher found that automated and control monitoring systems gave managers enhanced operational visibility and improved the identification of operational system defects.

Geske (2024) evaluated how artificial intelligence (AI) impacts operational efficiency within air transport. The study concluded that real-time data analytics and predictive decision-making boosts operational performance in complex aviation environments.

Hassan et al. (2019) evaluated automated bag detection using computer vision tech in airport security. The study showed operational errors in baggage handling can be significantly reduced and the accuracy of baggage identification increased using deep learning models.

Tan and Masood (2021) completed a systematic literature review of Industry 4.0 tech in airport contexts. The study concluded that airport operation systems can be transformed and systems efficiencies improved with the adoption of artificial intelligence, big data analytics, and automation.

The economic impact of artificial intelligence (AI) technologies was analyzed by Brynjolfsson and McAfee (2017) where it was noted that AI systems provide a means for organizations to enhance workforce productivity and improve operational efficiency by adopting data-driven decision-making.

The last of the studies looked at IATA's 2023 report and the global trends in the aviation industry and the need for the use of digital technology in managing the increase in the number of passengers. The report stated that digital technology, including artificial intelligence, will be essential for enhancing the operational efficiency of airports in the coming decades.

All the studies mentioned above show that artificial intelligence has great potential to be used to increase the efficiency of complex systems such as airport baggage handling systems. The majority of studies, however, focus on general aviation activities or the digital transformation of airports and few studies focus on the use of artificial intelligence to enhance baggage handling systems in Saudi Arabian Airports.

7.8. Research Gap

Despite the emphasis placed on the value of artificial intelligence in transforming airport operations, the literature is deficient in many areas. Most literature concentrates on the use of artificial intelligence in aviation safety, air traffic management, and passenger processing systems. There is a glaring absence of studies that focus specifically on the role of artificial intelligence in baggage handling systems.

Second, nearly all previous studies, focused on developed airline markets, notably Europe and North America, while research on the application of artificial intelligence technologies in airport environments in the Middle East remains scarce.

Third, most previous studies have concentrated solely on the technological components of digital transformation in airports without exploring the connection between artificial intelligence technologies and the operational efficiency of individual components within the baggage handling systems.

Hence, this study aims to fill these gaps by investigating the impact of artificial intelligence technologies on the operational efficiency of baggage handling systems in international airports in Saudi Arabia.

7.9. Conceptual Framework

In view of the literature reviewed in this chapter, this study presents a conceptual framework attempting to determine the relationship between artificial intelligence technologies and operational efficiency of airport baggage handling systems.

In this framework for the study, artificial intelligence technologies are treated as the independent variable. Some of these technologies include predictive maintenance systems, smart baggage tracking systems, automated monitoring systems, and AI decision support systems. With these technologies, airports are able to collect, analyze, and make predictions

about operational data and system failures, as well as optimize the entire baggage handling process.

Operational efficiency is defined as the capacity of airport baggage handling systems to process passenger luggage with the utmost accuracy and efficiency while keeping system downtime, operational delays, and baggage mishandling to a minimum.

The conceptual framework based on the theory of operational efficiency indicates that the integration of artificial intelligence systems will operationalize efficiency through the improvement of reliability, baggage tracking accuracy, reduction of operational failure of the system, and improvement of the decision-making process.

7.10. Development of Hypothesis

This section will develop the research hypothesis based on empirical evidence and theories already established in the literature.

☐ Artificial Intelligence and Operational Efficiency

The impact of artificial intelligence (AI) technologies is undeniable when it comes to operational efficiency. This is particularly the case with the transportation and aviation industries. AI technologies provide the means to process and analyze big data, identify operational inefficiencies and provide evidence based solutions to operational challenges. AI technologies provide the ability to monitor operational systems, identify and resolve issues, and provide optimum functionality to operational processes in real time. This is particularly important in airports.

Davenport and Ronanki (2018) noted that the use of artificial intelligence (AI) in the workforce allows the simplification of intricate tasks and improves the quality of decision-making within the organization. This is also the case with Russell and Norvig (2021), where AI-based systems are able to interpret and assess the levels of complexity within the

organization and provide insight and recommendations to better the overall management of the organization.

AI within the systems of automated baggage handling in airports can improve and optimize the routing of AI and can also detect and address issues that arise within the operational units and the overall system. All of these things maintain the operational system and lowers the inconsistencies faced with system reliability.

With these assertions in mind, the following hypothesis is put forward.

H1: There is a considerable positive influence of AI on the operational efficiency of baggage handling systems in international airports.

H2: The reliability of baggage handling systems at international airports improves significantly through predictive maintenance driven by artificial intelligence.

H3: Intelligent baggage tracking technologies improve the accuracy of baggage handling within airport baggage handling systems.

8. Research Methodology

8.1. Research Design

Research design is a strategy for integrating the components of a study into a coherent whole. A good design ensures that the problem is resolved and the objectives of the study are accomplished. Research design guides researchers in the systematic collection and analysis of data in order to answer the question and test the hypotheses (Saunders et al., 2019).

8.2. Research Methodology

Research methodologies can be qualitative, quantitative, or mixed method. This study will use a quantitative methodology because it tries to measure how artificial intelligence technologies relate to operational efficiency in baggage handling systems.

Management and operations research tend to prefer a quantitative methodology because it aids in establishing relationships among a number of variables through statistical

techniques. This study aims to demonstrate, using statistical techniques, the measurable causal relationship between the artificial intelligence technologies and the efficiency of the baggage handling systems.

For the study, it is rational to use the quantitative methodology, as it aims to test a number of hypotheses, such as predictive maintenance, intelligent baggage tracking, automated monitoring systems, and operational efficiency.

8.3. Study Population

A study's population is the entire set of individuals or elements that the researcher intends to study. For this study, the population centers on the operational staff of international airports in the Kingdom of Saudi Arabia, particularly in the departments of baggage handling systems.

These workers include airport operations managers, engineers for baggage handling systems, maintenance staff, logistics personnel, and airport baggage management technical staff. These individuals have practical experience with and knowledge of the systems and technologies that comprise the handling systems of airports.

The research covers employees at major international airports in Saudi Arabia, which include:

- King Abdulaziz International Airport in Jeddah
- King Khalid International Airport in Riyadh
- King Fahd International Airport in Dammam

These airports serve as the greatest aviation hubs in the Kingdom, processing a large share of international airline passenger traffic.

8.4. Sampling Technique

Sampling is the process of choosing a portion of the subjects in a population to be included in the research study. Since obtaining data from a whole population is seldom

feasible, researchers usually choose a sample that is supposed to be representative of the population's traits.

The study employs a particular type of non-probability sampling method called purposive sampling, for participant selection, concerning their knowledge and experience with baggage handling operations. Obtaining knowledge and experience with baggage handling transactions is the critical reason this type of sampling will work for this study, as it will enable the respondents to handle and provide substantial details regarding the airport processes concerning their baggage.

In quantitative studies, sample size estimation techniques are well documented. For management studies, sample size between 150 to 300 is acceptable (Saunders et al., 2019).

Thus, the study will attempt to ensure that no less than 200 participants involved in the operational management of baggage handling of the international airports in Saudi Arabia, are used in the study.

8.5. Data Collection Techniques

In order to develop key variables within the research model, the questionnaires are divided into different sections of the following: artificial intelligence technologies, predictive maintenance systems, intelligent baggage tracking, automated monitoring systems, and operational efficiency metrics.

The questionnaires are made available to participants electronically, in order to maximize ease of data collection from staff at all airport locations. Upon collecting the questionnaires, participants will be informed of the objectives of the research, as well as their confidentiality.

8.6. Research Instrument (Questionnaire Development)

In this Research Study, the principal Research Instrument remains a structured questionnaire. It is a form of a questionnaire that is created based on the different

measurement scales, which are borrowed from previous research works on efficiency and use of artificial intelligence.

In total, the questionnaire is divided into several sections, as follows:

Section A: Demographic Data

In this section, the respondents give data about their Job Position, department and years of experience.

Section B: Technologies of Artificial Intelligence

This section evaluates the application of artificial intelligence technologies in airport baggage handling systems.

Section C: Systems of Predictive Maintenance

This section evaluates the application of predictive maintenance technologies in baggage handling systems.

Section D: Technologies for Intelligent Tracking of Baggage

This section evaluates the application of sophisticated technologies for tracking baggage.

Section E: Baggage Tracking Technologies

This section evaluates operational efficiency metrics, including the reliability of the system, the precision of tracking baggage, and the reduction of downtime.

The items in the questionnaire will be measured based on a five-point Likert scale for the following: 1 = Strongly Disagree , 2 = Disagree , 3 = Neutral , 4 = Agree , 5 = Strongly Agree

8.7. Reliability and Validity

The reliability and validity of the research instruments are the hallmarks of quality research. Validity is the degree to which a measurement tool measures what it purports to measure. In this research, the validity of the content will be ascertained by subjecting the questionnaire to experts with academic qualifications and practitioners in the airport

operations field. Reliability is defined as the instrument's measuring the amount of consistency. Using Cronbach's Alpha, reliability will be evaluated, as it assesses the internal consistency of a survey's items. Hair et al. (2019) state that a Cronbach's Alpha of .70 is considered acceptable reliability.

8.8. Techniques of Analyzing Data

Data will be analyzed using Statistical Package for the Social Sciences (SPSS) software after the survey responses have been collected. Three types of analyses will be performed, starting with

☐ Descriptive Statistics

This will analyze the collected data to summarize the data as well as describe the demographic traits of the respondents.

☐ Reliability Analysis

In order to analyze the internal consistency of the measurement scales, I will utilize Cronbach's Alpha. Upon completion of the previous analysis, Correlation Analysis

This will analyze the associations of the AI technologies and the indicators of operational efficiency.

☐ Regression Analysis

This will test the AI technologies on the operational efficiency of the hypotheses and determine impacts of the research on the efficiency of the baggage handling systems.

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Appendix A

10.Questionnaire

10.1. Demographic Information

1. Gender

Male

Female

2. Age

Less than 30

30–40

41–50

More than 50

3. Educational Level

Diploma

Bachelor's Degree

Master's Degree

PhD

4. Job Position

Airport Operations Staff

Baggage Handling Technician

Maintenance Engineer

Airport Operations Manager

Other

5. Years of Experience

Less than 5 years

5–10 years

11–15 years

More than 15 years

6. Airport

King Abdulaziz International Airport (Jeddah)

King Khalid International Airport (Riyadh)

King Fahd International Airport (Dammam)

10.2. Variables and Measurement

Variable	Type	Number of Items
Artificial Intelligence Technologies	Independent Variable	5
Predictive Maintenance	Independent Variable	5
Intelligent Baggage Tracking	Independent Variable	5
Automated Monitoring Systems	Independent Variable	5
Operational Efficiency	Dependent Variable	5

Likert Scale

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

10.3. Artificial Intelligence Technologies

No	Statement	1	2	3	4	5
1	Artificial intelligence technologies are used in airport baggage handling systems.					
2	AI technologies improve operational monitoring in baggage handling systems.					
3	AI systems help detect operational problems quickly.					
4	AI technologies improve decision-making in airport operations.					
5	AI technologies improve coordination between airport operational systems.					

10.4. Predictive Maintenance

No	Statement	1	2	3	4	5
6	Predictive maintenance systems help detect equipment failures early.					
7	AI-based maintenance systems improve baggage handling equipment reliability.					
8	Predictive maintenance reduces unexpected equipment breakdowns.					
9	Predictive maintenance improves maintenance planning efficiency.					
10	AI maintenance systems reduce system downtime.					

10.5. Intelligent Baggage Tracking

No	Statement	1	2	3	4	5
11	Advanced technologies improve baggage tracking accuracy.					

12	AI technologies improve baggage identification processes.					
13	Smart baggage tracking systems reduce baggage loss.					
14	Real-time baggage monitoring improves airport operational efficiency.					
15	AI technologies improve baggage routing accuracy.					

10.6. Automated Monitoring Systems

No	Statement	1	2	3	4	5
16	Automated monitoring systems detect operational problems quickly.					
17	AI monitoring systems improve baggage flow management.					
18	Automated monitoring systems improve system reliability.					
19	Monitoring systems help reduce baggage handling disruptions.					
20	AI monitoring systems improve operational control.					

10.7. Operational Efficiency of Baggage Handling Systems

No	Statement	1	2	3	4	5
21	AI technologies improve baggage processing speed.					
22	AI technologies improve system reliability.					
23	AI technologies reduce baggage handling errors.					
24	AI technologies reduce operational delays.					
25	AI technologies improve overall airport operational efficiency.					