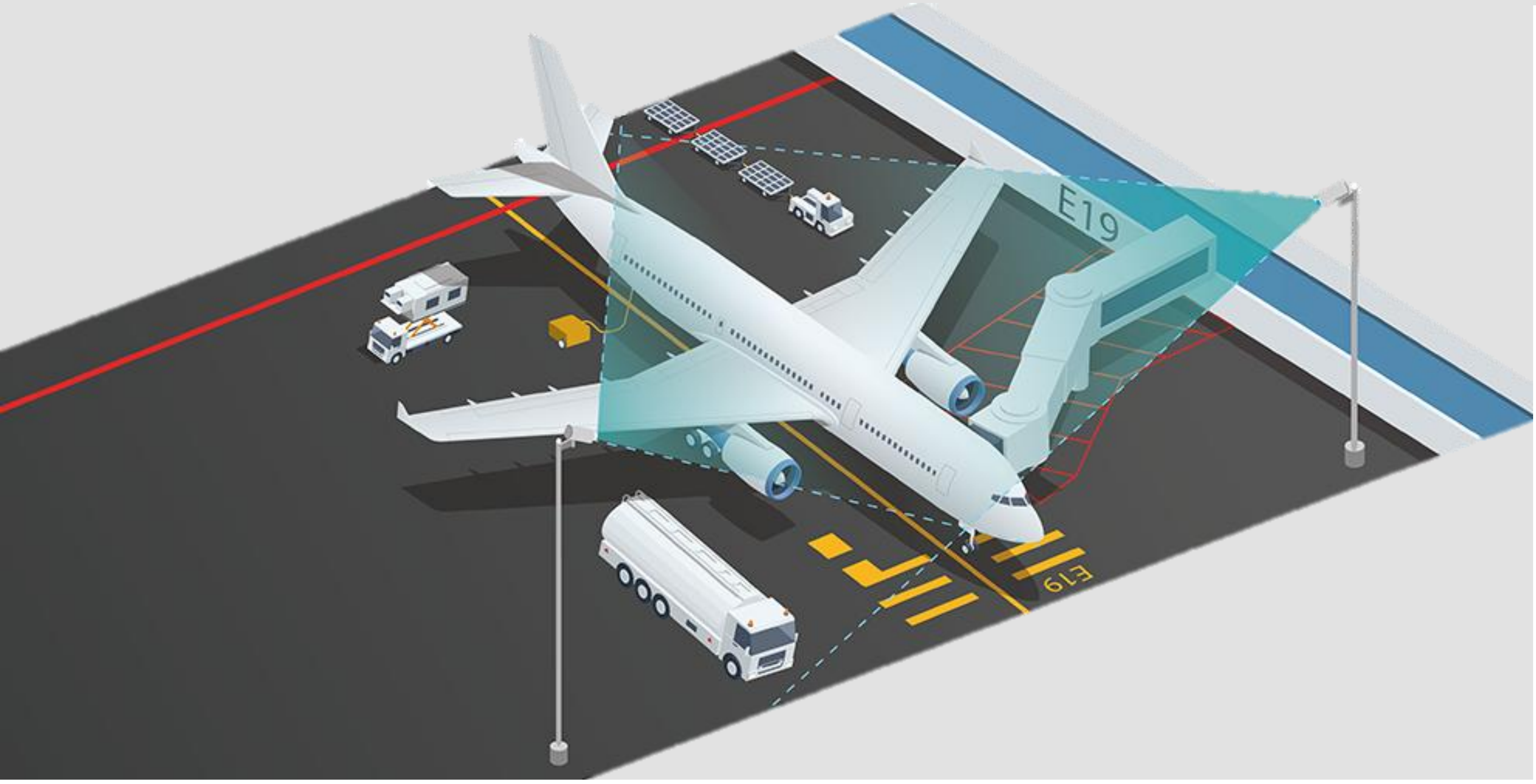
UNAUTHORIZED PUSHBACKS

Evaluating the possibilities behind the integration of Deep Turnaround data into a pushback incursion detection application.



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ABSTRACT

This research looks at the possibility of using the existing Deep Turnaround camera system at Schiphol to detect unauthorized pushbacks. A pushback is the moment an aircraft is pushed away from the stand before taxiing. Because this is a safety-critical operation, it may only happen after approval from ground control. Even with the current procedures and communication protocols, situations still occur where pushback is started without proper authorization or coordination.

The research focused on how Deep Turnaround camera data could be used to detect these situations and how this data could be combined with operational systems already used at Schiphol. To answer this, the pushback process was analysed, interviews were conducted, and different system outputs and datasets were examined.

The results show that Deep Turnaround can detect several relevant events, such as aircraft movement, turnaround milestones, and tug activity. However, camera data alone is not enough to determine whether a pushback is authorized, because verbal clearances and readback communication cannot be detected by cameras. Because of this, the research concluded that synchronization with clearance information from the electronic flight strips is necessary.

Based on the findings, a conceptual detection and alarming framework was developed. The system combines Deep Turnaround events with the clearance state to determine whether a pushback is authorized. If aircraft movement is detected without an active clearance, the system generates an alert for ground control and/or the outbound planner.

The research shows that the concept is technically, operationally, and organizationally feasible, but further validation and testing are needed before operational implementation can be considered. The reliability of Deep Turnaround events and the minimization of false alerts are especially important for future development.

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LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
AAS	Amsterdam Airport Schiphol
A-CDM	Airport Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance–Broadcast
AMS	Amsterdam
API	Application Programming Interface
ATC	Air Traffic Control
ATM	Air Traffic Management
AUAS	Amsterdam University of Applied Science
CISS	Centraal InformatieSysteem Schiphol
DMAN	Departure Manager
DT	Deep Turnaround
EASA	European Union Aviation Safety Agency
EFS	Electronic Flight Strip
FOD	Foreign Object Debris
GSE	Ground Support Equipment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILABS	Innovation Laboratorium
KLM	Koninklijke Luchtvaart Maatschappij
LVNL	Luchtverkeersleiding Nederland
MLAT	Multilateration
OPL	Outbound Planner
PEGT	Prediction End of Ground handling Time
PiC	Pilot in Command
RIASS	Runway Incursion Alert System Schiphol
RT	Radio Telepathy
TSAT	Target Start-up Approval Time
TWR-APP	Tower Approach
VEMMIS	Veiligheid, Efficiency en Milieu managementinformatiesysteem

1. INTRODUCTION

Efficient aircraft turnaround operations are important for maintaining airport capacity, scheduling reliability, and safe apron management. The turnaround phase can be defined as the period between aircraft arrival at the stand and its departure. In this phase a set of tightly coordinated ground handling activities must be performed within limited time windows. These activities include passenger boarding and deboarding, baggage handling, refuelling, catering, cleaning, technical checks, and final departure preparations. The completion of these separate activities is also known as the *turnaround milestones*. Because aircraft rotations are interconnected across the airport network, even small disruptions during turnaround can propagate into delays for other aircraft.

To assure these delays are mitigated as much as possible, turnaround processes require explicit communication between ground handling crew, airlines and flight crew, airport operations, and air traffic control. Each party holds distinct responsibilities. Ground handling organizations execute physical servicing activities, airlines and flight crew oversee flight readiness, the airport operator manages stand allocation, and air traffic control ensures safe aircraft movement in the movement areas, which are the runway, taxiway, and aprons at an aerodrome, through clearance, timing, and separation management. While operational responsibilities are clearly defined, the operational environment remains dynamic and time sensitive. Maintaining situational awareness is key for all stakeholders to continue safe operations.

One of the most critical and safety sensitive activities of the turnaround phase that needs maintained situational awareness is the aircraft pushback. During pushback, the aircraft is moved from the parking stand to a taxi position where it can proceed under its own power. This operation requires explicit authorization from air traffic control and precise coordination between the flight crew, ground personnel, and ground control. Because pushback directly affects traffic flow and runway scheduling, any deviation, misalignment, or premature initiation may disrupt departure planning and increase operational risks for the airport. However, pushbacks can be initiated without proper clearance, resulting in an unauthorized pushback. This type of pushback incursion jeopardizes the safety of the movement areas.

With the idea of improving oversight of turnaround milestones and situational awareness, Amsterdam Airport Schiphol has implemented the Deep Turnaround system. Deep Turnaround uses fixed apron camera infrastructure combined with data processing and machine learning algorithms to detect and predict turnaround milestones, to then support scheduling tools for the air traffic controllers.

Currently, the primary ideology of Deep Turnaround remains focused on turnaround milestone detection and predictions for planning purposes. While the system generates a lot of rich visual data regarding aircraft presence and servicing progress. The broader operational potential of this data, particularly its use in active deviation detection and decision-making support within Amsterdam Airport Schiphol, has not yet been fully explored.

This research therefore aims to evaluate, on a conceptual level, how the Deep Turnaround system can be extended beyond its current predictive function to support additional operational applications within pushback management. The study investigates the technical possibilities, organizational implications, and integrations requirements associated with such an extension. By analysing current processes, assessing system capabilities, and developing a conceptual integration framework and system diagram, the research seeks to provide a clear roadmap outlining how the Deep Turnaround system could be expanded beyond prediction, including its technical possibilities, integration requirements, and practical implementation considerations.

1.1. PROBLEM STATEMENT

In some cases, unauthorized pushback initiation is not timely detected, as monitoring primarily relies on human communication and observations resulting in vulnerable airport operations or unsafe.

1.2. OBJECTIVES

The main objective of this research is to determine how the Deep Turnaround system can be utilized to detect unauthorized pushbacks and how its data can be integrated to support pushback authorization processes through the development of a conceptual alarming and data integration framework.

From the main objective the following sub objectives have been established:

i. Define how pushback authorization, coordination, and execution are currently organized within apron operations and identify vulnerabilities where unauthorized pushback initiation may occur. This will establish a foundation for the operational context, identify systematic gaps and establish functional requirements for a detection and alarming system.
ii. Examine the data outputs, functionalities, and technical interfaces of the Deep Turnaround system and other supportive external systems to evaluate their suitability for operational monitoring and system integration. This will determine the technical feasibility and integration potential of using existing camera infrastructure for operational applications.
iii. Create a conceptual detection and notification framework and system diagram to evaluate how pushback incursions can be identified using camera data and to evaluate suitable video-analytics and system processes capable of detecting such events at a conceptual level. This framework will define the detection logic and alarm principles required for detection and notification system.
iv. Evaluate product feasibility by investigating stakeholder responsibilities, and regulatory consideration that may influence the implementation and operational use of a camera-based alarming system. This will identify practical constraints, stakeholder requirements, and implementation feasibility.

1.3. SCOPE

This study focuses on the operational, technical, and organizational possibilities of utilizing Deep Turnaround camera data for detection of aircraft pushback deviations. The primary use case examined in depth is the detection and notification of unauthorized pushback initiations within the operations of Amsterdam Airport Schiphol (AAS), with the objective of providing accurate operational data to the relevant stakeholder. This serves as an anchor for exploring how camera-based data can support operational situation awareness. This research does not analyse the possibilities of integrating data to support other turnaround use cases.

The scope of the research is limited to the use of existing Deep Turnaround infrastructure at Schiphol Airport and its interaction with current apron operations involving LVNL, Schiphol Group, and airlines stakeholders. The study investigates a conceptual system design, data flows, alarm logic, integration opportunities, and stakeholder impact, rather than the development or deployment of a fully realized operational software solution. No live system implementation, algorithm training, or real-time operational testing will be performed

From a technical perspective, the research explores feasible video analytics approaches at a conceptual level and evaluates system integration based on existing documentation, interviews, and process analysis. Detailed software engineering, hardware modification, and certification processes fall outside the scope of the study.

From an operational perspective, the study examines how camera-based alarming and data integration could fit within current apron workflows, roles, and responsibilities. However, it does not redesign ground control or apron procedures, assess financial perspectives nor will an implementation plan be created.

From a system perspective, the scope of this study is limited to the conceptual design of a notification system and alarming function based on Deep Turnaround camera data. The proposed system will only focus on highlighting the conditions related to unauthorized or improperly coordinated pushback initiation and generating a corresponding notification to the appropriate operational department. While the video analytics of Deep Turnaround may technically be capable of detecting additional turnaround incidents or operational deviations, the identification, analysis, or classification of other event and their causes fall outside the scope of this study. The system is therefore limited to highlighting the requirements for a notification.

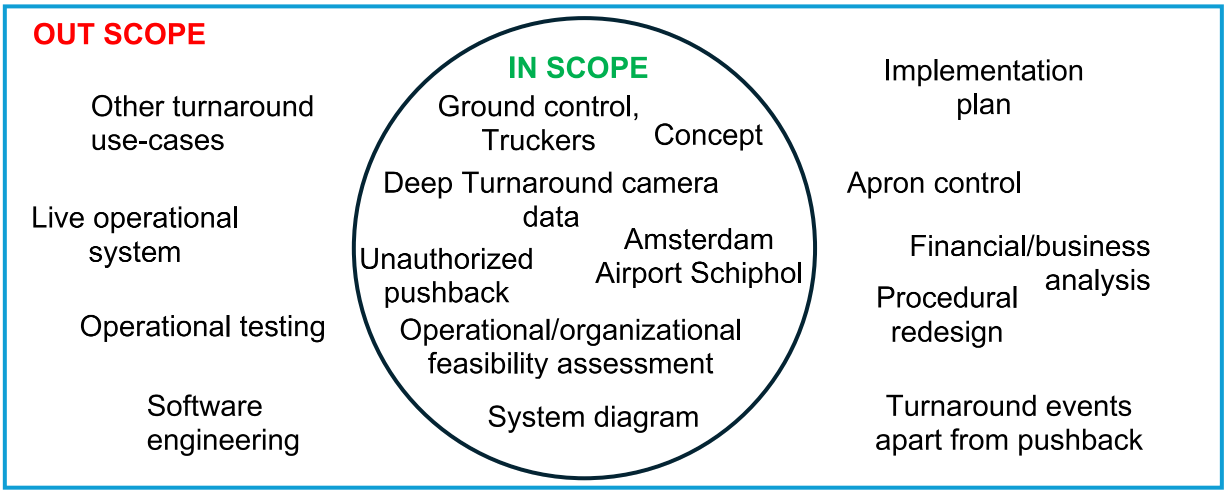


Figure 1: Project scope visualisation

1.4. STRUCTURE

The document is set out as follows. Chapter 2 provides the literature regarding relevant context for the research. Followed by chapter 3, which contains the theoretical framework. Within the theoretical framework methods for the methodology are discussed. In chapter 4 the methodology is explained. Next is the results in chapter 5. Followed up by a summary of the results with the findings in chapter 6. Finally, the discussion and limitations, recommendations, and future work is highlighted in chapter 7, the conclusion.

2. LITERATURE REVIEW

2.1. AIRCRAFT OPERATIONS

Aircraft ground operations include all aircraft movements and handling activities that take place on the aerodrome surface, except for the actual flight phase. These operations occur within the aerodrome movement area, which consists of the runway, taxiway, and apron. The runway is primarily used for take-off and landing, taxiways connect the runway with the apron, and the apron is used for aircraft parking, loading and unloading of passengers and cargo, refuelling, and other ground services (ICAO, 2019). Because aircraft, ground vehicles, and personnel operate simultaneously in these areas, the environment is complex and presents risks such as collisions between aircraft and vehicles or hazards caused by jet blasts and vehicle movement. For this reason, aircraft ground operations must be carefully coordinated and controlled to ensure safe and orderly movement on the aerodrome surface (ICAO, 2016).

Aircraft ground operations involve multiple stakeholders who each have specific responsibilities to maintain safe operations. Air traffic control is responsible for issuing clearances and maintaining separation between aircraft and other traffic on the movement area, as clearances are used to ensure safe and orderly traffic flow (ICAO, 2016). The pilot in command (PiC) remains responsible for the safe operation of the aircraft and must comply with air traffic control clearances and instructions. Ground handling personnel are responsible for activities at the stand such as docking, refuelling, loading, catering, and pushback operations, which are necessary to prepare the aircraft for departure. In addition, the aerodrome operator is responsible for providing a safe operating environment and managing apron safety and infrastructure (IATA, 2026) (ICAO, 2019).

Aircraft are not permitted to move on the movement areas without proper clearance from air traffic control. Clearances are required for start-up, pushback, taxi, runway crossing, and take-off (ICAO, 2016) (AMS schiphol, 2026), and these clearances are issued to ensure separation between aircraft and to maintain an orderly flow of traffic on the ground and in the air. Standardized phraseology is used during communication between pilots and air traffic control to avoid misunderstandings and to ensure that instructions are clearly understood and acknowledged before aircraft movement begins (ICAO, 2016). For example, pushback must be requested by the pilot and approved by the control tower before the operation can begin, and taxi instructions must be issued before an aircraft may taxi on the manoeuvring area. Aircraft ground movement is therefore a highly procedural system in which movement is controlled through clearances and standardized communication.

Situational awareness plays an important role in aircraft ground operations because pilots, controllers, and ground personnel must continuously understand the systematic and physical position of the aircraft, and the movement of vehicles and other aircraft in the vicinity. The movement areas contain multiple hazards, including the risk of collision between aircraft and vehicles, confusion due to markings and signage, and hazards created by jet blast and ground equipment operating near aircraft. Maintaining situational awareness is therefore important for safe operations, as air traffic control clearances are based on known traffic conditions and the safe execution of those clearances depends on all stakeholders having an accurate understanding of the operational situation (AMS schiphol, 2026).

2.2. TURNAROUND PROCEDURES

The aircraft turnaround process refers to the period between an aircraft's arrival at the stand and its subsequent departure from that stand. During this period, a series of ground handling activities must be completed in order to prepare the aircraft for its next flight. These activities typically include passenger disembarkation and boarding, baggage unloading and loading, refuelling, catering, cleaning, and technical inspections. Each of these activities is performed by different ground handling teams and must be coordinated so that the aircraft can depart safely and on schedule. Turnaround can directly affect departure timing and overall airport capacity (IATA, 2023).

Turnaround operations are characterized by a high level of coordination and time pressure because many ground handling activities take place simultaneously and are often dependent on one another. For example, boarding must be completed before the bridge can be detached, or the pushback truck must be connected before the aircraft can depart. If one activity is delayed, it can affect subsequent activities and ultimately delay the departure of the aircraft. For this reason, airports use coordinated decision-making processes such as Airport Collaborative Decision Making (A-CDM), which aims to improve the predictability and efficiency of turnaround operations by sharing accurate and timely information between stakeholders such as airlines, ground handlers, and air traffic control. The objective of A-CDM is to ensure that all parties have a common operational picture and can make decisions based on reliable information about the turnaround process (EUROCONTROL, 2017).

To monitor and manage turnaround operations, airports use defined turnaround milestones that indicate the progress of the aircraft through the turnaround process. Such milestones include, but are not limited to, on-block time, which is the time the aircraft arrives at the stand, the start and completion of boarding, the start and completion of refuelling, and off-block time, which is the moment the aircraft leaves the stand to begin pushback. Off-block time is particularly important because it marks the transition from turnaround operations to taxi and departure operations and is used by ATC (Air Traffic Control) to plan taxi and departure sequencing (EUROCONTROL, 2017). The Deep Turnaround (DT) system predicts the off-block time, allowing airport operations and air traffic control to anticipate delays or changes in departure planning (AMS Schiphol, 2026).

Once turnaround activities have been completed and the aircraft is ready for departure, the flight crew must request start-up and pushback clearance. Start-up clearance allows the aircraft to start its engines, while pushback clearance allows the aircraft to be pushed back from the stand, by a pushback truck. These clearances are technically separate but are issued together in practice (Schiphol, 2025). Pushback may only begin once clearance has been received by the pilot and transferred to the ground crew, to which they must confirm that the aircraft and surrounding area are ready for the manoeuvre before departing from the stand (Schipol, 2024). The pushback represents the final step of the turnaround process and marks the moment at which the aircraft transitions from stand operations to ground movement under air traffic control.

2.3. PUSHBACK PROCEDURES.

Pushback is the procedure in which an aircraft is pushed backwards from its parking position at the stand, by a pushback tug, so that it can safely start taxiing under its own power. Aircraft are generally unable to move backwards using engine thrust at the stand, the aircraft that technically could push back under their own power are not allowed due to the engine jet blast of the reverse thrust kicking up debris which could get sucked up by the engines and cause catastrophic damage (EASA, 2026). For this reason, pushback is performed by trained ground handling personnel using specialized pushback tugs. Pushback marks the transition between stand operations and aircraft ground movement under air traffic control, and it is therefore a critical phase in the departure process that must be conducted in a controlled and coordinated manner (AMS schiphol, 2026) (Schiphol, 2025).

Pushback operations involve multiple stakeholders who each have specific responsibilities during the operations. The flight crew remains responsible for the aircraft and communicates with air traffic control to request start-up and pushback approval. The headset operator, who is connected to the aircraft via intercom, is being communicated with by the flight crew, who coordinates the pushback tug, then initiates the pushback procedure on behalf of the ground crew. The pushback driver operates the pushback tug and executes the pushback procedure. In addition, a team coordinator, part of apron control or ramp control, often called a turnaround coordinator, may be responsible for overseeing the overall turnaround process at the stand, ensuring that ground handling activities are completed on time and that the aircraft is ready for departure, after which the coordinator communicates the aircraft status to multiple stakeholders, most relevantly, the Operations Control Centre and Schiphol Group (KLM, 2026). Air traffic control, specifically ground control, is responsible for issuing pushback clearance and ensuring that the pushback operation does not conflict with other traffic on the apron or taxiways. If an aircraft does execute a pushback without clearance, an unauthorized pushback has occurred. This event compromises airport safety. Pushback operations therefore rely on coordination between the flight crew, ground crew, and air traffic control, with each party responsible for a specific part of the operation. A summary of the stakeholder interactions is provided in Figure 2: Pushback stakeholder interaction diagram

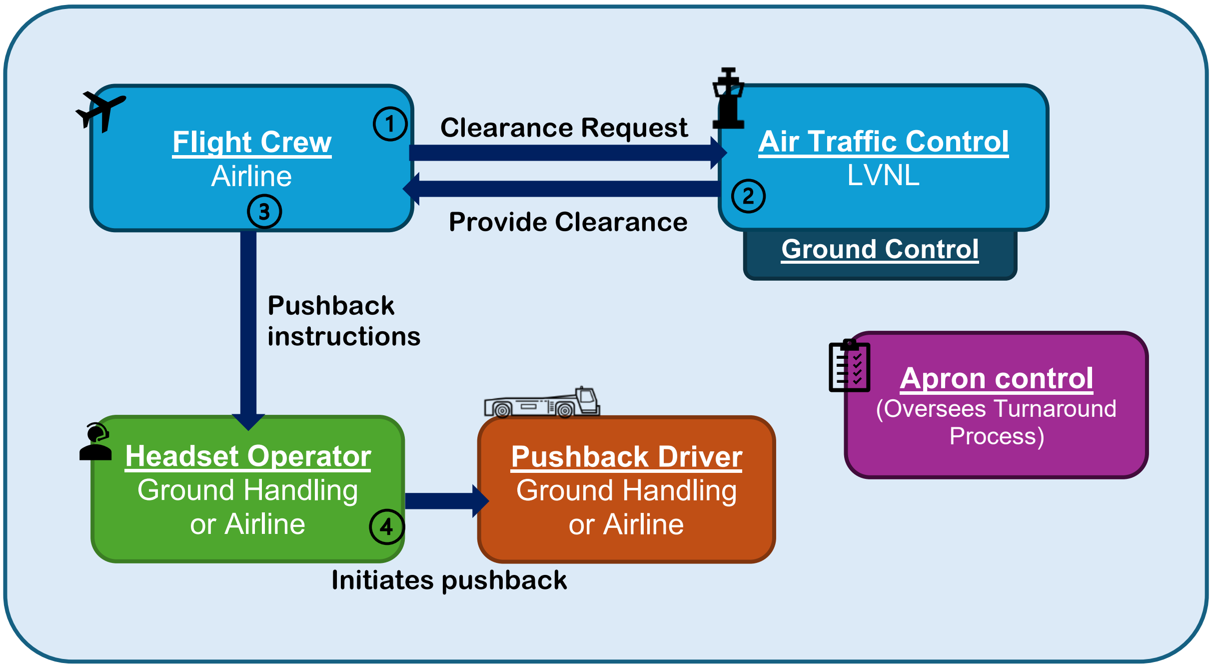


Figure 2: Pushback stakeholder interaction diagram

The pushback procedure follows a defined sequence of steps that must be completed before the aircraft can begin taxiing, these steps vary from airport and piers but are generally conducted the same. First, the aircraft must be ready for departure, meaning that all turnaround activities have been completed and the aircraft doors are closed, the bridge is detached, tug connected, wheel chocks removed, and all Ground Support Equipment (GSE) is cleared from the stand (Schipol, 2024). The flight crew then requests start-up clearance from air traffic control to start the aircraft engines. After start-up clearance has been received, the flight crew requests pushback clearance from ground control. Once pushback clearance has been granted and the ground crew has confirmed that the area behind the aircraft is clear, the flight crew releases the parking brake, and the pushback operation begins. The aircraft is then pushed back to the designated taxi position, after which the pushback tug disconnects and the aircraft requests taxi clearance from ground control. This sequence ensures that pushback operations are coordinated with other apron traffic and that aircraft movement only occurs when it is safe to do so (ICAO, 2016). Figure 3: Pushback process diagram shows a simplified version a pushback process.

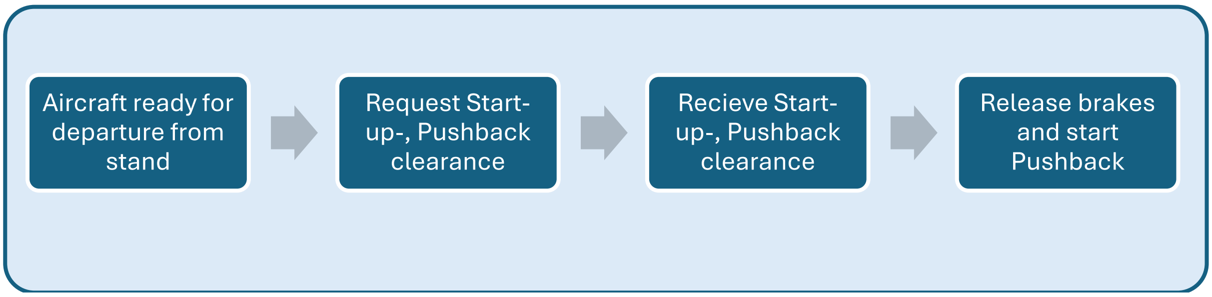


Figure 3: Pushback process diagram

Pushback operations take place in a congested movement area where multiple aircraft and ground vehicles operate simultaneously and where visibility from the cockpit is often limited, particularly behind the aircraft. Because the flight crew cannot see the area directly behind the aircraft, they rely on the ground crew to ensure that the area is clear and that the pushback manoeuvre can be performed safely. In addition, pushback operations require coordination with air traffic control to avoid conflict with taxiing aircraft and other traffic. Miscommunication, loss of situational awareness, or procedural deviations during pushback can therefore create hazardous situations, these events are classified as incursions and are the reason why pushback procedures are strictly regulated and standardized (AMS schiphol, 2026).

A pushback incursion can be defined as a pushback operation that deviates from the procedure, that is initiated without clearance from ground control, that deviates from ground control instructions, that has received improper instruction or clearance from ground control, or other reasons (KLM, 2026). Such incursion may occur due a variety of reason, from miscommunications to loss of situational awareness by one of the parties involved in the operation (KLM, 2026). Because pushback involves moving a large aircraft in a confined operational environment with limited visibility and multiple moving vehicles and aircraft, unauthorized or improperly coordinated pushback operations can create safety risks and operational disruptions. Monitoring pushback operations and detecting deviations from normal procedures is therefore important for maintaining safe and efficient apron operations.

2.4. DEEP TURNAROUND SYSTEM AND IMPLEMENTATION FACTORS

The Deep Turnaround system was developed to provide better insight into aircraft turnaround operations and to improve collaboration between airport stakeholders. At large airports such as Schiphol, turnaround operations involve many different parties and delays during turnaround can lead to operational disruptions and inefficient use of gates and runways. One of the main challenges in turnaround operations is the lack of real-time insight into the status of ground handling activities, which can lead to suboptimal planning and last-minute changes. Deep Turnaround was developed to address this problem specifically, by providing real-time and predictive insights into the turnaround process using camera data and artificial intelligence (AMS Schiphol, 2026). In complex operational environments, decision-making often depends on the availability of accurate and timely information, a lack of shared information between stakeholders can lead to operational inefficiencies or even accidents (Endsley, 2015).

Deep Turnaround works by using cameras installed at aircraft stands to capture images of the turnaround process. These images are analysed by artificial intelligence models that detect which ground handling activities are taking place and when these activities start and stop. The system uses one model to detect real-time events occurring during the turnaround process and a second model that combines these detections with flight data to predict when the turnaround will be completed and when the aircraft is expected to be ready for pushback. In this way, Deep Turnaround converts camera images into operational data that can be used for monitoring and planning purposes (AMS Schiphol, 2026). However, video analytics systems rely on object detection and activity recognition algorithms, which are subject to uncertainties such as occlusion, lighting conditions, and classification errors, meaning that detected events must be interpreted within an operational context rather than treated as absolute truth (Yildiz et al., 2022).

The Deep Turnaround system produces several types of operational data. The system detects and records turnaround events, automatically generating timestamps for these events. Based on these detections, the system predicts the end of ground handling time (PEGT), which indicates when the aircraft is ready to leave the stand and begin pushback. The data generated by DT is made available through different platforms, including live dashboards, Wilbur, that show the progress of turnarounds, data streams that can be integrated into airport operational systems through an API, and historical databases that can be used for post-operational analysis and process improvement (AMS Schiphol, 2026).

The data generated by DT is used by multiple operational stakeholders. Gate planners use the PEGT to plan gate allocation and reduce last minute gate changes, while ground handlers use real-time turnaround information to allocate personnel and equipment more efficiently. Airlines use the data to monitor turnaround performance and improve on-time performance, and ATC can use the PEGT to improve departure sequencing and runway planning. By providing a shared and objective source of turnaround information, DT improves collaboration and situational awareness among stakeholders involved in aircraft turnaround operations (AMS Schiphol, 2026).

The functioning of the Deep Turnaround system is inherently based on video analytics, which forms the core mechanism through which camera data is translated into operational information. Video analytics refers to the use of computer vision algorithms to automatically interpret video images and detect objects, movements and label them as events (Goswami, 2020). In Amsterdam airport Schiphol, video analytics are used to detect aircraft, ground vehicles, and ground handling activities by analysing camera images and identifying patterns that correspond to specific events (AMS Schiphol, 2026). (Bou et al., 2025) describes video analytics as a process in which image data is converted into structured information, such as object presence, movement detection, and activity recognition, allowing video footage to be used as an operational data source. This makes it possible to automatically detect operational events, such as the start of aircraft movement, based on changes in position detected in the video feed.

Video analytics systems detect movement by analysing changes in pixel positions between consecutive images and identifying when an object changes position beyond a predefined threshold. In the case of aircraft stand-based camera systems, the monitored area is limited to the aircraft stand, which means that movement detection is limited to aircraft movement within that defined area. For the Deep Turnaround system, this implies that movement detection is primarily focused on aircraft and ground handling activity within the stand area, which defines the observable scope of potential pushback related events (AMS Schiphol, 2026). To prevent false detections caused by small movements such as camera noise, personnel movement, or minor aircraft position adjustments, movement detection systems typically use predefined thresholds that must be exceeded before movement is recorded as an event (Goswami, 2020). (Bou et al., 2025) describes this as a trade-off between false positives and false negatives, where a threshold that is too low may result in false alarms, while a threshold that is too high may result in missed events. This means that movement detection systems must be carefully calibrated to ensure reliable event detection.

The data produced by video analytics systems typically consists of even timestamps, movement detections, and activity classifications, which in the case of Deep Turnaround are directly translated into turnaround milestones predictions. These data outputs can be used to reconstruct operational timelines, monitor process performance, and detect deviations from expected operations. (Bou et al., 2025) says such systems transform raw sensor data into operational value that can support decision-making process. However, the presence of data alone does not automatically result in improved operational decisions, as the data must be interpreted and acted upon by operational staff. This means that the effectiveness of video analytics systems depends not only on detection accuracy but also on how the information is integrated into operational processes.

The implementation of video analytics systems in operational environments is not only a technical challenge but also an organizational and human factors challenge. (Parasuraman et al., 2000) describe that automation in safety-critical environments must be carefully designed because human operators must understand, trust, and correctly interpret automated system outputs. If automated systems generate too many alerts, operators may begin to ignore them, a phenomenon known as alarm fatigue. consequently, if automated systems are not trusted, operators may ignore useful information. In the context of Deep Turnaround, this highlights that any extension of the system towards real-time alarming must carefully consider how information is presented and how operators interact with it. This means that the successful implementation of video analytics systems depends not only on detection capability but also on how alerts and information are presented and integrated into operational procedures.

The introduction of new monitoring technologies in airport operations must be integrated into existing organizational structures and procedures. Aviation operations are often described as socio-technical systems, in which technology, humans, and organizational procedures interact to ensure safe operations (ICAO, 2018). For Deep Turnaround, this means that extending its functionality towards detection and notification requires clear procedures, defining who receives information, who is responsible for taking action, and how the system integrates within existing operational responsibilities. Without clear procedures and responsibilities, additional information systems may increase complexity rather than improve operational performance (Parasuraman et al., 2000).

3. THEORETICAL FRAMEWORK

Research in operational and organizational environments typically relies on a combination of qualitative and quantitative data collection methods to obtain an understanding of complex processes. The Theoretical Framework highlights that selecting appropriate research methods depend on the nature of the research questions, the type of data required, and the context in which the research is done. (Saunders et al., 2023) describe business and management research as a structured process in which researchers select suitable data collection methods to systematically investigate a problem and produce reliable insight.

Within applied research, qualitative methods are frequently used to explore processes, behaviours, and decision-making structures. Case study research examines a real-world situation or phenomenon in depth, especially when it is difficult to separate the issue from the context in which it occurs. Researchers usually collect information from several sources, such as interviews, observations, and documents, to gain a thorough understanding of the topic being studied (Yin, 2009). In addition to qualitative approaches, quantitative research methods are used to collect and analyse numerical data to identify patterns, relationships, or trends. Quantitative research typically involves structured data collection methods such as surveys or structured observations, followed by statistical analysis to describe or examine relationships between variables. Quantitative methods can be used in descriptive research to provide an overview of a situation using measurable data. The selection of quantitative methods depends on whether the research aims to describe a situation, examine relationships between variables, or test hypotheses (Ghanad, 2023).

3.1. QUALITATIVE METHODS

One commonly used method for collecting qualitative data is the interview. Interviews are a qualitative data collection method used to obtain detailed insights from individuals with direct knowledge or experience of a particular phenomenon. They typically involve structured, semi-structured, or unstructured conversations, meaning the researcher has either prepared fixed questions or leads off answers or has not prepared any questions beforehand. This allows researchers to explore participants' perspectives, experiences, and decision-making processes. Interviews enable researchers to obtain detailed insights into experiences, perceptions, and operational practices from individuals who are directly involved in the phenomenon under investigation. Semi-structured interviews are particularly useful because they combine a predefined set of questions with flexibility to explore new themes that may arise during the discussion. This flexibility allows researchers to obtain rich information that might not emerge through a fixed questioning format. However, interviews may also introduce challenges such as interviewer bias, subjective interpretation of responses, and the time required to conduct and analyse conversations (Saunders et al., 2023) (Creswell, 2009).

Observations represent another important qualitative research method. Through direct observation, researchers can watch and record how processes unfold in practice and identify behaviours, interactions, and environmental conditions that may not be captured through self-reported data. Observational research is especially useful in operational environments where activities involve coordination between multiple parties and systems. The strength of this method lies in its ability to capture real-time behaviour and contextual factors. Nevertheless, observations can be limited by restricted access to operational settings and by the possibility that individuals modify their behaviour when they are aware of being observed (Saunders et al., 2023).

Document analysis is frequently used, alongside other more qualitative methods, to examine existing information sources such as reports, procedures, technical documentation, and organizational records. This method allows researchers to analyse formal descriptions of processes and historical records without requiring direct interactions with participants. Document analysis can provide valuable background information and help validate findings obtained through other methods. However, its limitations include potential incompleteness of documentation and the possibility that documents reflect formal procedures rather than actual operational practices (Creswell, 2009).

Focus groups represent another qualitative method that facilitates several participants collectively discuss a specific topic or issue. In contrast to individual interviews, focus groups allow participants to interact with one another, which can stimulate discussion and reveal collective perspectives or shared challenges. The method can generate a wide range of ideas and viewpoints within a relatively short period of time. However, focus groups may also present limitations, including the possibility that dominant participants influence the discussion or that some individuals are less willing to share critical opinions in a group setting (Saunders et al., 2023) (Creswell, 2009).

3.2. QUANTITATIVE METHODS

Experimental research is a quantitative method used to determine cause and effect relationships between variables. In experimental research, the researcher manipulates on independent variable and measures its effect on a dependent variable while controlling other variables. This method is particularly useful when the objective is to test whether a specific change leads to a measurable outcome. However, experimental research often requires controlled conditions, which may be difficult to achieve in real-world operational environments (Ghanad, 2023).

Survey research represents a widely used quantitative data collection method. Surveys are structured questionnaires and enable researchers to collect standardized information from a larger number of respondents, allowing patterns and trends to be analysed systematically. It is important to validate the sample population used for the questionnaire. Surveys are particularly useful when researchers seek to obtain measurable data or compare responses across groups of participants. Their strengths lie in their scalability and efficiency, as they can reach a large population with relatively limited resources. However, surveys often provide less detailed insights than qualitative methods, and response accuracy may depend on participants' interpretation of the provided questions and willingness to provide truthful answers (Saunders et al., 2023).

Descriptive Quantitative research is used to describe characteristics of a situation, process, or population. The goal of this type of research is not to determine relationships between variables, but to provide a clear numerical overview of what is happening. Researchers collect measurable data and summarize it using statistics such as averages, percentages, frequencies, and distributions. Descriptive research answers questions such as 'What is happening, how often it happens, or how much of something occurs.'. This type of research is particularly useful when the objective is to provide a structured overview of a current situation using measurable data rather than to test cause and effect relationships. (Ghanad, 2023).

Inferential research is used to draw conclusions about a larger population based on a sample of data and to test relationships between variables. This type of research uses statistical test such as regression analysis, correlation analysis, and hypothesis testing to determine whether relationships between variables are statistically significant. Inferential research answers questions such as 'Does variable A influence variable B'. The goal is not only to describe data, but to make predictions or test hypotheses (Ghanad, 2023).

3.3. ANALYTIC METHODS

A more analytical approach often applied in applied research is gap analysis. Gap analysis focuses on identifying inconsistencies between the current situation and a desired or improved state. By comparing existing practices with potential improvements, researchers can identify shortcomings, operational inefficiencies, or opportunities for system enhancement. This approach is particularly useful when the objective of the research is to assess how current processes could be improved or supported through technological or organizational changes. Nevertheless, the effectiveness of gap analysis depends heavily on the availability of reliable information about both the current situation and the desired state.

Process mapping is used to visually represent the sequence of activities, decision, and parties involved in a specific operational process. It helps identify inefficiencies, coordination points, and potential vulnerabilities within complex workflows.

Stakeholder analysis identifies the individuals, groups, or organization that influence or are affected by a particular system or process. The method helps clarify responsibilities, interests, and potential conflicts between stakeholders.

Conceptual system design is used to develop a structured representation of how a proposed system or framework would function. It typically outlines system components, information flows, and interactions without implementing a full technical solution (Yin, 2009).

A flowchart is a visual modeling technique used to represent the sequence of activities, decisions, and information flows within a process. The method focuses on illustrating how individual process steps are connected and how actions progress from an initial input to a desired outcome. By using standardized symbols and directional arrows, flowcharts provide a structured overview of process logic, decision points, and interaction between stakeholders or systems. This makes the method particularly useful for analyzing operational procedures, identifying dependencies, and understanding how information or responsibilities are transferred throughout a process. The strength of a flowchart lies in its ability to simplify complex processes and communicate them in a clear and concise manner. As a result, it can support the identification of inefficiencies, bottlenecks, redundancies, and opportunities for process improvement. However, flowcharts typically represent processes in a simplified form and may not fully capture exceptions, informal practices, or contextual factors that influence process execution (Creswell, 2009).
Process analysis is a method used to examine and understand how activities, decisions, and information flows are organized within a process. The method focuses on identifying the sequence of steps leading to a target outcome, the stakeholders involved, and the interactions that occur between them. By analysing a process in a structured manner, researchers can identify decision points, dependencies, bottlenecks, inefficiencies, and areas for improvement. Process analysis is particularly useful in operational environments where multiple actors and systems use coordinate their activities to achieve a common objective. The strength of this method is that it provides a clear overview of how a process functions in practice and helps identify where deviations or vulnerabilities may occur. However, the accuracy of the analysis depends on the quality of available information and may not fully capture informal practices that are not documented or observed (Saunders et al., 2023).

Together, these research methods provide a range of approaches for collecting and analysing data in complex operational environments. The methodology literature emphasises that combining multiple methods can enhance the reliability and validity of research findings by allowing different sources of evidence to complement and verify on another. The principle, often referred to as methodological triangulation, enables researchers to build a more comprehensive understanding of the research problem by integrating insights obtained through different data collection techniques (Creswell, 2009).

4. METHODOLOGY

4.1. METHODOLOGY FLOWCHART

This research follows a structured methodology consisting of several sequential steps, which are illustrated in Figure 4: Methodology Flowchart. Each step contributes to the development of a conceptual detection and notification framework and the evaluation of its feasibility within apron operations.

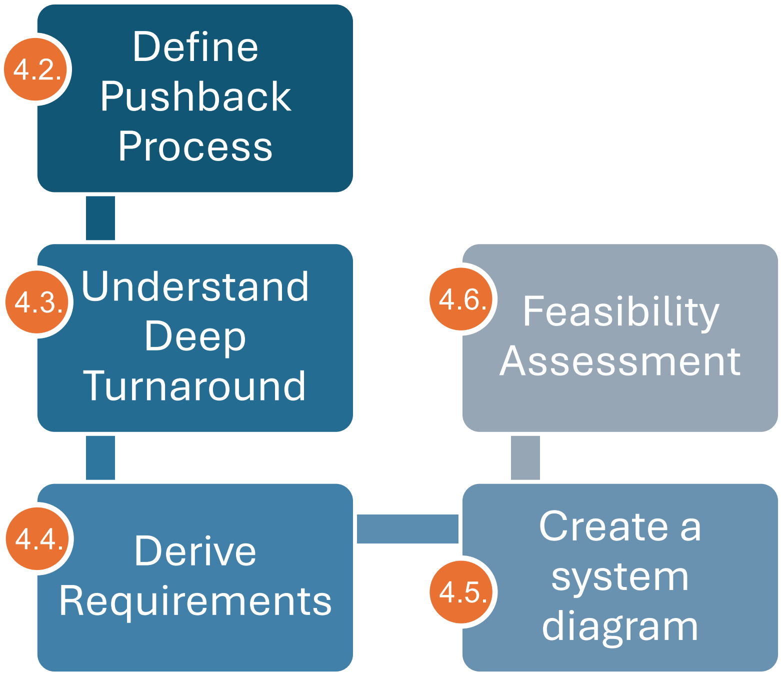


Figure 4: Methodology Flowchart

4.2. PUSHBACK PROCESS

This step aims to define how pushback authorization, coordination, and execution are currently organized within apron operations to identify potential vulnerabilities in the process. Understanding the pushback process is essential for determining where unauthorized or improperly coordinated pushback initiation may occur and for establishing a foundation for subsequent system design.

To achieve this, document analysis is conducted using operational procedures from Schiphol airport manuals, regulations, and internal documentation related to pushback operations. This method allows for a structured examination of formal processes and has been partially performed in previous chapters to establish the operational context. Document analysis is a commonly used method in applied research to analyse existing information sources and understand organizational processes (Saunders et al., 2023).

In addition, semi-structured interviews are conducted with operational stakeholders, including ground control personnel and ground handling staff. These interviews provide insight into how pushback operations are performed in practice and allow for the identification of discrepancies between formal procedures and real-world execution. Semi-structured interviews are suitable for exploring complex operational processes, as they provide flexibility while maintaining a consistent structure across participants (Creswell, 2009).

The collected information is translated into a process map, which visually represents the sequence of activities, decision points, and interactions between stakeholders during pushback operations. Process mapping enables the identification of critical coordination moments and potential vulnerabilities within the process, particularly where miscommunication or procedural deviation may occur.

The result of this step is a detailed description and visualization of the pushback process, including identified coordination points and vulnerabilities. These findings serve as input for defining pushback incursions and for deriving functional requirements for a detection and notification system.

4.3. DATA OUTPUTS

This step focuses on identifying and analysing operational systems that generate relevant data outputs which could support the detection of pushback incursions and the development of an integrated notification framework. Gaining insight into the characteristics, accessibility, and operational background of these data outputs is essential for determining how different systems can contribute to the situational awareness and automated event detection within apron operations.

To achieve this, document analysis is conducted using available system documentation, technical descriptions, operational procedures, and existing research to airport operational system and video analytics. The analysis focuses on systems that generate operational data relevant to aircraft movement, turnaround progress, clearances, ground operations, and other key decisions points gathered from the previous steps. Examples include systems such as Deep Turnaround, Centraal Informatie Systeem Schiphol (CISS), Electronic Flight Strip (EFS), and VEMMIS. Document analysis is used to obtain a structured understanding of functionalities, generated outputs, and integration possibilities of these systems (Saunders et al., 2023).

In addition, semi-structured interviews are conducted with technical experts and operational users of these systems. These interviews provide insight into how operational data is generated and used in practice, the reliability and operational value of the outputs, and potential limitation related accessibility, integration, or interpretation. In this context, semi-structured interviews are useful for capturing operational and technical knowledge that may not be fully documented while still allowing flexibility for additional insights from respondents (Creswell, 2009).

The collected information is analysed through a system analysis focusing on the relationship between system inputs, generated outputs, and operational applicability. Attention is given to identifying which systems generate data relevant to pushback authorization, coordination, movement detection, or operational status monitoring. In addition, the analysis examines how and where these outputs are stored.

The result of this step is a structured overview of the details behind the most relevant operational systems within the airport environment. Also including their capabilities, limitation, and potential contribution to pushback incursion detection. These findings provide essential input for deriving system requirements and for the development of the conceptual detection and notification framework in the following steps of the research.

4.4. SYSTEM LOGIC

This step focuses on deriving system requirements for a conceptual detection and notification application based on the findings from the previous steps. The objective is to translate the operational process, the definition of pushback incursions, and the capabilities of the Deep Turnaround system into a structured set of requirements that define what the system must achieve.

To achieve this, the process map developed in the first step is used to perform a process analysis, focusing on identifying critical moments within the pushback process where detection and intervention would be required. These moments include key coordination points and decision points where deviations may occur and where the application could provide added value.

To accomplish this, a gap-analysis-like comparison of what should be identified and which systems can detect it is conducted in which the current monitoring situation is compared with a desired future situation in which automated detection and notification are implemented The current situation is characterized by monitoring that primarily relies on human communication and observation, while the desired situation involves the use of camera-based data to support real time detection of pushback incursions. Gap analysis is a commonly used method to identify missing capabilities and areas for improvement by comparing existing processes with potential future solutions (Saunders et al., 2023).

Based on the results of the gap analysis and process analysis, requirements are derived at a conceptual level. These include functional requirements, which describe what the system would need and what it should be able to do, such as detecting specific events that could lead to the detection of pushback incursions and generating notifications. It also includes system requirements, which describe how the system should interact with existing infrastructure and operational processes.

The result of this step is a structured set of requirements that define the expected functionality and integration of the proposed system. These requirements form the foundation for the development of the conceptual system diagram in the next step of the research.

4.5. CONCEPTUAL SYSTEM DIAGRAM

This step focuses on developing a conceptual system diagram that illustrates how pushback incursion detection and notification could be implemented using Deep Turnaround data. The objective is to translate the previously defined requirements into a structured and visual representation of the proposed system.

To achieve this, a conceptual system design approach is applied, in which the key components of the system, their interactions, and the flow of data between them are defined and highlighted. This includes identifying how camera-derived data is processed, how detection logic is applied, and how notifications are generated and communicated to relevant stakeholders. Conceptual system design is commonly used in applied research to structure complex systems at a high level without requiring detailed technical implementation.

The system design is then visualized, in which the diagram represents the sequence of processes, decision points, and data exchanges within the system. The diagram should provide a clear and accessible way to communicate how the system operates and how different components interact with each other.

The development of the system diagram is based on the combination of findings from previous steps, including the pushback process analysis, the definition of pushback incursions, the capabilities of the Deep Turnaround system and the derived system requirements. This ensures that the proposed system design is grounded in both operational work environment and technical feasibility.

The result of this step is a conceptual system diagram that describes the detection logic, data flow, and notification process of the proposed system. This diagram serves as a foundation for evaluating how the system could be implemented within the existing operational environment in the following steps of the research.

4.6. PRODUCT FEASIBILITY

The final step of the methodology focuses on evaluating the feasibility of implementing the proposed detection and notification system within apron operations. The objective of this step is to assess whether the system is technically, operationally, and organizationally feasible, considering existing infrastructure, workflows, and stakeholder responsibilities.

To achieve this, semi-structured interviews are conducted with operational stakeholders and technical experts to gain insight into the practical applicability of the proposed system. These interviews provide information on potential constraints, system acceptance, and the impact of implementation on existing operational processes. Semi-structured interviews are particularly suitable for evaluating feasibility, as they allow for in-depth exploration of stakeholder perspectives and practical considerations (Creswell, 2009).

In addition, document analysis is conducted using relevant regulations, operational procedures, and system documentation including LVNL documentation. This analysis helps identify regulatory requirements and operational constraints that may influence the implementation of the proposed alarming system. Document analysis is an effective method for examining formal constraints and ensuring that proposed solutions align with existing frameworks (Saunders et al., 2023).

The feasibility assessment is based on three key criteria:

- Technical feasibility concerns whether the Deep Turnaround system provides sufficient data, reliability, and capability to support the detection of pushback incursions and the generation of timely notifications. This includes evaluating the accuracy of camera-based outputs, the availability of relevant data points, and the capability to integrate with existing systems.
- Operational feasibility focuses on how the proposed system fits within current live apron processes and workflows. It includes assessing whether the system supports or disrupts current operations, whether alarms can be effectively interpreted and acted upon, and whether the system enhances situational awareness without introducing additional complexity or workload.
- Organizational feasibility addresses stakeholder roles, responsibilities, and system acceptance It includes evaluating which organization is responsible for monitoring and responding to alarms, how responsibilities are distributed among stakeholders such as LVNL, Schiphol, and pushback truckers, and whether the system aligns with existing organizational structures and processes.

The result of this step is an assessment of the feasibility of the proposed system, including identified constraints and conditions for implementation. This assessment contributes to the overall objective of the research by determining to what extent the conceptual system can be realistically applied within apron operations.

5. RESULTS

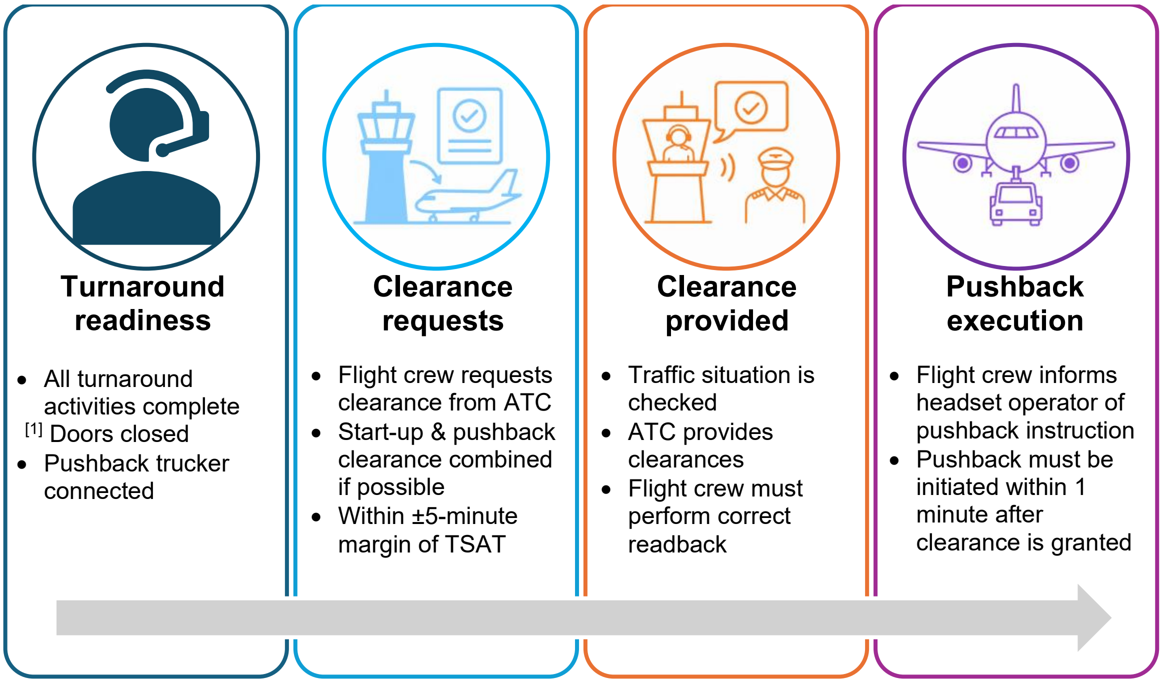
5.1. PUSHBACK PROCESS DEFINITION

The analysis of operational procedures and documentation related to pushback operations, together with the unstructured interview of a ground controller at AAS shows that the process is organized as a structured sequence of authorization, coordination, and execution steps involving multiple stakeholders. These stakeholders primarily include flight crew, ground control/ATC operated by LVNL, and ground handling personnel including truckers. The process is embedded within the broader start-up procedure and relies on clearly defined responsibilities and standardized communication with a small amount of redundancy to ensure safe and efficient aircraft movement on the apron.

The process is initiated by the flight crew through a start-up request directed at ground controller or the outbound planner (OPL). In case the OPL is contacted, they will check if there is enough runway availability for the aircraft, then forward the flight crew to ground control. The start-up and pushback request should be within a margin of 5 minutes of the target start up approval time (TSAT), and only after all other turnaround activities are complete. Based on the operational manual of LVNL Tower-Approach (TWR-APP) (LVNL, 2026) and Schiphol airport manual (Schipol, 2024), start-up approval at AAS is typically issued in combination with pushback clearance (LVNL, 2026), meaning that approval of start-up also implies authorization to commence pushback within one minute of the received clearance and vice-versa. However, this only applies to the smaller aircraft families i.e. B737, and A320. Since these aircraft are assured to not provide critical levels of jet blast. The clearance is only given after ground control has evaluated the local traffic situation and if the aircraft is ready, notifying ground control is the flight crew's duty.

Following the clearance, the flight crew is required to perform a full readback of clearance received from ground control. This readback/hearback loop represents a key verification method within the process, ensuring that the clearance is correctly understood and confirmed by both parties, the instructions are then given to the trucker by the flight crew. The analysis indicates that this communication step is essential for maintaining operational safety, as any deviation or misunderstanding at this stage may directly affect the subsequent execution of pushback.

The execution of pushback itself is performed by ground handling personnel, who are responsible for physically moving the aircraft using a pushback tug. During this phase, communication occurs primarily between the ground crew and the flight crew via headset communication, while Air Traffic Control remains responsible for overall traffic coordination. The ground crew ensures that the pushback is executed according to the clearance received and within the defined safety boundaries of the stand and taxiway environment.



[1] Doors closed is part of the turnaround activities but also an indication that its nearing completion

Figure 5: Pushback Process

Several key coordination and decision points can be identified within this process. The completion of previous turnaround activities is a key coordination point since it validates aircraft readiness. The moment of clearance issuance represents the primary control point, where authorization is granted based on the current operational situation. The readback/hearback loop forms a secondary control point, ensuring that the clearance is correctly interpreted. Conversely, the reliance on radio communication between flight crew and ATC introduces potential vulnerabilities related to readback/hearback discrepancies, incorrect interpretation of clearances, or delayed communication. These communication dependent steps are critical, as they directly determine whether pushback is initiated under correct authorization.

Another important vulnerability is the separation between decision-making and execution. While ATC is responsible for issuing clearances, the actual execution of pushbacks is performed by ground handling personnel based on instructions relayed through the flight crew. This indirect communication chain introduces the potential for information loss or misinterpretation, particularly in high workload situations or when multiple aircraft are being handled simultaneously.

Furthermore, the process is largely dependent on procedural compliance and human observation, with limited real-time verification of whether pushback is initiated in accordance with the issued clearance. This creates a situation in which deviations, such as premature pushback initiation or incorrect execution relative to the clearance, may not be immediately detected by the controlling authority.

These results indicate that the pushback process at Schiphol is a fairly simple process where the flight crew requests start-up approval from ground control after the turnaround is complete, and within a margin of ±5 minutes of the TSAT. Ground control evaluates the traffic situation and issues clearance with specific instructions. The flight crew must read back this clearance to confirm correct understanding. Pushback is then executed by ground handling personnel using a tug, under guidance from the flight crew. Ground control oversees the operation and ensures safe separation from other traffic, while coordination relies heavily on accurate communication and procedural compliance.

5.2. DATA OUTPUTS

To determine which operational data sources may contribute to the conceptual unauthorized pushback detection system, several airport and air traffic management systems were identified through non-structured interviews with operational stakeholders and then investigated through document analysis and semi-structured interviews. The objective of this analysis is to identify what operational data outputs are generated within the airport environment, how these data are collected, where they are stored, which stakeholders manage the systems, and how the outputs may contribute to the situational awareness regarding aircraft turnaround and pushback operations.

The systems discussed within this chapter vary in operational purpose and technical functionality. Some systems primarily support real-time air traffic control operations, while others are focused on operational coordination, turnaround prediction, or historical analysis. Although not every system directly contributes to real-time pushback detection, each system was evaluated based on its ability to generate operationally relevant outputs related to aircraft movement, turnaround progress, or pushback authorization.

The analysis indicates that operationally relevant data within the airport environment is distributed across multiple systems rather than stored within a single centralized platform. As a result, different systems provide different parts of the operational context required to determine whether a pushback operation is authorized, coordinated, and executed according to procedure.

5.2.1. ELECTRONIC FLIGHT STRIPS

The Electronic Flight Strip system is the digital replacement of traditional paper flight progress strips used within tower operations. At Schiphol, the system supports operational coordination between air traffic controllers by providing a shared real-time overview of aircraft statuses, clearances, and flight progression states.

The primary function of EFS is to support flight progression management, operational coordination, and clearance administration during aircraft ground and departure operations. The system is actively used by controllers during live operations and therefore functions as a real-time operational control system within the LVNL tower environment.

Data within EFS is collected through a combination of manual controller input and automated system integration. Air traffic controllers manually update operational states such as runway assignment, coordination actions, and clearance-related information. In addition, the system exchanges operational information with connected ATM systems such as Departure Manager (DMAN) and A-CDM related environments.

The data generated by EFS is handled by LVNL and stored within the operational ATM infrastructure used within tower operations. Because the system functions in real-time, the generated data continuously reflects the current operational state of aircraft under air traffic control.

Error! Reference source not found., shows a cropped version of the Electronic Flight Strip interface used within tower operations. Each strip, like shown in Figure 7: Electronic Flight Strip aircraft strip, represents an individual aircraft and contains operational information such as stand position, call sign, aircraft type, and departure related data like, the allocated waypoint. Controllers use these to manage responsibility for aircraft throughout the departure process. As aircraft progress through operational phases, the corresponding strip is moved between columns representing different control states, such as pushback and taxi. This provides controllers with shared real-time overview of aircraft phase status and responsibility.

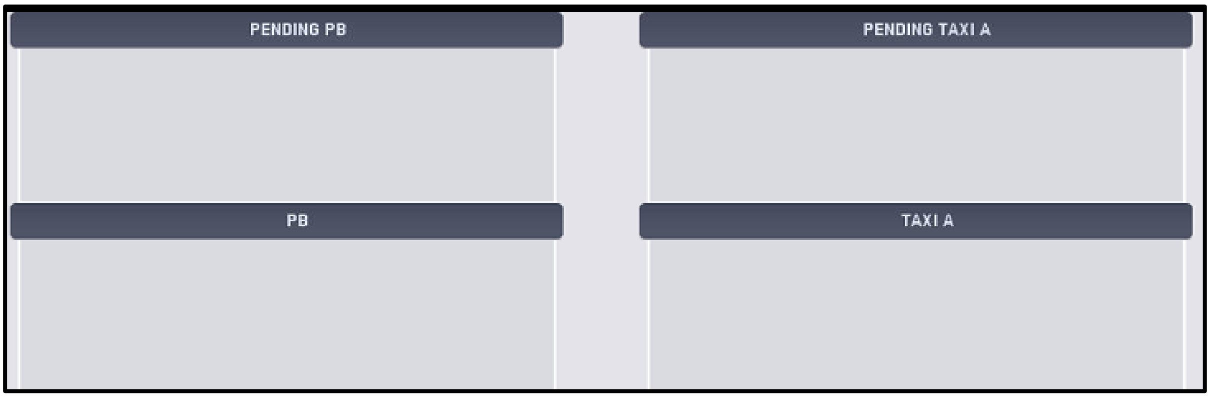


Figure 7: Electronic Flight Strip interface

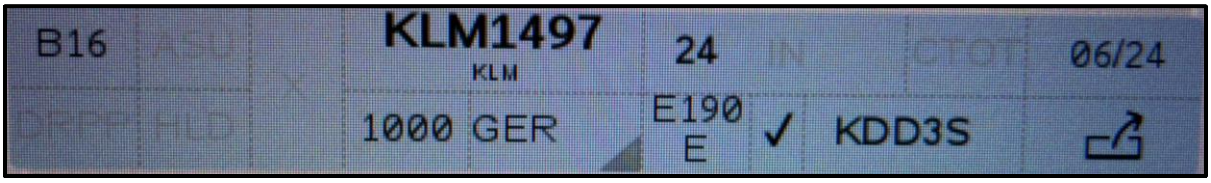


Figure 6: Electronic Flight Strip aircraft strip

Potentially relevant outputs generated by EFS include the pushback clearance status and start-up approval status, the departure sequencing states can provide meaningful information for the distinction between authorized and unauthorized.

From the perspective of this research, EFS is particularly relevant because the system contains operational information related to pushback authorization and clearance status. However, while EFS contains authorization-related information, the system itself does not verify whether the physical pushback movement is initiated according to the issued clearance.

5.2.2. VEMMIS

VEMMIS is a historical ATM data environment used within Dutch air traffic management operations. The system is primarily used for operational replay, post-operational analysis, safety investigations, and performance analysis.

The primary function of VEMMIS is not real-time operational control, but rather the aggregation, storage, and visualization of historical operational ATM data originating from multiple source systems. Based on interviews and operational documentation, VEMMIS aggregates data from approximately thirteen ATM-related systems.

The source systems connected to VEMMIS differ in both functionality and data collection methodology. Some source systems collect data through surveillance technologies such as Surface Movement Radar, Automatic Dependent Surveillance-Broadcast (ADS-B), multilateration (MLAT), and transponder signals, while other systems rely on human operational input, such as controller actions entered into Electronic Flight Strips.

The collected data is centralized and stored within the VEMMIS environment, where it becomes available for replay and analytical purposes. The system and underlying datasets are managed by LVNL and ILABS.

Because VEMMIS stores historical rather than live operational data, the system is primarily suitable for post-operational analysis rather than direct real-time monitoring. This means that VEMMIS itself is not directly suitable as the primary source for a real-time pushback detection system. However, the historical datasets may provide operational value for analysing previous pushback events, validating operational timelines, or reconstructing incidents.

From the perspective of this research, VEMMIS is primarily relevant as a historical validation and analysis environment rather than a direct operational detection system.

5.2.3. AIRPORT COLLABORATIVE DECISION MAKING

Airport Collaborative Decision Making is an operational coordination methodology designed to improve predictability and efficiency within airport operations through information sharing between operational stakeholders. A-CDM itself is not a standalone database or operational system, but rather a collaborative operational framework in which information from multiple operational systems is combined and synchronized to support shared decision-making.

The framework relies on operational data originating from airlines, ground handlers, airport systems, turnaround systems, and air traffic management systems. These systems collectively provide operational milestone information related to aircraft turnaround and departure planning.

The operational data used within A-CDM environments is stored across multiple connected airport and ATM systems managed collaboratively by Schiphol Airport, LVNL, airlines, and EUROCONTROL related stakeholders. A-CDM on its own does not have any data outputs since it is a methodology

From the perspective of this research, A-CDM is primarily relevant because it provides synchronized operational milestone information used for departure planning and operational coordination.

5.2.4. CENTRAAL INFORMATIESYSTEEM SCHIPHOL

The Centraal Informatiesysteem Schiphol functions as a central airport operational information platform used to distribute and synchronize operational information between stakeholders operating at Amsterdam Airport Schiphol.

The primary function of CISS is not to generate operational data itself, but rather to distribute operational information originating from multiple airport-related systems. Such as, the airliner, ground handlers, LVNL Eurocontrol, KNMI, and many more. As a result, ownership of the original operational data remains with the connected source systems and operational stakeholders.

Data within CISS is gathered through automated integrations with operational airport systems, airline systems, handling systems, and ATM-related systems. The system distributes operational information between stakeholders such as Schiphol Airport, airlines, handling agents, and operational coordination departments.

The operational data distributed through CISS is stored within centralized airport operational information environments managed by Schiphol Airport and associated operational stakeholders.

Potentially relevant outputs available through CISS include flight status information, the stand allocation since some aprons have a slightly altered pushback process, and airport resource information regarding the presence of the truck for example.

From the perspective of this research, CISS is relevant because it provides airport-wide operational situational awareness and distributes operational statuses between multiple stakeholders involved in aircraft turnaround and departure operations. However, this dataset is partially post-operations, some events such as tug availability is humanly updated and not necessarily real-time, thus the event is not applicable for a real-time system.

5.2.5. DEPARTURE MANAGER

Departure Manager is a departure sequencing system used within air traffic management operations to improve outbound traffic flow and runway planning.

The primary function of DMAN is to optimize departure sequencing by calculating efficient departure orders and start-up planning based on operational traffic conditions and available airport capacity.

Data within DMAN is collected through integrations with operational ATM systems, surveillance systems, flight planning systems, and A-CDM related operational milestones.

The system is managed within the LVNL ATM environment and supports operational planning activities related to outbound aircraft movement.

Potentially relevant outputs generated by DMAN include the TSAT, since the pushback usually must be initiated within a ±5-minute margin of the TSAT

From the perspective of this research, DMAN is relevant because the system contributes to the operational planning environment surrounding pushback authorization and departure sequencing.

5.2.6. DEEP TURNAROUND

Research and an explanation regarding Deep Turnaround have been provided in the previous chapters. This paragraph serves as evidence that an analysis was done on the Deep Turnaround system.

Table 1: Data Sources

System	Source	Handler	Description
EFS	Human controller input + ATM datasets	LVNL	A tool used within the tower to coordinate responsibility within tower departments.
VEMMIS	ATM datasets	LVNL	A post-op database that stores the historical data of several other systems, to be used for analysis.
A-CDM	N/A + Human updates	Schiphol Group, and airlines	A framework to synchronize different stakeholders through data sharing.
CISS	Integrated airport systems	AAS	An Airport Operational Database contains flight information from almost all airport operational stakeholders. Semi-live updated information.
Deep Turnaround	DT Cameras	Schiphol Group	A camera infrastructure that with the help of two algorithms can predict the end of ground handling services time.
DMAN	ATM datasets	LVNL	A tool used within the tower to optimize real-time departure sequencing.

5.3. SYSTEM LOGIC

The analysis of the pushback process and operational data outputs shows that an authorized pushback consists of several operational events and conditions that must occur before and during the execution of the pushback movement. By comparing these operational requirements with the available data outputs generated by existing airport systems, it becomes possible to determine which events are detectable, which events are predictable from data, and which events currently remain undetectable in live operation.

The analysis indicates that not all operational conditions required for an authorized pushback can be directly observed through camera-based monitoring systems such as Deep Turnaround. Certain procedural requirements, such as the illumination of specific aircraft lights prior to pushback, are operationally required but are not reliably detectable using the currently available camera infrastructure. In addition, several identified pushback incursions originate from interactions and decision-making processes within the cockpit environment. As cockpit activity is not observable from stand-based camera systems, these interactions cannot be directly monitored by Deep Turnaround or other operational status tracking systems.

Communication-related events form another important limitation within the detection process. An authorized pushback requires correct clearance issuance and a successful readback/hearback loop between flight crew and ground control. While the verbal readback itself cannot be recorded or verified by Deep Turnaround, the operational clearance state can be tracked through systems such as EFS, where clearances and operational states are logged. This system is only operable within tower operations and not yet accessible outside of this work environment. This indicates that certain conditions may not be directly detectable through video analytics alone but can potentially be collected through integration with operational ATM systems.

The analysis further shows that several operational events related to turnaround completion and pushback preparation, retrieved from the process analysis, are detectable through the Deep Turnaround camera systems. Detectable events include *aircraft presence at stand*, *aircraft position relative to the stand*, and several turnaround milestones generated through Deep Turnaround. Examples include each individual *door closure status*, that means that the system must reflect that every door that opens must receive a closed indication. Furthermore, *foreign object debris (FOD) clearance* around the stand, *Ground Safety Equipment (GSE) clearance*, and the *presence and connection status of pushback tugs* are also detectable. All these events provide observable indicators that the aircraft is transitioning from turnaround towards pushback readiness. Additionally, since the DT system can detect when the pushback truck moves away, either due to disconnecting the aircraft or a pushback, it is possible to reinforce the integrity of the system by demanding both tug movement and aircraft movement events must return *true* for the system to state a pushback is being initiated.

At the same time, certain operational conditions remain difficult or impossible to detect reliably through currently available data outputs. For example, wheel chock removal is operationally relevant for pushback execution but is not consistently detectable through existing camera-based monitoring. This creates a decrease in redundancy that leads to a less secure integrity in a tool that should determine whether all required conditions for authorized pushback have been fulfilled.

The comparison between operational requirements and available data outputs therefore shows that the conceptual detection system cannot rely on a single data source. Instead, the analysis indicates that reliable detection requires a combination of operational system states and camera-derived observations. This includes combining operational clearance information from ATM-related systems with observable aircraft movement and turnaround events generated through camera analytics. In addition, the analysis reinforced the importance of minimizing false positives and false negatives within the detection logic through redundant event detection, as incorrect alarming may reduce operational trust and negatively affect system usability.

Based on these findings, a structured overview is developed in which operational events, their applicability to authorized pushback detection, and their corresponding data sources are compared. Table 2: Event names & information shows an overview of the event candidates and their applicability for the conceptual system.

Table 2: Event names & information

Operational Event	Detectable	Source	Limitation
AircraftAppears	Real-Time	Deep Turnaround	None
AircraftStopsInPosition	Real-Time	Deep Turnaround	None
AircraftMovesOutOfPosition	Real-Time	Deep Turnaround	Direction is not detected.
LastCargoDoorCloses	Real-Time	Deep Turnaround	None
PaxDoor**[Variable]**Closed	Real-Time	Deep Turnaround	All doors that are previously perceived as open, should return the mark "Closed". There is no event for all doors.
FreeApron	Real-Time	Deep Turnaround	It checks for both GSE and FOD simultaneously, not separately.
CameraUp	Real-Time	Deep Turnaround	Not typically necessary.
Tug availability	Planned	CISS	Not updated live, so can be inaccurate.
Tug Presence	Real-Time	Deep Turnaround	None
TugIdleConnectedStarts	Real-Time	Deep Turnaround	Only detects when tug is stationary and hugging the front wheel.
TugIdleConnectedEnds	Real-Time	Deep Turnaround	Typically returns true when pushback is initiated but can also return true when prematurely disconnects.
Wheel chocks off	N/A	N/A	An important milestone for pushback readiness detection but not available.
Aircraft light illumination	N/A	N/A	A procedural milestone for pushback readiness

			detection but not available.
Start-up / pushback clearance	Real-Time	EFS	Available only in tower
Readback/Hearback confirmation	N/A	N/A	A key decision point in whether a pushback is unauthorized. Not logged in any current system.

5.4. SYSTEM DIAGRAM

The analysis of the pushback process, system logic, and available data outputs shows that several key operational phases and events are essential for the conceptual detection system. The system diagram is structured around these three key phases: turnaround readiness, pushback initiation, and clearance status.

The first important phase is turnaround readiness. The research indicates that the system must first determine whether the aircraft is operationally preparing for pushback before movement detection becomes relevant. This phase is important because unauthorized movement detection without operational context would significantly increase the likelihood of false positives. The analysis shows that several turnaround-related events generated by Deep Turnaround can be used to establish this operational readiness state. Relevant events include *AircraftStopsInPosition, LastCargoDoorCloses, PaxDoor…Open, PaxDoor…Close, FreeApron,* and *TugIdleConnectedStarts.*

These events collectively provide indications that the turnaround process is nearing completion, the apron surrounding the aircraft is cleared from GSE and FOD, and that the tug is connected and ready for pushback. The analysis also indicates that the Deep Turnaround system does not differentiate between aircraft types. As a result, the system may monitor specific passenger door statuses even when those doors are not physically present on the aircraft type involved. To minimize faulty system results, the detection logic requires that every passenger door event that returns an open status must subsequently return a corresponding closed status before proceeding. The detection logic is provided in Figure 8: Turnaround readiness detection logic.

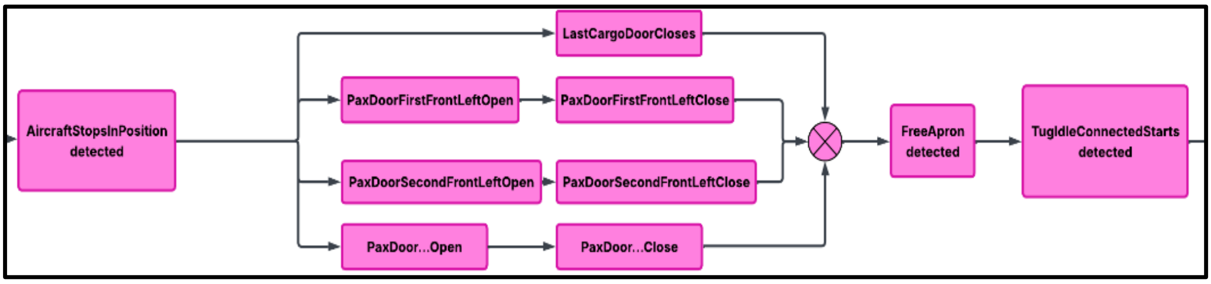


Figure 8: Turnaround readiness detection logic.

The second key phase is pushback initiation. The research indicates that the system must reliably determine whether aircraft movement corresponds to an actual pushback rather than unrelated vehicle movement or tug repositioning. For this reason, the detection logic requires both *AircraftMovesOutOfPosition* and *TugIdleConnectedEnds* to occur simultaneously. The latter indicates that the tug leaves its connected idle state. However, this can mean it has started pushback or is driving away, the system cannot detect whether the truck is still connected it has to assume. The conceptual system therefor requires both events return a positive state before the system recognizes the operation as an active pushback. The detection logic is provided in Figure 9: Pushback initiation detection logic.

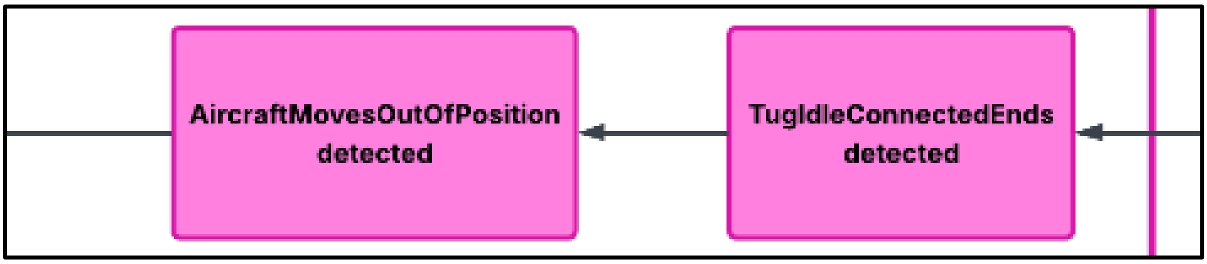


Figure 9: Pushback initiation detection logic.

The third key phase is clearance status. Since DT cannot detect or verify verbal clearances, the conceptual system relies on synchronization between DT and ATM-related operations. The clearance status is obtained through EFS. By synchronizing aircraft movement detection with the operational clearance state, the system can determine whether detected pushback corresponds with an authorized state. The detection logic is provided in Figure 10: Pushback authorization detection logic.

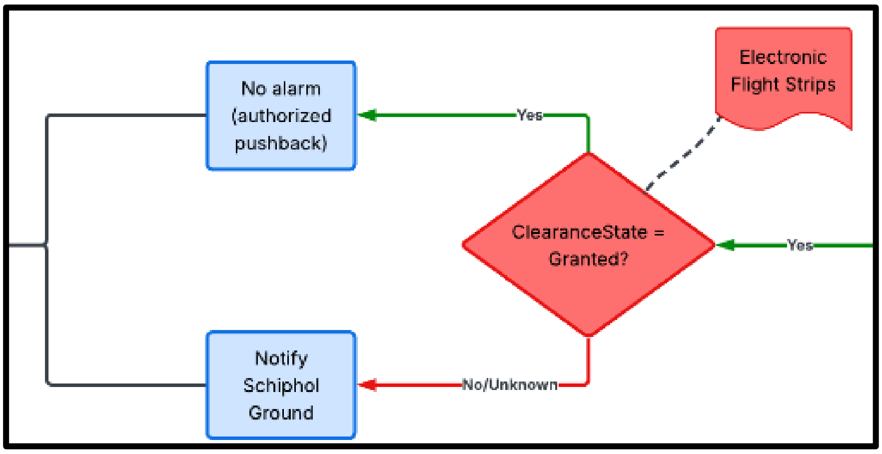


Figure 10: Pushback authorization detection logic

The research has highlighted that, additional systems, such as CISS, can provide supporting operational information including tug availability and TSAT related planning information. However, these outputs primarily represent planning-oriented or historical data rather than real-time value, although they may still contribute to broader operational awareness or future system extensions.

Combining all previously mentioned system designs, a completed conceptual system design combined with the complete pushback process has been provided in Figure 11: Conceptual Unauthorized Pushback Detection System. An enlarged version can be found in Appendix A: Figure 12: Conceptual System Design - enlarged.

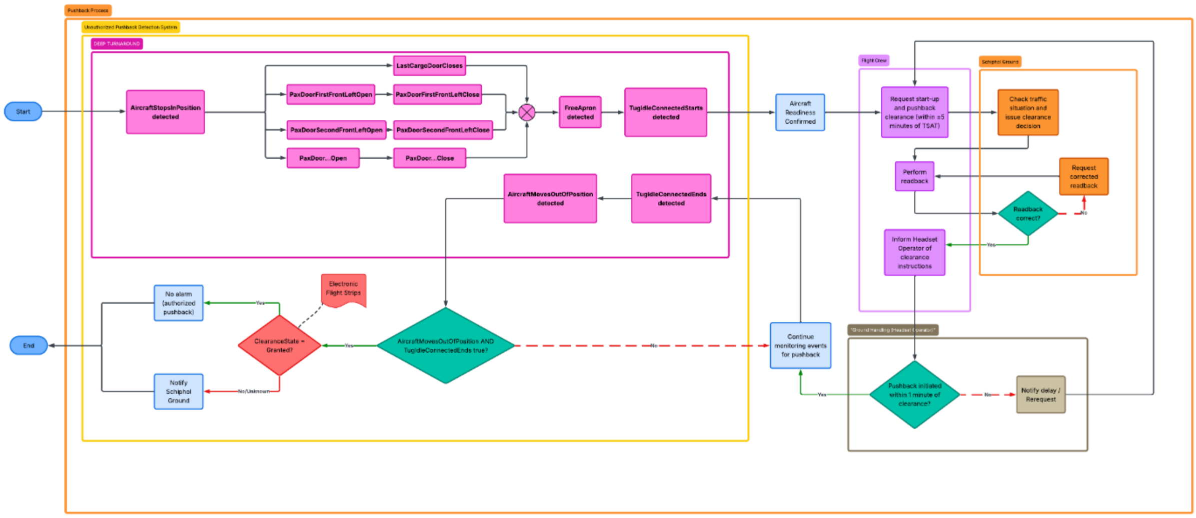


Figure 11: Conceptual Unauthorized Pushback Detection System Design

5.5. FEASIBILITY ASSESSMENT

The analysis of the Deep Turnaround system and related operational systems indicates that the conceptual detection system is technically feasible, although several limitations remain. Deep Turnaround is currently a relatively immature but operational system in which additional data outputs and events are still being developed. The currently available data outputs are considered sufficient to support the conceptual detection logic. However, events are only considered operationally usable when their detection reliability exceeds an F1-score of 80%. The exact accuracy of the currently available Deep Turnaround events is unknown, meaning that the operational reliability of the proposed system cannot yet be fully determined. The analysis further indicates that additional data sources and event redundancy are necessary to improve detection reliability.

The operational feasibility analysis indicates that the conceptual system can be integrated into existing apron operations with close to no procedural impact. The system functions primarily as an alerting layer on top of existing workflows. In the proposed operational structure, alerts would only be generated in situations where unauthorized pushback activity is detected. These alerts would be presented to ground control and outbound planning personnel. The analysis indicates that the primary operational system requiring modification would be the electronic flight strip system, where the alerting functionality could be integrated. Existing tower workflows and operational responsibilities would largely remain unchanged, apart from the introduction of a subtle but clearly recognizable alert indication.

The organizational feasibility analysis shows that system responsibilities and operational acceptance are critical factors for implementation. The proposed alerting structure would involve both ground control and outbound planning personnel as operational recipients of alerts. In addition, the analysis indicates that system management, maintenance, and integrity monitoring would likely require a dedicated department or an external third-party organization. This includes responsibilities related to technical management, system monitoring, and cybersecurity testing such as pentesting. The semi-structured interviews further indicate that operational acceptance by air traffic controllers strongly depends on the reliability of the system. Controllers indicated that the system would only be considered acceptable if unauthorized pushbacks are consistently detected while false alerts are minimized as much as possible. Excessive false would result in an increased workload and stress within the operational environment.

6. FINDINGS

The expectation of the initial research did not expect a secondary system to be necessary. For the system to work properly the EFS system is necessary to detect whether a pushback is authorized or not. The EFS system can also be used as the primary alerting method.

The analysis of the pushback process at Schiphol shows that pushback operations are organized through a structured sequence of authorization, coordination, and execution involving flight crew, ATC, and ground handling personnel. The analysis identified several critical operational phases and decision points that must occur before pushback can be considered authorized. These points are ***aircraft presence***, ***door status***, if the apron is ***cleared from FOD and GSE***, and ***tug connection status***.

The results further show that the conceptual detection system should focus on three primary operational phases: turnaround readiness, pushback initiation, and clearance status. The turnaround readiness phase is established through Deep Turnaround events called AircraftStopsInPosition, LastCargoDoorCloses, PaxDoor[Variable]Close, FreeApron, and TugIdleConnectedStarts. The pushback initiation phase is based on the correlation between aircraft movement and tug movement events, specifically *AircraftMovesOutOfPositon* and *TugIdleConnectedEnds.* It is recommended that the data generated by DT is continued to be monitored and evaluated as the system develops further. DT is still in an experimental phase in which new operational events and functionalities are continuously being added. Additional detectable events may improve the reliability and capability of the detection system.

The analysis of operational data outputs indicates that Deep Turnaround and Electronic Flight Strips provide the most relevant data for the conceptual system. Deep Turnaround provides camera-derived operational events related to turnaround progression and aircraft movement, while the electronic flight strips provide the operational clearance state required to determine whether a detected pushback is authorized. Additional systems such as CISS, VEMMIS and DMAN provide operationally relevant information, but these outputs were determined to provide limited direct value for the system.

Based on these findings, a conceptual detection system was developed in which Deep Turnaround events are synchronized with the clearance states from the EFS. The system continuously monitors pushback readiness and reflects pushback execution against clearance status. The system generates an alert to ground control and outbound planning personnel, only when necessary. It is recommended that future development of the alerting system consider existing operational alerting systems already used within the tower, such as Runway Incursion Alerting System Schiphol (RIASS). Since RIASS already functions as an alerting system, its alerting philosophy, visual presentation, and operational integration may provide valuable insight into how alerts can be presented effectively without unnecessarily increasing workload or stress for operational personnel.

The feasibility assessment indicates the conceptual system is technically feasible, as the currently available Deep Turnaround outputs are sufficient to support the proposed detection logic. However, the exact reliability of the current events remains unknown, meaning that additional redundancy and future data expansion are required to improve operational reliability. Which directly leads us to the operational feasibility, the system can be integrated with close to no procedural impact, as it functions as an additional alerting layer within an existing workflow. Consequently, the system acceptance by air traffic controllers strongly depends on detection reliability and the minimization of false alerts. The accuracy and reliability of both the system and DT should remain a priority before operational implementation is considered. The research showed that the operational acceptance of the system strongly depends on minimizing false alerts and ensuring reliable event detection. For this reason, testing should be conducted to determine the actual accuracy, reliability, and performance of DT and the detection system with a fixed threshold that it must surpass before continuing. Determining what that threshold should be is for future work.

7. CONCLUSION

This research aimed to determine how the Deep Turnaround system can be utilized to detect pushback incursions and how its data can be integrated to support pushback authorization processes through the development of a conceptual alarming and data integration framework, with regards to the feasibility of the result.

Overall, the research demonstrates that Deep Turnaround data can be utilized to support the detection of unauthorized pushback initiation and that integration with the Electronic Flight Strip system enables the development of a conceptual alarming framework. Although additional validation and system development are required before operational implementation can be considered, the research demonstrates that the integration of camera-derived operational events and ATM-related system states provides a feasible foundation for supporting pushback authorization processes within apron operations at Schiphol Airport.

7.1. DISCUSSION AND LIMITATIONS

At the start of this research, it was expected that Deep Turnaround data alone could provide sufficient information to detect unauthorized pushback initiation. However, the analysis showed that camera-based events alone are not enough to determine whether a pushback is authorized. Although Deep Turnaround can detect aircraft movement, turnaround milestones, and tug activity, it cannot detect verbal clearances or readback/hearback communication between flight crew and ground control. As a result, synchronization with operational clearance states from the electronic flight strips became necessary for the conceptual detection framework.

Another important limitation was the uncertainty regarding the reliability of the currently available Deep Turnaround events. During the research, it became clear that operational use of Deep Turnaround events depends on a minimum reliability threshold, commonly described as an F1-score above 80%. However, the exact reliability of the currently available events could not be verified within the scope and timeframe of this research. Additional interviews or access to system performance data could have provided more insight into the actual accuracy of the generated events and the reliability of the conceptual system. In addition, the interview findings within this research were based on a limited number of participants per subject area, resulting in several findings primarily reflecting operational perspectives and experience rather than a broader shared operational perspective.

The research also focused primarily on typical turnaround scenarios at Schiphol. As a result, the conceptual framework was developed using standard turnaround sequences and standard pushback procedures. Atypical situations, such as remote stand operations, towing procedures, maintenance-related stand occupancy, or irregular turnaround scenarios, were not included in the analysis. This means that the applicability of the conceptual system outside standard turnaround operations remains uncertain.

Finally, the developed framework remains conceptual and has not been tested in a live operational environment. The system logic, event correlation, and alerting structure were derived from operational analysis, available data outputs, and stakeholder input, but no operational validation or live testing was performed. As a result, the practical performance, operational reliability, and real-world usability of the conceptual system could not be fully evaluated within this research.

7.2. FUTURE WORK

Several areas for future work are identified. First, additional validation and operational testing should be performed to evaluate the accuracy, reliability, and real-time performance of the conceptual detection system under live operational conditions. This includes testing the reliability of Deep Turnaround events and determining the operational impact of false alerts within the tower environment.

Future research should also further investigate how existing operational alerting systems, such as RIASS, manage alert presentation and operational integration. The alerting philosophy and interface design of RIASS may provide valuable insight into how alerts from the conceptual system can be integrated into tower operations without unnecessarily increasing workload or stress levels.

In addition, this research focused primarily on detecting unauthorized pushback initiation. Future research could expand the detection logic towards additional types of pushback incursions and operational deviations. Examples include pushback execution deviating from issued instructions, incorrect pushback direction, or other coordination-related deviations during apron operations.

Future research is also recommended to investigate the implementation of a secondary authorization verification logic based on radiotelephony (RT) communication. The current pushback clearance is considered sufficient, but some after-deadline research concluded that the procedures regarding provided clearance within EFS are not always upheld. In normal operation this is not a problem. But, in some very specific cases where the flight strip has been provided clearance when it audibly has not been provided. This specific scenario does impede with the current conceptual authorization logic. A secondary verification method based on RT communication could provide additional redundancy, improve clearance detection, and reduce the likelihood of incorrect alerts in exceptional operational circumstances.

In addition, future research should investigate whether separate detection logic is required for different operational responsibilities within the manoeuvring area. While departing and arriving aircraft at Schiphol are primarily coordinated by ground control, general aircraft movements like stand relocations are coordinated by apron control. As these operational follow different authorization procedures and communication flows, separate detection and authorization logic may be required to ensure reliable operation across all pushback scenarios.

Finally, further research is also recommended regarding the most suitable system architecture and integration methods for the final operational solution. This includes evaluating which systems should function as primary data sources, how operational and camera-derived data should be synchronized, and which integration methods are most suitable for tower operations.

7.3. SELF REFLECTION

Looking back on this thesis project, I am satisfied with how I approached the research process and how I managed to develop the project from an initial idea into a structured outcome. One of my strengths during the project was my willingness to fully understand a subject before drawing conclusions. During interviews and discussions with stakeholders, I often adjusted my questions to gain a deeper understanding of the information provided. This helped me understand not only what was happening within a process, but also why certain decisions and procedures existed.

Another strength was my approach towards using AI tools. Throughout the project, I learned the importance of critically evaluating all generated information. Rather than accepting information at face value, I verified sources, reviewed the original material, and rewrote information in my own words and style. This approach improved the quality of the research and helped me maintain ownership of the final product.

I also believe that I managed the scope of the research well. Early in the project, I developed a clear understanding of what could realistically be achieved within the available timeframe. This helped me make decisions about which topics should be included and which topics should be left out, even when time had already been invested in them. Although my planning was generally effective, I also realized that additional time would have allowed for a more extensive validation of certain findings and assumptions.

One of the main challenges during the project was my tendency to make assumptions before fully validating them. In several cases, these assumptions later proved to be incomplete or incorrect, which required additional research and adjustments to the project. This taught me the importance of validating key assumptions as early as possible. At the same time, I learned that not every assumption can be investigated immediately due to time constraints, making it important to identify which assumptions have the highest impact on the research outcome.

Another area for improvement includes communication. I noticed that I was often hesitant to repeatedly contact stakeholders when responses to emails were delayed or absent. Because I did not always follow up as actively as I could have, certain opportunities for additional interviews and observations were missed. For example, this affected my ability to conduct planned observations of pushback procedures and air traffic control operations. In future projects, I would be more proactive in following up on requests and scheduling meetings.

The feedback received during the project also played an important role in improving the research. One example was the development of the conceptual framework. Initially, I focused on creating a detailed flowchart, but feedback showed that a stronger approach was to emphasize the operational process, the involved stakeholders, and the position of the proposed system within that process. This resulted in a clearer and more practical framework.

During the project, I noticed that I work best when information is structured logically. When processes, systems, and relationships are clearly organized, I can understand them quickly and identify connections between different topics. However, I also learned that this preference could become a limitation when information is incomplete or poorly structured, as I tend to spend additional time trying to fully understand every detail before moving forward.

Overall, this project strengthened my skills in conducting research, interviewing stakeholders, evaluating information critically, and translating complex operational processes into structured and understandable models. The most important lesson I will take into future projects is the need to balance curiosity and thoroughness with practical decision-making, while validating key assumptions earlier and communicating more proactively with stakeholders.

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APPENDICES

APPENDIX A: CONCEPTUAL SYSTEM DESIGN

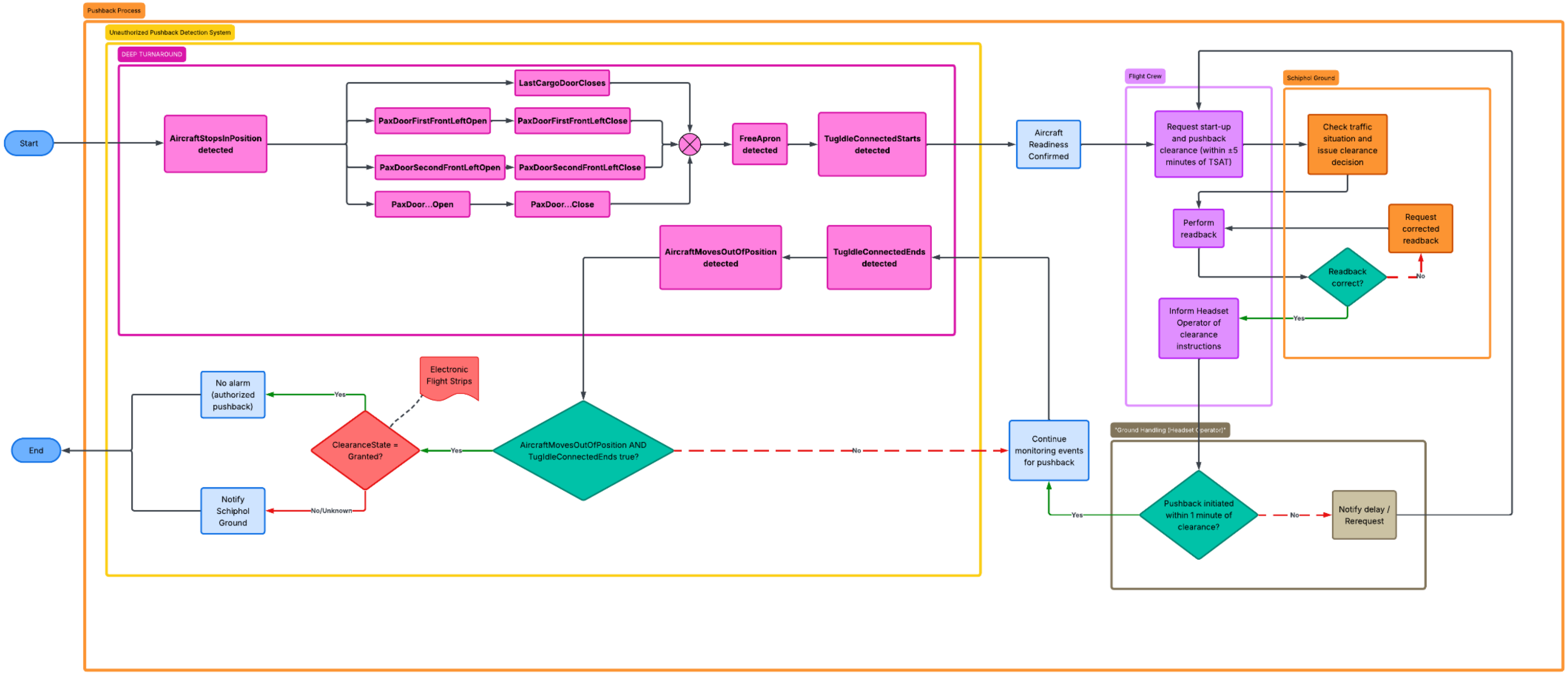

Figure 12: Conceptual System Design - enlarged

APPENDIX B: AI DISCLOSURE FORM

Table 3: AI Disclosure Form

4. Prompts Used	**Where was the information used?**
[1] Explain what you meant with "…".	[1] Whenever the AI generated a piece of text that didn't fully resonate with me. (Throughout the entire document)
[2] Who are the relevant stakeholders affected by [Implement Problem Statement]?	[2] When I wanted to double-check the stakeholders in the Problem Statement.
[3] The following paragraph is "…", what would you recommend is missing with regards to these guidelines "…"?	[3] Whenever I wanted to double check for missing, relevant content within an important chapter. (the first three chapters, after this I took a different approach)
[4] How do you recommend I start with "…"	[4] As help with the Literature Review. I mainly used peers and the mentors for guidelines.
[5] We are going to do major rehaul. This is what we used before [submit paragraph], I would like to follow this new structure. [submit new guidelines or inspiration] Would this change anything in the document apart from the associated chapter?	[5] Mainly whenever I wanted to implement a big amount of feedback, no minor changes. (When I needed to change an entire chapter)
[6] What (type of) sources are good regarding "…"? Explain why.	[6] When I needed a start regarding a certain concept. (mainly theoretical framework & literature review)
[7] [submit statement] What **type of** source would support this statement, and (if applicable) what sources would not support this?	[7] Within the Theoretical Framework, when the statement was almost common sense.
[8] Generate a pictogram of "…"	[8] Turnaround process diagram.
[9] Generate a format for the pushback process, use this as your context [INSERT CONTEXT HERE].	[9] For the layout of the pushback process used in the intermediate progress presentation.