

# Assessing the Operational Use of Deep Turnaround Data at LVNL for Outbound Operations



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## Use of Generative AI disclaimer

would like to acknowledge the use of Google Gemini Flash 2.5 in the preparation of this research. Specifically, I used AI to:

- **Structure the report:** AI was used to help outline and organize the flow of the research paper.
- **Summarize text:** AI assisted in creating concise summaries of existing literature and research findings.
- **Check grammar and punctuation:** AI tools were employed to review the text for grammatical errors and correct punctuation.
- **Source discovery:** AI was used to help identify potential sources and relevant academic literature for this study.

All ideas, arguments, and conclusions presented in this paper are my own. The AI tools served solely to enhance the efficiency and quality of the writing and research process. I have carefully reviewed all content and take full responsibility for the accuracy and integrity of the final submission.

## Preface

This thesis presents both the research results and my personal development during a challenging project at Luchtverkeersleiding Nederland (LVNL). Working within a large, safety-oriented organisation required a high degree of precision and transparency in my approach. The considerable size and complexity of LVNL created unexpected difficulties in accessing data, coordinating with stakeholders, and understanding operational systems, which influenced the pace and efficiency of the research.

Throughout the project, I enhanced my skills in planning, interviewing, and managing expectations. Progress was at times impeded by organisational dependencies, which revealed shortcomings in my initial stakeholder mapping and assumptions about data availability. Addressing these challenges required adaptability and more proactive communication, ultimately strengthening the quality and coherence of the final report.

The report was intentionally structured to communicate complex operational findings in a clear and defensible manner. Figures and tables were developed to facilitate the interpretation of temporal patterns and comparative results, rather than functioning as standalone illustrations. This approach enhanced the persuasiveness of the analysis and increased the accessibility of its technical findings. One important lesson I learned is to spend more time at the start of a project identifying stakeholders, checking whether data is available, and ensuring everyone's expectations are clear. In future projects, I plan to set aside time for these steps to avoid delays later and work more efficiently.

I would like to thank Koos Noordeloos for his valuable guidance, Veronica de Groot for sharing her expertise regarding operations at Schiphol, and Catya Zúñiga Alcaraz for her constructive feedback on the report's structure and clarity. I am also grateful to my family and friends for their continued support throughout this project.

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Mitch Beintema

## Abstract

Outbound operations at Amsterdam Airport Schiphol (AMS) face capacity constraints, making stable and predictable departure planning essential. Under the Airport Collaborative Decision-Making (A-CDM) framework, Luchtverkeersleiding Nederland (LVNL) relies on the Target Off-Block Time (TOBT) as the main readiness milestone linking ground handling to outbound planning. TOBT is updated manually, resulting in inconsistent patterns and limited accuracy. Quantitative analysis shows that TOBT updates are infrequent and mostly occur late in the turnaround process. Consequently, inaccurate TOBT definitions cause TSAT volatility, increase controller workload, reduce sequencing stability, and lead to inefficient runway use.

To address these limitations, this study evaluates the operational value of turnaround timestamps generated by Deep Turnaround (DT). The main research question of this thesis is stated as:

*“Which departments and functions at LVNL can benefit from turnaround-generated timestamps produced by Deep Turnaround associated with operational opportunities, and how can this information support traffic management decision-making at Amsterdam Airport Schiphol?”*

This mixed-methods case study combined quantitative analysis of TOBT and DT-derived timestamps with qualitative insights from expert interviews. The findings show that DT provides detailed turnaround event data that is analytically valuable but not directly usable in live operations. Its operational value emerges when processed into predictive outputs, particularly the Predicted End of Ground Handling Time (PEGT). Since PEGT is a continuously updated prediction with limited spatial coverage at AMS, it cannot serve as an independent planning milestone. Instead, DT acts as an additional information layer that supports existing A-CDM milestones. Comparing TOBT and PEGT reveals different readiness behaviours: TOBT shows little improvement in accuracy and infrequent updates, while PEGT becomes more frequent and precise as ground handling progresses, surpassing TOBT in accuracy during the late turnaround phase.

The findings further show that greater predictive accuracy does not always lead to operational usability in capacity-constrained air traffic management. Multiple parallel readiness timestamps increase cognitive load for outbound planners and conflict with DMAN design principles that prioritize planning stability. PEGT should therefore act as a conditional filter on TOBT, supporting validation and early deviation detection without triggering premature resequencing. Outbound Planning and Ground Control can use DT through contextual pushback-connection indicators on Electronic Flight Strips, while Capacity Management and Safety Management benefit from DT data in post-operational analysis and performance monitoring.

Overall, DT enhances the reliability and interpretability of aircraft readiness information for outbound traffic management at LVNL without altering the existing A-CDM planning architecture.

# Table of Contents

<b>Use of Generative AI disclaimer</b> .....	<b>4</b>
<b>Preface</b> .....	<b>5</b>
<b>Abstract</b> .....	<b>6</b>
<b>Table of Contents</b> .....	<b>7</b>
<b>List of Tables</b> .....	<b>9</b>
<b>List of Figures</b> .....	<b>9</b>
<b>List of Abbreviations</b> .....	<b>10</b>
<b>1. Introduction</b> .....	<b>11</b>
1.1. Problem Background.....	11
1.2. Problem Statement .....	12
1.3. Thesis Objectives .....	12
1.4. Research Question .....	12
1.5. Scope & limits.....	12
1.6. Thesis Structure.....	13
<b>2. Literature Review</b> .....	<b>14</b>
2.1. Methodological Literature Review .....	14
2.1.1. Qualitative Data Collection Theories .....	14
2.1.2. Stakeholder Analysis as Theory .....	15
2.1.3. Qualitative and Quantitative Data Analysis .....	15
2.1.4. Validity and reliability .....	16
2.2. Literature Review .....	16
2.2.1. The Aircraft Turnaround Process .....	16
2.2.2. Airport Collaborative Decision-Making (A-CDM).....	17
2.2.4. Deep Turnaround System .....	20
2.2.5. Comparative Analysis of TOBT and PEGT .....	21
<b>3. Methodology</b> .....	<b>24</b>
3.1. Analysis of turnaround process, A-CDM with a focus on TOBT .....	24
3.2. Analysis of the value of Deep Turnaround, characteristics and PEGT .....	25
3.3. Analysis and Comparison of TOBT and PEGT Update Behaviour and Accuracy .....	26
3.4. Stakeholder Analysis & Qualitative Thematic Coding to Determine DT Opportunities at LVNL .....	26
3.5. Synthesis of Research Findings.....	27
<b>4. Results</b> .....	<b>28</b>
4.1. Deep Turnaround Data Identification and Limitations .....	28
4.1.1. Turnaround Insight Event Dataset .....	28
4.1.2. Turnaround Insight CDM Dataset .....	29
4.1.3. Current State of Deep Turnaround.....	31
4.2. Comparative Analysis of the Differences Between TOBT and PEGT .....	32
4.2.1. Update Distribution of PEGT Relative to AEGT .....	33
4.2.2. Update Distribution of TOBT Relative to AEGT .....	34
4.2.3. Update Frequency per Turnaround.....	35
4.3. LVNL Internal Stakeholder Analysis.....	36
4.3.1. Department-Level Stakeholder Identification .....	36
4.3.2. Function-Level Stakeholder Identification .....	39
4.4. Qualitative Results of Thematic Coding.....	42
<b>5. Findings and Recommendations</b> .....	<b>46</b>
5.1. Key Findings.....	46
5.1.1. From DT-data Properties to Operational Usability .....	46
5.1.2. PEGT and TOBT Accuracy and Update Behaviour .....	46

5.1.3.	Boundary Conditions of Deep Turnaround .....	46
5.1.5.	Compatibility of DT-derived Signals with DMAN Logic .....	48
5.2.	Recommendations.....	50
5.2.1.	Adoption of PEGT Filter on TOBT in DMAN.....	50
5.2.2.	Pushback Connection Checkbox on EFS .....	50
5.2.3.	Trigger Alert for Ground Control for Pushback Control.....	51
5.2.4.	Use of DT Data for Analytical Support in CMA and ORM.....	51
<b>6.</b>	<b>Conclusion .....</b>	<b>52</b>
<b>7.</b>	<b>Future Work.....</b>	<b>54</b>
	<b>References.....</b>	<b>55</b>
	<b>Appendix I: LVNL Department Descriptions .....</b>	<b>60</b>
	<b>Appendix II: Turnaround Insights API Events.....</b>	<b>62</b>
	<b>Appendix III: OPS, P&amp;D, ORM Organogram .....</b>	<b>64</b>
	<b>Appendix IV: Pushback Deviations from ATC Clearance Data.....</b>	<b>65</b>
	<b>Appendix V: Interview Transcript Data Scientist I .....</b>	<b>66</b>
	<b>Appendix VI: Interview Transcript Data Scientist II .....</b>	<b>69</b>
	<b>Appendix VII: Interview Transcript Data Owner.....</b>	<b>71</b>
	<b>Appendix VIII: Interview Transcript Product Director .....</b>	<b>73</b>
	<b>Appendix IX: Interview Transcript Outbound Planning .....</b>	<b>75</b>
	<b>Appendix X: Interview Transcript ORM .....</b>	<b>77</b>

## List of Tables

Table 1. Comparison of Qualitative Data Collection Methods .....	15
Table 2. Methodological Steps per Sub-Objective.....	24
Table 3. Turnaround Insight Event Dataset example .....	28
Table 4. DT Events Categories.....	29
Table 5: DT CDM Dataset Example .....	30
Table 6. Selection Matrix Department-Level.....	38
Table 7. Selection Matrix Function-Level .....	40
Table 8. Interview participants, coded with the first letter of their company (L = LVNL, S = Schiphol).....	42

## List of Figures

Figure 1. Generic Turnaround Process Chart (Fuchte et al, 2012).....	16
Figure 2. Milestone Approach (Eurocontrol, 2024) .....	17
Figure 3. Positioning of DT within A-CDM Timeline .....	20
Figure 4. MAE vs Horizon to AEGT (adoption from Bremer, 2026) .....	22
Figure 5. Error vs AEGT Distribution - PEGT vs TOBT (Bremer, 2026).....	23
Figure 6. Partial Coverage of DT on C-pier .....	32
Figure 7. Distribution of PEGT Updates by Timebin to AEGT .....	33
Figure 8. Distribution of TOBT Updates by Timebin to AEGT .....	34
Figure 9. Distribution of Updates per Turnaround .....	35
Figure 10. TOBT and PEGT Evolution with AEGT Marker.....	35
Figure 11: Organogram of LVNL .....	37
Figure 12. Operational Acceptance Conditions .....	44
Figure 13. Pushback-without-clearance Safety Net Design .....	51

## List of Abbreviations

<b>AAS</b>	Amsterdam Airport Schiphol
<b>A-CDM</b>	Airport Collaborative Decision-Making
<b>AEGT</b>	Actual End of Ground Handling Time
<b>AIBT</b>	Actual In-Block Time
<b>AOBT</b>	Actual Off-Block Time
<b>ANSP</b>	Air Navigation Service Provider
<b>ATRICS</b>	Air Traffic Runway and Capacity System
<b>BPO</b>	Business Platform Operations
<b>CISS</b>	Central Information System Schiphol
<b>CMA</b>	Capacity Management
<b>CPDSP</b>	Collaborative Pre-Departure Sequence Planning
<b>DT</b>	Deep Turnaround
<b>DMAN</b>	Departure Manager
<b>EFS</b>	Electronic Flight Strips
<b>IATA</b>	International Air Transport Association
<b>LVNL</b>	Luchtverkeersleiding Nederland
<b>MAE</b>	Mean Absolute Error
<b>ORM</b>	Operational Risk Management
<b>PEGT</b>	Predicted End of Ground Handling Time
<b>SESAR</b>	Single European Sky ATM Research
<b>SESAR JU</b>	SESAR Joint Undertaking
<b>STW</b>	Slot Tolerance Window
<b>TOBT</b>	Target Off-Block Time
<b>TSAT</b>	Target Start-Up Approval Time
<b>TTOT</b>	Target Take-Off Time
<b>UTC</b>	Coordinated Universal Time

## 1. Introduction

Large international airports function in environments characterised by high traffic demand and constrained operational capacity. Runways, parking positions, and airspace can accommodate only a limited number of aircraft simultaneously. As traffic levels approach these thresholds, minor disruptions can rapidly escalate into widespread delays. Therefore, structured and reliable planning and management of aircraft departures are essential for maintaining efficient airport operations.

Amsterdam Airport Schiphol (AAS) ranks among the busiest airports in Europe, managing a substantial volume of daily departures within a complex operational context. Effective coordination of aircraft movements is required to ensure safe and efficient departures. In such an environment, departure planning cannot rely exclusively on pre-determined schedules. Instead, it depends on timely, accurate information about when aircraft are ready to leave their parking positions. Early and precise readiness information enables stable departure planning, whereas inaccurate or delayed updates complicate the management of departing flights.

### 1.1. Problem Background

At AAS, this challenge is tightly connected to the aircraft turnaround process, defined as the interval between an aircraft's arrival at the parking position and its subsequent departure, during which all necessary ground-handling activities are completed. The timing of these activities determines when the aircraft is ready for departure and can be integrated into the departure flow. Therefore, accurate aircraft readiness information is essential for efficient management of departing flights. The Target Off-Block Time (TOBT), which estimates when an aircraft will be ready to move, is manually updated by ground-handling personnel during the turnaround. Although written procedures exist to facilitate the use of shared planning information, in practice, these data sources often differ in timing and accuracy. TOBT updates are frequently provided late in the turnaround process, sometimes only after delays or deviations have already occurred.

This situation results in a reactive operational environment. Those responsible for managing departures at Luchtverkeersleiding Nederland (LVNL) rely on readiness information to organise the departure sequence, defined as the planned order in which aircraft are expected to depart. When data is inaccurate, sequences must be adjusted under high time pressure, leading to increased controller workload and the instability of departure flows. At the system level, these late-stage changes result in "lost" runway slots and underutilisation of existing capacity. These effects are not isolated incidents; they repeat daily, undermining the efficiency of the entire airport hub.

A closer examination shows that these effects are driven by structural causes. From a human perspective, readiness estimates depend heavily on manual input and local judgement, introducing variability in how and when updates are made. From a process perspective, there are no consistent procedures for validating or adjusting readiness information based on the actual progress of ground-handling activities. From a technological perspective, information generated during the turnaround is not always fully shared among all stakeholders, resulting in fragmented situational awareness.

In response, Royal Schiphol Group developed Deep Turnaround, an AI-driven system that automatically and continuously monitors turnaround activities to generate predictive readiness indicators, such as the Predicted End of Ground Handling Time (PEGT). However, while this technology provides a clearer view of readiness, its operational role in supporting LVNL's departure decision-making has not yet been defined.

## 1.2. Problem Statement

The Turnaround process at Amsterdam Airport Schiphol is characterised by insufficient accuracy in turnaround-related timestamps used for outbound operations.

## 1.3. Thesis Objectives

The objective of this thesis is to determine how turnaround-generated timestamps by Deep Turnaround can be used by LVNL to support air traffic management decision-making at Amsterdam Airport Schiphol, and to identify which specific LVNL departments can benefit from this information, along with the operational opportunities.

To address this, the following sub-objectives are formulated:

- I. To analyse the aircraft turnaround process at Amsterdam Airport Schiphol within the A-CDM framework, with focus on the characteristics of TOBT, and to assess how TOBT is used for outbound planning and traffic management decision-making.
- II. To analyse Deep Turnaround by determining data elements that hold qualities for ATM by understanding the properties of turnaround event timestamps, and its prediction capabilities, with specific focus on the Predicted End of Ground Handling Time (PEGT).
- III. To analyse the accuracy, update behaviour, and characteristics of TOBT and PEGT relative to actual turnaround times.
- IV. To compare TOBT and PEGT by differences in their accuracy, update behaviour, and characteristics
- V. To identify the departments and their operational functions within LVNL that could utilise Deep Turnaround datasets, and to determine the opportunities for supporting air traffic management.

## 1.4. Research Question

The main research question of this thesis is stated as:

*“Which departments and functions at LVNL can benefit from turnaround-generated timestamps produced by Deep Turnaround associated with operational opportunities, and how can this information support traffic management decision-making at Amsterdam Airport Schiphol?”*

## 1.5. Scope & limits

This thesis investigates and evaluates the use of turnaround readiness information to support outbound operational decision-making at AAS but not implemented. The scope is explicitly limited to the operational output of the Deep Turnaround system, specifically predictive timestamps that reflect the progress and expected completion of ground-handling activities during aircraft turnaround. The focus is on the accuracy, timing, and operational relevance of these turnaround-related timestamps in the outbound phase. The analysis compares different

readiness information sources and examines how variations in update behaviour and accuracy influence the stability and predictability of outbound operations. The study is confined to the turnaround process and the early phase of the outbound operational window.

The thesis does not investigate the internal technical functioning of the Deep Turnaround system. Components such as camera infrastructure, raw video feeds, computer vision methods, machine-learning algorithms, data-processing pipelines, and cloud architecture are outside the scope and are treated as given inputs. Likewise, the study does not include software development, system engineering, or technical implementation of system interfaces. Integration of Deep Turnaround data into LVNL operational systems is addressed at a conceptual and exploratory level only. This thesis identifies potential operational use cases and implications for decision support but does not cover procedural validation, safety assessment, controller training, or live deployment within air traffic control operations. Auxiliary operational data sources, such as detailed flight planning systems, runway planning tools, and broader network management data, are excluded, except where required for contextual understanding. The scope is geographically limited to AAS and LVNL.

## **1.6. Thesis Structure**

This thesis is organised into seven chapters, beginning with this introduction. Chapter 2 provides a literature review that establishes the theoretical and operational context. This chapter defines the current state of knowledge and identifies the specific knowledge gap addressed by this study. Chapter 3 outlines the research methodology, detailing the research design, data sources, analytical methods, and qualitative approaches employed to investigate the research objectives. Chapter 4 presents the results of the quantitative analysis, focusing on the accuracy, update behaviour, and operational characteristics of turnaround-related timestamps. It also evaluates their relevance for outbound traffic management decision-making. Chapter 5 discusses these results by interpreting the key findings in relation to the research question, the organisational roles within LVNL and presenting recommendations. Chapter 6 concludes the thesis by synthesising the key findings, reflecting on their implications for outbound operations at AAS. Finally, Chapter 7 provides directions for further research on this topic.

## 2. Literature Review

This chapter outlines the theoretical foundations of the study. It first reviews methodological literature on mixed-methods research in complex operational environments, then synthesizes domain-specific literature on aircraft turnaround operations, Airport Collaborative Decision-Making (A-CDM), Departure Manager (DMAN) logic, and the development of Deep Turnaround and predictive timestamps.

### 2.1. Methodological Literature Review

Research in complex operational environments frequently employs a mixed-methods approach. Quantitative analysis alone is insufficient to explain how or why operational actors interpret and act on information, while qualitative analysis without numerical grounding limits systematic comparison (Creswell & Clark, 2018; Yin, 2018). Quantitative research emphasises measurement and comparison, whereas qualitative research focuses on meaning and interpretation. By integrating these methods, mixed-methods research provides a comprehensive understanding, capturing both the measurable outcomes and the interpretative processes that define complex decision-making in operational settings.

Within the scope of this thesis, descriptive analytics characterise system behaviour by analysing distributions and variability in time-based data (Teradata, 2025). This approach determines the extent to which planned and realised events align in practice. Methods such as correlation and regression identify statistical relationships and offer predictive insight. However, these methods depend on assumptions of linearity, independence, and causality, which are often challenging to uphold in dynamic, multi-actor operational environments (Field, 2018).

#### 2.1.1. Qualitative Data Collection Theories

Qualitative data collection methods differ in the type of insight they provide and in how they balance depth, interaction, and standardisation. Table 1 summarises the primary qualitative data collection approaches discussed in the literature, highlighting their analytical focus, strengths, and limitations.

<b>Method</b>	<b>Primary focus</b>	<b>Key strengths</b>	<b>Main limitations</b>
<b>Document analysis</b>	Formal processes and institutional intent	Non-reactive; stable; supports triangulation (Bowen, 2009)	Limited insight into informal practices
<b>Semi-structured interviews</b>	Individual reasoning and interpretation	Depth; flexibility; explanatory power (Adeoye-Olatunde & Olenik, 2021)	Time-intensive; respondent bias
<b>Focus groups</b>	Shared perspectives and sense-making	Efficient; interactive; intuitive outcomes (Krueger & Casey, 2015)	Group dynamics; limited anonymity
<b>Observation</b>	Enacted behaviour in context	Captures tacit practices; situational insight (Angrosino, 2007)	Reactivity; researcher bias

<b>Surveys</b>	Standardised responses across actors	Scalable; comparable (Groves et al., 2011)	Limited contextual explanation
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Table 1. Comparison of Qualitative Data Collection Methods

As shown in Table 1, qualitative data collection methods differ in how they balance depth, interaction, and standardisation. Document analysis is a form of research where documents are interpreted to give voice and meaning to the area under investigation (Bowen, 2009). Semi-structured interviews address this limitation by allowing an in-depth exploration of individual reasoning while maintaining analytical focus through predefined themes (Adeoye-Olatunde & Olenik, 2021). Focus groups ignite collective sense-making through participant interaction, efficiently crafting shared perspectives. However, focus group results are sensitive to group dynamics and power relations (Krueger & Casey, 2015). Observation uncovers informal behaviours and contextual cues that participants may not articulate, although it introduces risks of reactivity and researcher influence (Angrosino, 2007). Surveys extend reach and ensure comparability across larger populations, but typically lack the contextual richness required to explain operational mechanisms or decision logic (Groves et al., 2011).

### 2.1.2. Stakeholder Analysis as Theory

Stakeholder analysis provides a theoretical framework for identifying, categorising, and prioritising actors based on attributes such as interest, influence, and impact. Classical stakeholder theory conceptualises organisations as networks of interdependent actors rather than isolated decision-makers (Mitchell et al., 1997). Basic stakeholder mapping enhances analytical clarity but may oversimplify complex relationships. More advanced stakeholder analysis approaches incorporate dynamic interdependencies and contextual variation, supporting systematic yet bounded inquiry into roles and responsibilities (Freeman & McVea, 2001). In qualitative research, stakeholder analysis supports the structured selection of interview participants and frames interpretation by individual perspectives.

### 2.1.3. Qualitative and Quantitative Data Analysis

Interviews generate textual data reflecting individual interpretations, experiences, and reasoning processes. Analysing this data requires qualitative analysis techniques that support systematic pattern identification while preserving contextual meaning.

Thematic analysis is an iterative qualitative data analysis method that involves coding, categorising, and unitising textual data to identify recurring patterns while maintaining contextual meaning (Braun & Clarke, 2006). Thematic analysis is well-suited for interpretative explanation within established conceptual frameworks. While discourse and narrative analysis emphasise language use and storytelling, they are less compatible with the interpretation of operational processes. Thematic analysis, therefore, provides a balance between structure and flexibility, facilitating systematic comparison without enforcing theoretical closure. Descriptive analytics summarise distributions, variability, and temporal patterns in quantitative data without introducing causal assumptions. Compared with correlation or regression analysis, descriptive statistics emphasise transparency and robustness with minimal assumptions. Although inferential and prescriptive methods provide predictive or optimisation capabilities, they rely on data quality, stability, and model assumptions that may

not be valid in constrained operational contexts (Field, 2018). Descriptive analytics thus serve as an analytical baseline that complements qualitative interpretation.

### 2.1.4. Validity and reliability

Qualitative research faces threats related to reactivity, researcher bias, and respondent bias. Literature emphasises mitigation through triangulation, prolonged involvement, member checking, peer debriefing, negative case analysis, and maintaining an audit trail (Lincoln & Guba, 1985). Each strategy addresses different validity threats, collectively enhancing credibility, transparency, and trustworthiness (Maxwell, 2012).

## 2.2. Literature Review

### 2.2.1. The Aircraft Turnaround Process

Airport operations are supported by a wide variety of tools, procedures, and performance metrics that enable planning, monitoring, and control. These tools are typically developed and optimised for stakeholder-specific objectives, including those of airlines, airport operators, air navigation service providers (ANSPs), and ground handling companies. As a result, operational monitoring has historically been fragmented, with limited data sharing between stakeholder-specific systems. (Zuniga & Herrero, 2024).

The aircraft turnaround is generally defined as the time interval between an aircraft's arrival at the stand (in-block) and its departure from that stand (off-block), during which all activities required to prepare the aircraft for its next flight are completed (IATA Airport, n.d.; Schmidt, 2017). This phase forms the operational bridge between the inbound (arrival) and outbound (departure) phases of a flight and is a critical determinant of airport capacity utilisation.

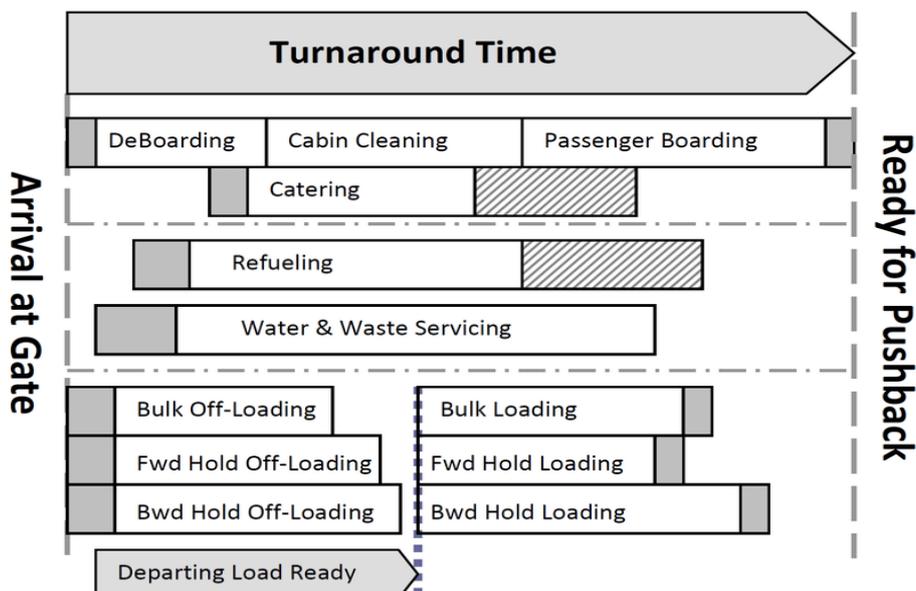


Figure 1. Generic Turnaround Process Chart (Fuchte et al, 2012)

During the turnaround, a set of ground-handling and operational tasks must be executed within a constrained time window, as illustrated in Figure 1. These tasks typically include passenger deboarding and boarding, baggage and cargo loading and unloading, catering and

cabin cleaning, refuelling, technical inspections, and flight crew preparation. Although these activities are often performed by different organisations, they are highly interdependent: delays or disruptions in one task can directly affect the feasibility and timing of subsequent tasks (Sheibani, 2019). These interdependencies form a parallel activity chain, of which the longest chain determines the effective turnaround duration. Delays within this chain, therefore, propagate directly to off-block readiness.

The turnaround process is largely identical across Schiphol (Airport Handling Manual (AHM), n.d.). The same functional roles are involved, although procedures, resource availability, and information systems may differ (IATA Ground Operations Manual (IGOM), n.d.). This generic structure enables conceptual standardisation of the turnaround process while remaining adaptable in practice. Beyond the physical execution of a turnaround, effective management depends on coordination across organisational and technical boundaries. Hereby relying on abstract representations of turnaround progress expressed through shared readiness indicators (Cm et al., n.d.). Inaccuracy in these indicators, such as inconsistent definitions, delayed updates, or insufficient reporting, can affect processes beyond the local turnaround and propagate into downstream air traffic management (EUROCONTROL, 2024)

Empirical studies demonstrate that turnaround variability, rather than consistent turnaround duration, is the dominant driver of departure delay propagation at hub airports. Small disruptions during ground handling can therefore have disproportionate effects on outbound sequencing and runway utilisation (Snijders, 2023).

### 2.2.2. Airport Collaborative Decision-Making (A-CDM)

A-CDM was introduced to address the fragmentation in operational data, where stakeholders historically relied on isolated information sources optimised for individual objectives. While optimisation supported local efficiency, it limited shared situational awareness and hindered coordinated decision-making at both airport and network levels (EUROCONTROL, 2016). As traffic volumes increased and operational margins narrowed, fragmented airport operations led to increasingly reactive delay management. Within the Single European Sky ATM Research (SESAR) initiative, it was therefore recognised that improving air traffic management performance required stronger coordination of airport operations and positioning airports as key contributors to network stability (SESARJU, 2019).

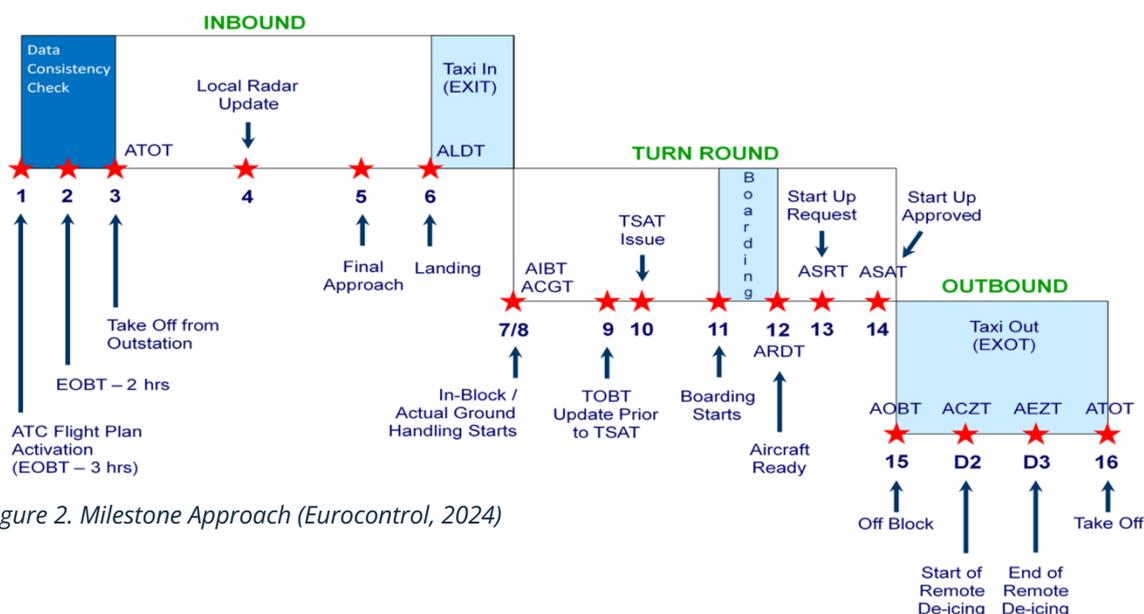


Figure 2. Milestone Approach (Eurocontrol, 2024)

A-CDM provides a structured framework for sharing operational information among stakeholders for collaborative decision-making. At its core lies the milestone approach (Figure 2), which standardises the turnaround process into a set of fifteen timestamped operational events (EUROCONTROL, 2017). These milestones allow stakeholders to track flight progression without requiring full visibility into each detailed operational process.

Empirical research at AAS highlights the critical role of A-CDM milestones in managing outbound capacity and departure predictability (MovingDot & NLR, 2019). In addition, milestone-based information exchange connects local airport operations to the European Network Manager, supporting slot management, demand–capacity balancing, and traffic flow optimisation at the network level (EUROCONTROL, 2025).

### **A-CDM at Amsterdam Airport Schiphol**

AAS is integrated into the European A-CDM network and exchanges operational departure data with EUROCONTROL’s Network Manager and local stakeholders (EUROCONTROL, 2017; LVNL, 2018). This information exchange is facilitated by the Central Information System Schiphol (CISS), which functions as the airport’s A-CDM information platform (Royal Schiphol Group, 2024).

Schiphol applies a selective A-CDM implementation, focusing on milestones that provide direct operational value for outbound planning, runway utilisation, and outbound predictability, rather than comprehensive inbound optimisation (EUROCONTROL, 2017; LVNL, 2018). AAS is an outbound-focused airport, meaning that departures are primarily managed by assessing local outbound capacity to determine feasible departure sequences (EUROCONTROL, 2025). This focus reduces the need for aircraft to enter airborne holding patterns or wait on ground buffer stands due to unavailable capacity. Within this configuration, the Target Off-Block Time (TOBT) serves as the central readiness reference, directly influencing downstream planning processes managed by LVNL.

### **Target Off-Block Time (TOBT)**

The TOBT is a milestone within the A-CDM framework, representing the target time at which an aircraft is operationally ready to leave the stand following completion of all ground handling activities (EUROCONTROL, 2017). TOBT serves as the primary target for departure readiness, acting as the interface between ground operations and outbound air traffic management.

At AAS, TOBT is the primary readiness input for outbound sequencing and outbound planning processes. Within both the current Collaborative Pre-Departure Sequence Planning (CPDSP) and the upcoming Departure Manager (DMAN), TOBT serves as the input from which downstream planning times are derived (MovingDot & Canso, 2017). This is ultimately subject to airport capacity and sequencing logic (ATRICs, 2021). Empirical findings confirm that TOBT is the primary driver of the relationship between turnaround execution and outbound planning outputs, directly constraining the generation of Target Start-up Approval Time (TSAT) and Target Take-Off Time (TTOT).

However, the operational effectiveness of TOBT is strongly dependent on its accuracy and update behaviour. TOBT relies on manual input by ground handlers, resulting in relatively small accuracy and inconsistent update practices (Snijder, 2023).

### 2.2.3. Departure Manager (DMAN) and Design Logic

A-CDM standardises the exchange of turnaround information through shared milestones but does not perform departure sequencing or capacity allocation (EUROCONTROL, 2025). These planning functions are executed by DMAN, which constructs outbound departure sequences in relation to runway and capacity constraints (EUROCONTROL, n.d.).

#### DMAN Design Logic

DMAN translates TOBT into an ordered departure sequence using predefined design logic, making TOBT a direct determinant of planning stability and resequencing. A core design objective of DMAN is departure stability: the Functional Specification requires that TSAT and TTOT are updated *“as rarely as possible and only as often as necessary”* (Frequentis, 2021). To support this, DMAN limits unnecessary resequencing and prioritises operational predictability over maximal precision. Based on TOBT, tactical planning variables are derived that determine runway assignment, priority ranking, freeze status, and ultimately capacity allocation (Frequentis, 2021).

DMAN operates through periodic calculation cycles. All milestone updates received since the previous cycle are processed and determine updates on other milestones and sequencing. To preserve stability, DMAN is explicitly required to publish only changed outputs, thereby reducing output volatility and preventing unnecessary disturbances (Frequentis, 2021).

Flights initially enter the ‘target state’ when they are more than approximately 40 minutes from TOBT. During the target state, TOBT is treated as a flexible planning estimate, and resequencing is unrestricted. Flights transition into ‘semi-stable’ state between TOBT -40 and TOBT -05 minutes, where TOBT is considered relatively reliable, and resequencing is limited. Stability close to execution (TSAT window T-5 to T+5) flights become ‘stable’ and are primarily enforced through the AutoFreeze mechanism. When AutoFreeze is active, a flight retains its assigned sequence position, and its TSAT and TTOT are treated as fixed constraints, regardless of changes elsewhere in the departure sequence (Frequentis, 2021). However, DMAN logic allows AutoFreeze to be overridden by a TOBT update or cancellation. As a result, a flight can be recalculated even shortly before execution, reintroducing volatility despite the system’s stability design (Frequentis, 2021).

The operational impact of TOBT changes is formally defined in Use Case UC-2147 (“Update Recalculation – TOBT update”), which categorises the TOBT update. These categories determine whether a TOBT update is absorbed by the system or triggers resequencing:

- **Cat 1: TOBT update towards TSAT (later,  $\leq$  TSAT)**  
TOBT is updated to a later time but remains earlier or equal to the last TSAT. Flight priorities are preserved, TSAT and TTOT remain unchanged.

- **Cat 2: TOBT delayed beyond TSAT**  
TOBT is updated to a time later than the last calculated TSAT, the flight is resequenced. This triggers recalculation of TSAT and TTOT.
- **Cat 3: TOBT delayed – regulated flight**  
TOBT update causes the TTOT to fall outside the Slot Tolerance Window (STW), the flight is resequenced.
- **Cat 4: TOBT earlier**  
Any TOBT update that moves the time earlier than the previous TOBT is treated as a resequencing trigger.
- **Cat 5: TOBT cancellation**  
TOBT deleted, or TSAT-state is set to cancelled or expired, the flight is removed from the departure sequence.
- **Cat 6: TOBT update after cancellation**  
New TOBT is entered after a cancellation or expiry event, the flight is re-introduced into the sequence. DMAN performs a full recalculation of TTOT-target, TTOT-optimal, TSAT, TTOT.

#### 2.2.4. Deep Turnaround System

Deep Turnaround (DT) is a machine-learning-based video recognition system developed by Royal Schiphol Group BPO to monitor aircraft ground-handling activities during the turnaround phase (Schiphol, n.d.). DT was a response to persistent problems with the accuracy and effects of manually maintained TOBT (Schiphol, n.d.). Hereby generating near real-time predictive operational information by translating observed stand activity into structured timestamps and status indicators (Aviation Solutions, n.d.). DT functions as an information-generation layer: it does not introduce new operational procedures or decision rules, but supplies automatically generated turnaround data that can be consumed by stakeholders. In this way, DT complements the existing A-CDM information without redefining its milestone structure or governance (Schiphol, n.d.).

DT observes turnaround operations using two fixed cameras per stand. These video feeds are processed using machine-learning algorithms to detect and classify ground-handling events across multiple turnaround processes. As a result, DT represents the turnaround as a sequence of standardised operational events and provides continuously updated timestamps and status indicators based on observed execution progress. (Royal Schiphol Group, 2025).

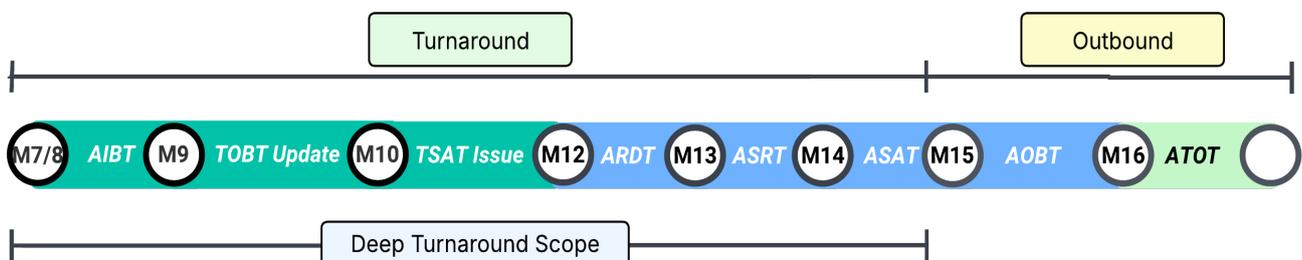


Figure 3. Positioning of DT within A-CDM Timeline

To clarify how Deep Turnaround information aligns with the A-CDM framework, Figure 3 conceptually positions DT within the turnaround and outbound process. This figure illustrates that DT operates only within the phase between Actual In-Block Time (AIBT) and Actual Off-

Block Time (AOBT). This positioning reflects a deliberate system design choice and defines the scope within which DT data are interpreted.

### **Generation of Timestamps Based on Events**

Each detected DT event represents a change in operational state and is assigned a timestamp based on observed execution rather than manually declared readiness. Event detection relies on confidence-based classification, meaning events are registered only once sufficient classification confidence is achieved. Consequently, DT timestamps reflect the moment an event is reliably recognised by the system rather than the exact physical instant at which it occurs on the stand. This represents a deliberate trade-off between temporal precision and robustness of event detection (Schiphol, 2025)

### **Predictive End Ground Handling Time (PEGT)**

The PEGT is a predictive indication that estimates the moment at which all ground handling activities required to prepare an aircraft for departure are expected to be completed, explicitly excluding pushback (Schiphol, n.d.). Its reference point, the Actual End of Ground Handling Time (AEGT), marks the moment when all ground handling activities during the turnaround process are completed.

Unlike traditional A-CDM milestones that rely on manual updates, PEGT is a continuous prediction that adapts as additional turnaround information is detected. As ground handling activities are completed, PEGT progressively converges toward AEGT, reflecting increasing certainty about readiness (Hartog, 2024). This convergence behaviour distinguishes PEGT and positions it as a dynamic indicator rather than a single information point. Existing studies emphasise PEGT's value for enhanced situational awareness and early deviation detection. PEGT can indicate potential readiness deviations earlier than late manual updates (Hartog, 2024; Schiphol, n.d.).

#### **2.2.5. Comparative Analysis of TOBT and PEGT**

Both TOBT and PEGT are intended to represent aircraft readiness for departure, but differ in the way they are produced. TOBT is manually determined and used as a target to work towards, and PEGT is produced with machine learning, which ultimately predicts. As such, existing studies emphasise that their operational usefulness should be evaluated by how closely predicted timestamps correspond to the actual completion of ground handling activities (Hartog, 2024; Bremer, 2026).

MAE vs Horizon to AEGT

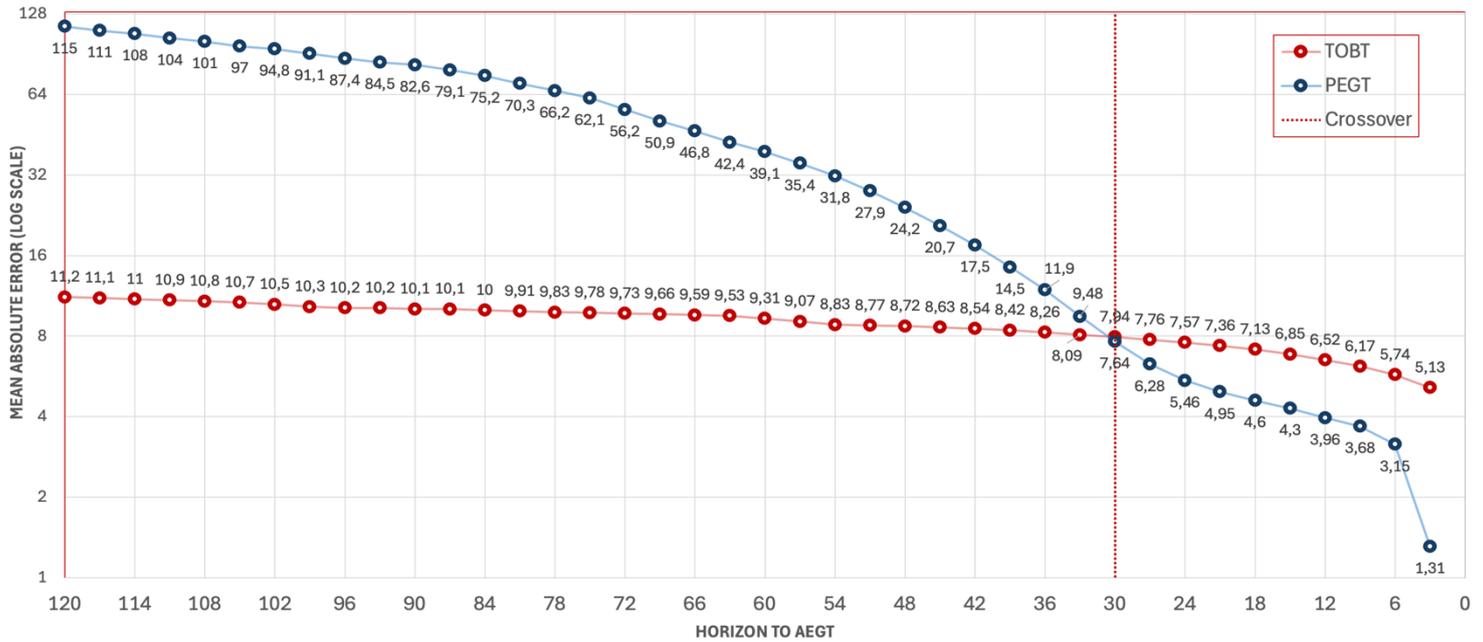


Figure 4. MAE vs Horizon to AEGT (adoption from Bremer, 2026)

Figure 4 plots the mean absolute error (MAE) of TOBT and PEGT as a function of the remaining time to the AEGT. The MAE represents, in this perspective, the absolute difference between a prediction or target and the actual time of turnaround completion. The horizontal axis represents the prediction horizon, expressed in minutes before AEGT, while the vertical axis presents the MAE in minutes on a logarithmic scale.

The TOBT is characterised by a relatively stable but weakly improving accuracy across most of the turnaround horizon. MAE remains close to eight minutes until approximately forty minutes before AEGT. Even in the final phase of the turnaround, TOBT continues to exhibit a persistent error of several minutes. In contrast, PEGT exhibits a distinct converging pattern. In early phases, PEGT is associated with high MAE values, reflecting considerable uncertainty when only limited data is available. As ground handling activities advance, PEGT accuracy improves rapidly. The MAE decreases non-linearly, demonstrating increasing accuracy in the prediction as DT accumulates turnaround information. In the final phase prior to AEGT, PEGT converges toward low error values and shows superiority regarding TOBT.

A crossover occurs approximately 30 minutes before AEGT, at which point PEGT becomes more accurate than TOBT. This crossover does not imply that PEGT is uniformly superior across the entire turnaround; it highlights that PEGT's accuracy advantage emerges as evidence of execution accumulates.

### TOBT and PEGT Error Precision

From a descriptive analytics perspective, precision is best understood through the shape, spread, and tail behaviour of error distributions rather than accuracy alone (Gneiting, 2009; Pernot & Savin, 2018).

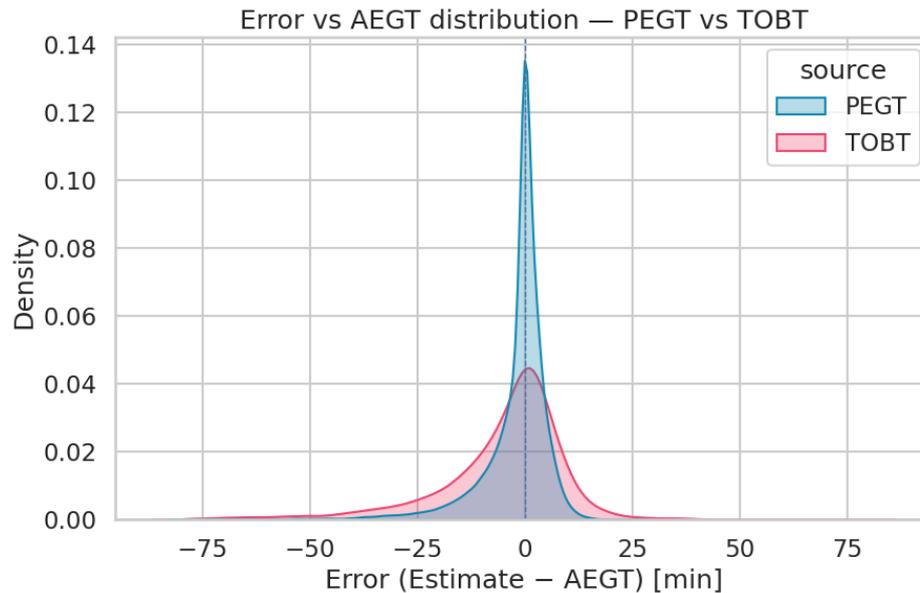


Figure 5. Error vs AEGT Distribution - PEGT vs TOBT (Bremer, 2026)

Figure 5 presents the density distributions of signed prediction errors for TOBT and PEGT relative to the AEGT. Both error distributions are centred close to zero, indicating that, when averaged across all flights, neither TOBT nor PEGT systematically overestimates or underestimates the end of ground handling time. However, the distributions differ substantially in their dispersion and concentration, which directly reflects differences in precision.

The PEGT error distribution exhibits a high central concentration with a narrow peak around zero and a rapid decline in density as error magnitude increases. This indicates that a large proportion of PEGT predictions fall within a relatively narrow error band, suggesting low error variability (Gneiting, 2021). The short, steep tails further indicate a low incidence of extreme deviations, suggesting that PEGT errors are not only relatively small but also tightly bounded. In contrast, the TOBT error distribution is markedly wider, with a flatter central region and extended tails reaching well beyond  $\pm 60$  minutes. This wider spread indicates substantial heterogeneity in TOBT prediction variability, with a probability of large deviations.

### 3. Methodology

This study adopted an exploratory, descriptive case study design situated within the operational environment of AAS and LVNL. The focus was emphasised on aircraft turnaround operations within the Airport A-CDM framework. Hereby, evaluating the characterising by comparing the accuracy and update behaviour of TOBT and PEGT. The research followed a mixed-methods approach, combining quantitative and qualitative analysis with operational interpretation and organisational applicability.

Qualitative findings were used to contextualise and interpret the operational meaning of quantitative patterns rather than to claim statistical generalisability. The methodology is explicitly structured as a sequence of analytical steps that collectively address the sub-objectives described in Table 2 and lead to answering the research question. These steps include analysing the turnaround process and A-CDM focus, evaluating the value of Deep Turnaround, and examining the update behaviour of TOBT and PEGT. Each step was designed to reveal insights critical to decision-making at LVNL by pinpointing how operational processes can be optimised, contributing directly to improved efficiency and accuracy in aircraft turnaround operations.

<b>Sub-Objective</b>	<b>Methodological Step</b>	<b>Data</b>	<b>Output</b>
<b>I</b>	Analysis of turnaround process, A-CDM with a focus on TOBT	A-CDM docs, LVNL procedures, DMAN and VEMMIS	TOBT role in outbound planning & update distribution per time bin
<b>II</b>	Analysis of the value of Deep Turnaround, characteristics and PEGT	Turnaround Insights dataset & Turnaround CDM dataset	DT data inventory, qualitative data elements for ATM & update distribution per time bin
<b>III</b>	Analysis of accuracy, update behaviour and characteristics of TOBT-PEGT	TOBT & PEGT update distributions	Plots of update distributions, convergence patterns
<b>IV</b>	Comparison of TOBT-PEGT by determining differences in accuracy, update behaviour and characteristics	Plots of update distribution	Relative performance comparison and differences
<b>V</b>	Stakeholder Analysis & Thematic Qualitative Analysis to Determine DT Opportunities at LVNL	LVNL Organograms & Interviews (n=7)	Departmental opportunities & constraints

Table 2. Methodological Steps per Sub-Objective

#### 3.1. Analysis of turnaround process, A-CDM with a focus on TOBT

To establish the operational baseline against which DT timestamps were analysed and compared, the study collected qualitative data from A-CDM documentation, Schiphol operational procedures, and LVNL manual of outbound planning. The purpose of this

collection was to identify the milestone structure of the turnaround process and to determine where TOBT is positioned as the primary readiness timestamp within outbound planning.

First, the turnaround process was decomposed into its milestone sequence, explicitly identifying which stakeholders are associated with each milestone and which milestones serve as decision inputs for ATM planning. Second, the TOBT-driven planning chain was mapped from readiness input (TOBT) to downstream planning outcomes like TSAT/TTOT generation and sequencing stability. The output of this stage was a clearly defined baseline model describing how TOBT is used in practice for outbound planning at LVNL. TOBT data was obtained from an LVNL internal A-CDM dataset derived from the VEMMIS Database (logging CPDSP calculation cycles) combined with milestone information from the Central Information System Schiphol (CISS). TOBT updates were linked to individual flights/turnarounds using flight identifiers (e.g., call signs).

TOBT updates were reconstructed per turnaround  $i$  as chronological sequences  $u = 1, \dots, n_i$ . The Actual End of Ground Handling Time (AEGT <sub>$i$</sub> ) was used as the operational reference event. For each TOBT update, the system clock time (UTC) at which the TOBT was registered ( $t_{i,u}^{\text{TOBT}}$ ) was extracted. The analytical purpose of the TOBT horizon formulation is to quantify how far in advance TOBT updates are registered relative to the AEGT:

$$H_{i,u}^{\text{TOBT}} = \text{AEGT}_i - t_{i,u}^{\text{TOBT}}$$

To analyse the update behaviour consistently over time, horizon values  $H_{i,u}^{\text{TOBT}}$  were categorised into fixed five-minute time-to-event bins (e.g., 0–5, 6–10, 11–15 minutes before AEGT). This choice was made to ensure that the intervals are short enough to capture meaningful variations in TOBT updates while still being easy to interpret. The distribution of TOBT updates across these bins was then analysed to describe when TOBT updates occur during the turnaround and update the distribution of TOBT.

### 3.2. Analysis of the value of Deep Turnaround, characteristics and PEGT

Data on DT was collected from the Turnaround Insights CDM dataset retrieved from the Schiphol Developer Portal. Data were extracted for the observation window from 1 August 2025 to 31 August 2025, covering turnarounds at AAS during high demand. As an initial step, the DT dataset was examined to inventory the available data sources. These sources were categorised and assessed for their relevance to the research objectives. Each data row contains a unique turnaround identifier, enabling the reconstruction of multiple PEGT updates for the same turnaround.

For each turnaround  $i$ , PEGT updates  $u$  were ordered chronologically with the same method as TOBT. The Actual End of Ground Handling Time (AEGT <sub>$i$</sub> ) was used as the reference event for ground handling completion. For each PEGT update, the time horizon to AEGT <sub>$i$</sub>  at which the prediction was issued ( $t_{i,u}^{\text{PEGT}}$ ) was formulated.

$$H_{i,u}^{\text{PEGT}} = \text{AEGT}_i - t_{i,u}^{\text{PEGT}}$$

Like the method used with TOBT, horizon values  $H_{i,u}^{\text{PEGT}}$  were categorised into fixed five-minute time-to-event bins (e.g., 0–5, 6–10, 11–15 minutes before AEGT). The distribution of PEGT updates across these bins was analysed to describe when PEGT updates occur during the turnaround.

### 3.3. Analysis and Comparison of TOBT and PEGT Update Behaviour and Accuracy

The analysis of TOBT and PEGT update behaviour was complemented by a literature review on the turnaround process, A-CDM at Schiphol, and accuracy and precision. Findings from prior studies were translated into an analytical baseline, which guided the selection of comparison dimensions: update timing, update density, and convergence towards the actual reference event.

The analysis used two independent operational datasets aligned to the same observation window (1 August to 31 August) to ensure temporal consistency. A turnaround was included in the comparison if it represented an outbound operation at AAS, the relevant actual reference time (AEGT) was available, and at least one timestamp update was recorded. Records with missing essential timestamps or non-linkable identifiers were excluded from the comparative analysis to preserve validity.

For direct comparison between the two timestamp types, horizons for both PEGT and TOBT were categorised into identical bins. Updates with negative horizon values ( $H < 0$ ) were excluded as they represent updates after the AEGT. This is ultimately incorrect, as TOBT-PEGT converges to AEGT and therefore cannot have negative values. The Analysis was conducted at two levels: (i) the update level, where each update was treated as an individual observation, and (ii) the turnaround level, where updates were aggregated per flight id to examine update frequency per turnaround.

Once all the updates were ordered, they were aggregated to obtain the total updates per bin. Because TOBT and PEGT differ in total update volume, absolute bin counts were normalised to relative frequencies to enable unbiased comparison of update distributions:

$$P_k = \frac{C_k}{\sum_k C_k} \times 100$$

where  $C_k$  is the count of updates in bin  $k$ . Update distributions were visualised using histograms with relative frequencies. In addition, representative turnarounds were visualised as time-ordered update series to illustrate convergence and correction dynamics. These series plotted successive TOBT and PEGT predictions relative to the relevant AEGT.

### 3.4. Stakeholder Analysis & Qualitative Thematic Coding to Determine DT Opportunities at LVNL

Qualitative data collection began with an internal stakeholder analysis within LVNL to identify organisational departments and functions. This stakeholder analysis subsequently identified internal candidates for interviews. Semi-structured interviews were then conducted with seven participants within the organisational context of LVNL and Schiphol between 24 September and 27 December. Interviews lasted approximately 30–45 minutes, were recorded

with permission, transcribed and translated to English, and anonymised. These transcripts were then returned to the respondents for confirmation of their intended meaning.

Interview data were analysed using thematic coding. First, transcripts were reviewed to familiarise with the dataset and to identify initial patterns. Second, open coding was applied to segments addressing (i) how turnaround readiness information is currently interpreted, (ii) perceived reliability and usability of TOBT versus PEGT-like information, (iii) workload and planning stability implications, and (iv) organisational or technical constraints for adoption. Third, codes were iteratively categorised into themes capturing recurring organisational patterns. Fourth, themes were cross-checked against the full dataset to ensure internal consistency and clear differentiation. Finally, the themes were analysed and determined how they are connected by writing out interpretation to capture the core results of the analysis.

The qualitative analysis served two operational purposes: it supported familiarisation with operational reality, and it enabled identification of where and how timestamp information could be used within LVNL functions.

### **3.5. Synthesis of Research Findings**

The final step consisted of an integrated synthesis combining quantitative analysis, qualitative thematic codes, and literature. Quantitative results on TOBT and PEGT update behaviour were reviewed with respect to their characteristics. Qualitative themes were used to interpret how these quantitative patterns relate to operational usability, organisational acceptance, and relevance within LVNL. Literature findings were used as a basis for validating the quantitative and qualitative results. Finally, the research question was answered through a combination of these three data sources.

## 4. Results

This chapter elaborates the results of the quantitative and qualitative analysis. The results are structured in four steps. First, the DT datasets are described to clarify what data is available, with corresponding scope and limitations. Second, TOBT and PEGT are analysed and compared based on their characteristics during the turnaround process. Third, usability of DT at LVNL is determined through an internal stakeholder analysis. Finally, the interview findings are elaborated and contextualised alongside the quantitative results.

### 4.1. Deep Turnaround Data Identification and Limitations

DT has developed two primary datasets that represent successive abstraction layers and serve complementary operational purposes. Tables 2–4 illustrate this layered structure, moving from raw visual observations through event classification to predictive outputs.

#### 4.1.1. Turnaround Insight Event Dataset

The Turnaround Insight Event Dataset represents the most granular data layer and provides information on individual ground-handling events detected by the machine-learning vision recognition algorithm. This algorithm detects, categorizes, and timestamps specific physical activities as they occur on the stand. Each detected event corresponds to a single, visually confirmed operational action and is stored as a discrete record. This dataset captures *what* happened and *when*, without assessing progress or delay. This data is not processed and serves as a raw data layer upon which predictive capabilities are built.

Each detected event is published as a structured data message containing a standardized event type and timestamp, linked to the corresponding aircraft and stand.

Data	Output
<i>Event ID</i>	43415082
<i>Event</i>	PowerConnects ramp: "D23"
<i>Airport</i>	"AMS"
<i>Timestamp</i>	"2025-09-23 T11:43:13Z"
<i>Event</i>	"PowerConnects"
<i>Turnaround ID</i>	"120d5e5f-55fe-44b8-8ec6-31b21a5a19fe"
<i>Ramp Status</i>	"OCCUPIED",
<i>Aircraft Registration</i>	"PHBGQ",
<i>Scheduled Date Inbound</i>	"2025-09-23",
<i>Flight Designator Inbound</i>	"KL0936",
<i>Main Handler</i>	"KLM",
<i>Airline ICAO</i>	"KLM",
<i>Handlers</i>	N.A.

Table 3. Turnaround Insight Event Dataset example

Table 3 presents an example record from the Turnaround Insight Event Dataset. The table illustrates the structure and content of a single raw event observation. The event row represents a single discrete operational event and shows how it is contextualized with aircraft, flight, handler, and ramp information.

In the example shown, the event *PowerConnects* indicates the moment at which a ground power unit was connected to the aircraft at ramp position D23. The timestamp reflects the exact time this event was detected. The Event ID uniquely identifies this observation, while the Turnaround ID links it to all other events in the same aircraft turnaround. Contextual attributes like ramp position, aircraft registration, inbound flight designator, airline, and handler information associate the event with its operational environment. These attributes ensure that each detected event can be traced to a specific aircraft and location.

Importantly, the event dataset does not contain sequencing logic, milestone evaluation, or performance interpretation. Each event is stored independently and does not indicate whether the turnaround is progressing on schedule or experiencing a delay.

### DT Events Categories

Category	Number of Events
Aircraft Events	4
Fuel Events	7
Pushback Events	4
Baggage/Beltloader Events	8
Cargo/Highloader Events	12
Line Maintenance Events	4
Water/toilet Events	2
Catering Events	4
Pax Bridge / Stairs / Pax Flow Events	14
Pax Door Events	32

Table 4. DT Events Categories

Table 4 lists the event categories from the Turnaround Insight dataset and the number of distinct event types identified within each category (see appendix III for all events). The number of event types per category reflects the granularity in which these activities can be distinguished by DT. Passenger-related activities are represented by a higher number of event types due to their sequential and state-dependent nature, such as doors open, start boarding, end de-boarding. DT events categories do not show timestamps but rather provides an overview of the different types of ground-handling events.

The number of events is operationally relevant because categories with higher event density can potentially provide earlier and more frequent indicators of turnaround progress, while categories with fewer event types primarily provide confirmation of completed activities rather than early warning signals.

#### 4.1.2. Turnaround Insight CDM Dataset

The Turnaround Insight CDM dataset represents a processed data layer derived from the raw Turnaround Insight event dataset. The CDM dataset combines TOBT from A-CDM, historical data, and the raw data from DT. Consequently, TOBT is manipulated by combining historical and raw data to predict the end of ground handling.

Where Tables 3 and 4 focus on observation and structure respectively, the CDM dataset represents in which DT data is processed into predictive information.

**Turnaround Insight CDM API' dataset example:**

Type	Output Sample 1	Output Sample 2
<i>ID</i>	5420072	5420073
<i>Event</i>	TurnaroundInsightsCdmEvent	TurnaroundInsightsCdmEvent
<i>Data</i>	"89d602c3-0f6c-4d24-a908-2db9e0b90e40"	"b63bb9bc-2df8-4044-8714-8268b964533a"
<i>Ramp</i>	"G08"	"G08"
<i>Airport</i>	"AMS"	"AMS"
<i>Aircraft Registration</i>	"PHTFM"	"PHTFM"
<i>Schedule Date Inbound</i>	"2025-10-27"	"2025-10-27"
<i>Flight Designator Inbound</i>	"OR822"	"OR822"
<i>Schedule Date Outbound</i>	"2025-10-27"	"2025-10-27"
<i>Flight Designator Outbound</i>	"OR381"	"OR381"
<i>AIBT</i>	10:36:24Z	10:36:24Z
<i>PEGT</i>	12:40:00Z	12:47:30Z
<i>PEGT Upper Bound</i>	13:00:00Z	13:00:00Z
<i>PEGT Lower Bound</i>	12:40:00Z	12:40:00Z
<i>PEGT Probability</i>	0.0	0.0
<i>PEGT Prediction at</i>	"2025-10-27 T12:30:25Z"	"2025-10-27 T12:31:04Z"
<i>Tug Connected</i>	"true"	"true"
<i>Last Tug Connected at</i>	"2025-10-27 T12:25:29Z"	"2025-10-27 T12:25:29Z"
<i>Main Handler</i>	"QQG"	"QQG"
<i>Airline ICAO</i>	"TFL"	"TFL"
<i>Handlers</i>	N.A.	N.A.
<i>TOBT Delay Advice</i>	10	0
<i>TOBT Advice</i>	"2025-10-27T12:40:00Z"	"2025-10-27T12:45:00Z"
<i>Last Updated at</i>	"2025-10-27T12:31:44Z"	"2025-10-27T12:30:42Z"
<i>PEGT Delay Explanations</i>	"BaggageNotFinished"	[N.A.]
<i>Delay Status TOBT advice</i>	"type":"major_delay","amount":600000	"type":"feasible","amount":0
<i>Delay Status PEGT</i>	"type":"major_delay","amount":600000	"type":"no_delay","amount":150000
<i>Ready for Pushback</i>	"false"	"false"

Table 5: DT CDM Dataset Example

Both samples from Table 5 contain consistent contextual information, including aircraft registration, inbound and outbound flight designators, scheduled dates, ramp position, airline, and handler identifiers. The presence of multiple records or samples for the same turnaround reflects the CDM dataset's continuous update mechanism as new information becomes available. PEGT is accompanied by upper and lower bounds that define the prediction's confidence interval. The PEGT prediction timestamp indicates when the prediction was produced.

Comparing Output Sample 1 and Output Sample 2 illustrates how PEGT values, TOBT advice, and delay classifications change as additional DT events are detected and incorporated into the prediction logic. While core identifiers remain unchanged, predictive fields are recalculated to reflect increasing certainty regarding turnaround completion. In contrast to the raw event dataset, Table 5 embeds predictive logic. It evaluates whether a turnaround is progressing according to plan, quantifies expected delay, and generates actionable TOBT advice. As such, the Turnaround Insight CDM dataset represents the transition from raw data to predictive information.

#### **4.1.3. Current State of Deep Turnaround**

Despite the potential of Deep Turnaround described above compared to manual milestones, there are current-state characteristics of Deep Turnaround to consider.

##### **Region of Interest**

Deep Turnaround operates within a fixed, camera-defined detection area that covers the stand up to the red line. Only ground-handling activities occurring within this predefined zone are observable by the system and can be detected and translated into timestamps. Events taking place outside this spatial boundary fall beyond DT's region of interest and are therefore not captured. This limitation reflects a bounding characteristic and directly determines which turnaround events can be observed.

##### **Partial Occupancy**

DT coverage at Schiphol is currently not uniform across all stands. At the time of data collection, 91 stands are equipped with DT camera and operational, with an additional 11 stands scheduled for future deployment, while 39 stands remain without DT coverage. As a result, DT-derived event detections and predictive outputs are only available for turnarounds occurring at covered stands. This ultimately leads to uneven data availability across AAS.

##### **Infrastructure and Stand Layout Constraint**

As mentioned in 2.1.8, DT is designed based on two cameras, allowing the stand to be analysed from two angles. Each stand's installed cameras are physically connected to a designated collection bay. From this collection point, all generated data from the turnaround is then sent to the DT system.

In some cases, it is not possible to add stands to DT network on AAS due to physical infrastructure limitations. There are two main reasons that cause this limitation:

- I. The airport and stand configuration are such that it is not possible to install a second camera, or
- II. The collection bay of physical wiring from stand cameras is at the limit, whereby new set-ups are only possible by increasing capacity.

Stand configuration constraints, particularly at the C-pier and F-pier, limit the feasibility of analysing the stand from both perspectives. Current stand layout on C-pier and obstructed views on the stand at F-pier are limiting the installation. Hereby, two technical mitigation pathways are identified: adaptation of DT to operate with a single camera at the constrained stands or modification of stand infrastructure.

Figure 6 illustrates the partial occupancy of DT at the C-pier. The highlighted stands C11, C13, C14, and C16 are not equipped with DT infrastructure. Consequently, turnarounds at these stands do not generate outputs and remain dependent on conventional A-CDM milestones.

It is therefore likely that the partial occupancy on AAS will remain for relative long period as the development of a solution cannot be achieved in a short term.

The characteristics and limitations described above define the conditions under which DT timestamps are produced. To assess whether these timestamps offer operational value, the next section examines how PEGT behaves over time and how this behaviour compares to the existing TOBT milestone used in outbound planning.

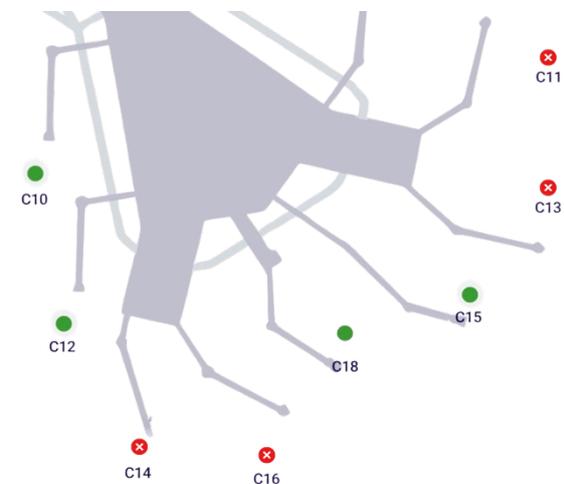


Figure 6. Partial Coverage of DT on C-pier

#### 4.2. Comparative Analysis of the Differences Between TOBT and PEGT

This section examines the difference in update behaviour of TOBT and PEGT, focusing on when and how frequently each timestamp is updated. The analysis aims to determine the operational suitability of TOBT and PEGT as readiness inputs for decision-making

### 4.2.1. Update Distribution of PEGT Relative to AEGT

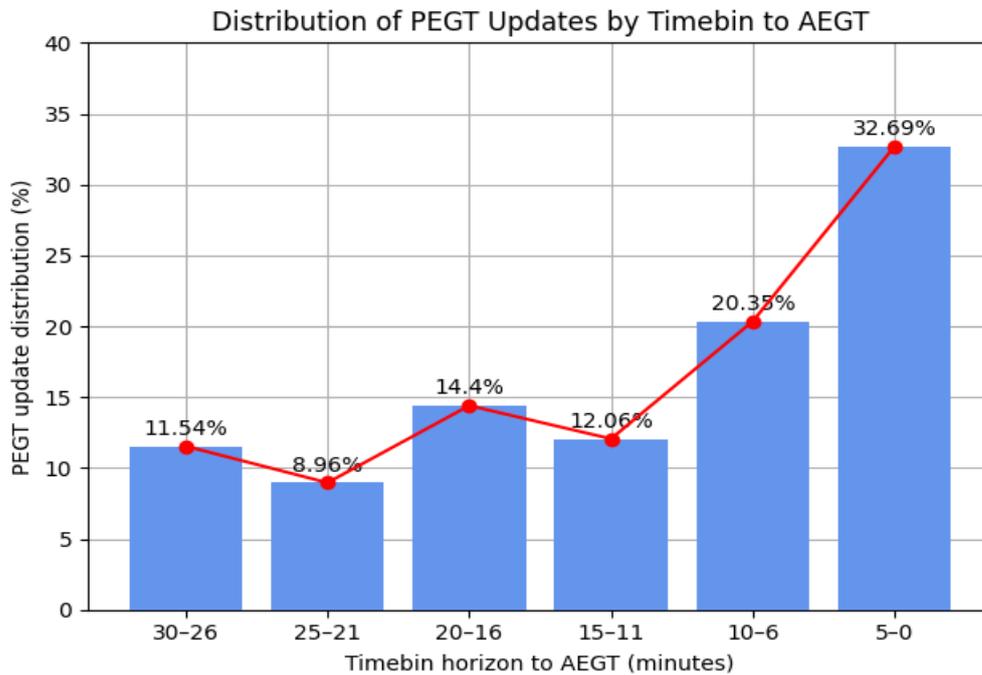


Figure 7. Distribution of PEGT Updates by Timebin to AEGT

Figure 7 illustrates the distribution of PEGT updates as a function of the remaining time to AEGT, providing insight into when PEGT updates are generated. Each bar represents the proportion of all PEGT updates categorised within a bin.

The distribution shows that PEGT updates are present across the entire observed turnaround window of 30 minutes before AEGT, but are not uniformly distributed over time. Instead, a clear pattern emerges in which update activity intensifies as the aircraft approaches the completion of ground handling. The highest share of updates (32.69%) occurs in the final 0–5 minutes before AEGT, followed by 20.35% in the 6–10 minute interval. Combined, 53.04% of all PEGT updates are generated within the last ten minutes before AEGT, indicating a strong concentration of update activity in the late turnaround phase.

Earlier in the process, PEGT updates are less frequent. Only 11.54% of updates occur more than 26 minutes before AEGT, while intermediate horizons (11–25 minutes) show moderate and fluctuating update shares. Early predictions are necessarily less detailed due to limited turnaround data generated. As a result, PEGT behaves as a progressively converging estimate, with the update density increasing as the turnaround approaches its actual completion. To interpret the operational significance of PEGT’s converging update pattern, it is necessary to contrast this behaviour with TOBT’s update dynamics.

#### 4.2.2. Update Distribution of TOBT Relative to AEGT

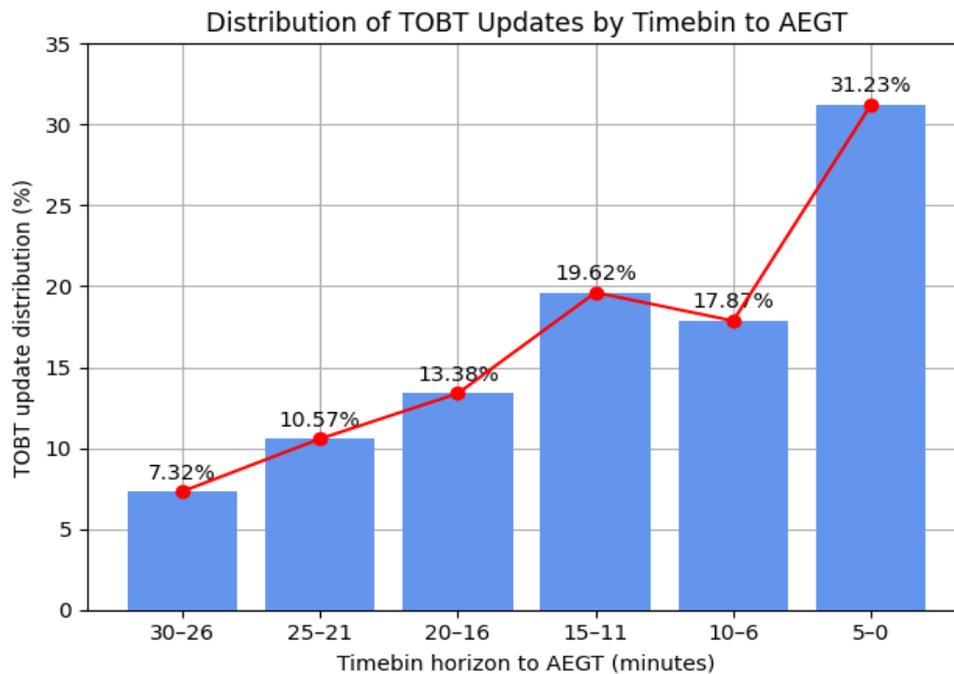


Figure 8. Distribution of TOBT Updates by Timebin to AEGT

Figure 8 illustrates the distribution of TOBT updates as a function of the remaining time to the AEGT, showing when TOBT updates are issued during the turnaround process. As in figure 7, each bar represents the proportion of all TOBT updates assigned to a fixed time bin. The distribution indicates that TOBT updates occur across the observed 30-minute turnaround window before AEGT, but they are not evenly distributed over time. Similar to PEGT, update activity increases toward the end of the turnaround. The largest share of TOBT updates (31.23%) occurs within the final 0–5 minutes before AEGT, followed by 17.81% in the 6–10 minute interval. Combined, 49.04% of all TOBT updates are generated within the last ten minutes before AEGT, indicating a strong concentration of updates in the late turnaround phase

In contrast to PEGT, TOBT updates are more prominently distributed across intermediate time horizons. The 11–15 minute bin shows a local maximum of 19.62%, while the 16–20 and 21–25 minute bins account for 13.38% and 10.57% of updates, respectively. Updates made less than 26 minutes before AEGT remain limited to 7.32%. The distribution shows that TOBT updates are less concentrated at the end of the turnaround and exhibit a broader spread across intermediate time bins.

While the distribution of TOBT and PEGT updates illustrates when each milestone typically becomes available, their update frequency is further analysed to deepen the comparison between the two.

### 4.2.3. Update Frequency per Turnaround

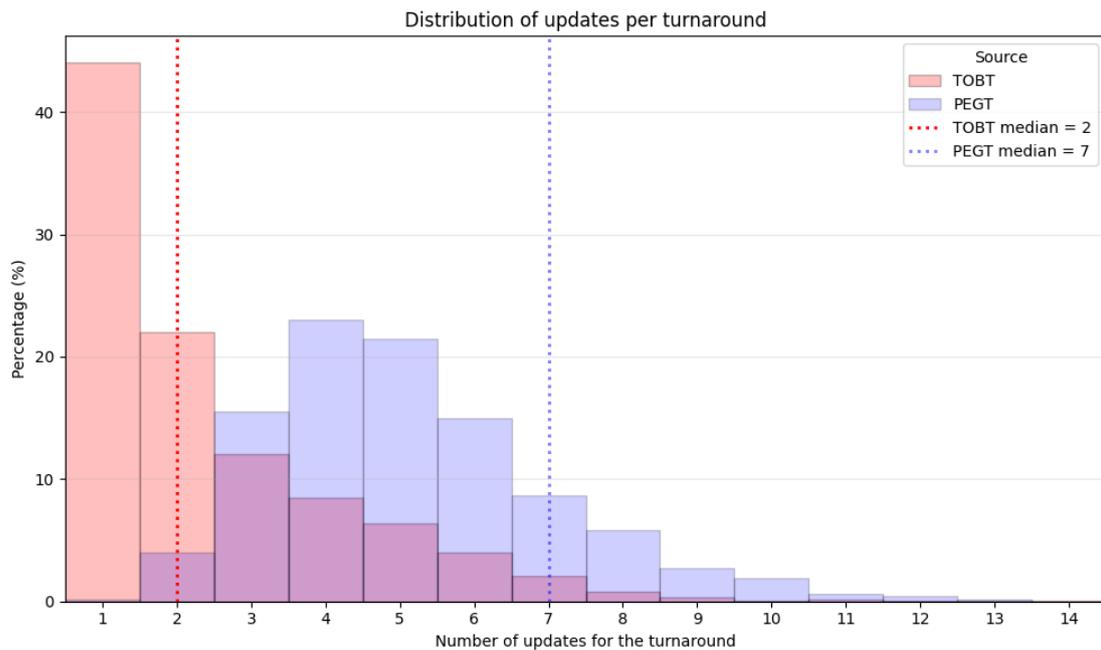


Figure 9. Distribution of Updates per Turnaround

Figure 9 presents the distribution of updates per turnaround for TOBT and PEGT. A clear difference in update behaviour is observed between the two milestones. TOBT updates are strongly concentrated at the lower end of the distribution, with most turnarounds receiving only one to three updates. The median number of TOBT updates per turnaround is 2, indicating that TOBT remains unchanged for much of the turnaround and is updated only occasionally. PEGT exhibits a broader, right-skewed distribution, with substantially more updates per turnaround. The median PEGT update count is 7, and several turnarounds have more than 10 updates. The wider spread of PEGT updates compared to TOBT reflects a higher update density per turnaround.

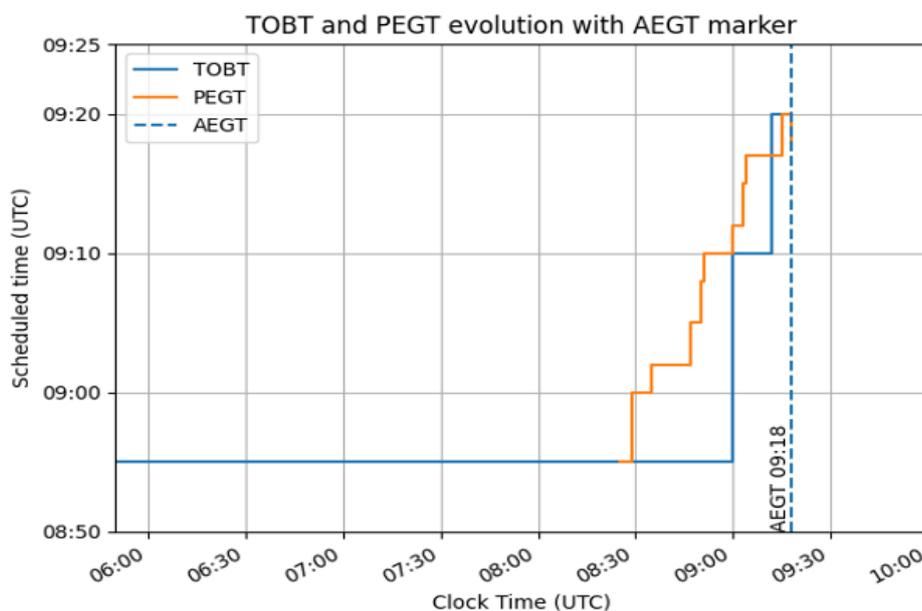


Figure 10. TOBT and PEGT Evolution with AEGT Marker

Figure 10 illustrates the evolution of TOBT and PEGT for a representative turnaround, with the AEGT included as a reference. The x-axis shows clock time (UTC), while the y-axis shows the scheduled time for each TOBT or PEGT update. This representation allows the magnitude and timing of successive updates to be visualised simultaneously, showing how each milestone is adjusted over time.

Generally, TOBT remains unchanged for an extended period, appearing as a horizontal line that indicates no updates during the early and mid-turnaround phases. Only in the final phase does TOBT change, where updates occur as larger, discrete step adjustments to a new scheduled time. PEGT shows frequent, incremental updates throughout the turnaround. These values are adjusted in small stepwise increments, resulting in a forward-moving pattern that progresses as clock time advances. The scheduled PEGT time is repeatedly revised, with each update shifting the predicted time closer to AEGT.

Figures 7 through 10 collectively demonstrate clear differences in the update behaviour of TOBT and PEGT. PEGT is characterised by frequent, incremental updates distributed across the turnaround window, with update activity intensifying as AEGT approaches. In contrast, TOBT updates occur less frequently, are often clustered in the late turnaround phase, and are separated by long periods without change. These patterns indicate fundamentally different readiness behaviours: PEGT evolves continuously as new turnaround information becomes available, whereas TOBT remains largely static until late-stage updates are applied.

The next section translates these quantitative differences in update behaviour into their organisational roles and decision-making context within LVNL.

### **4.3. LVNL Internal Stakeholder Analysis**

The primary objective of the stakeholder analysis is to determine which department, and their role would benefit from the use of DT data. Rather than assessing each department in depth and full width, this phase aimed to filter and prioritize the departments most likely to benefit using clear operational and organizational criteria.

#### **4.3.1. Department-Level Stakeholder Identification**

The relevance of DT data within LVNL is structurally bounded by both the DT operational scope and the organisational structure. As mentioned in section 2.1.4. and illustrated in Figure 3, DT is restricted to the aircraft turnaround and boundary of the outbound phase, covering the period between AIBT and AOBT. Within this window, DT provides turnaround insights that evolve as ground-handling activities progress. DT does not extend into inbound flow management or after off-block movement towards the runway.

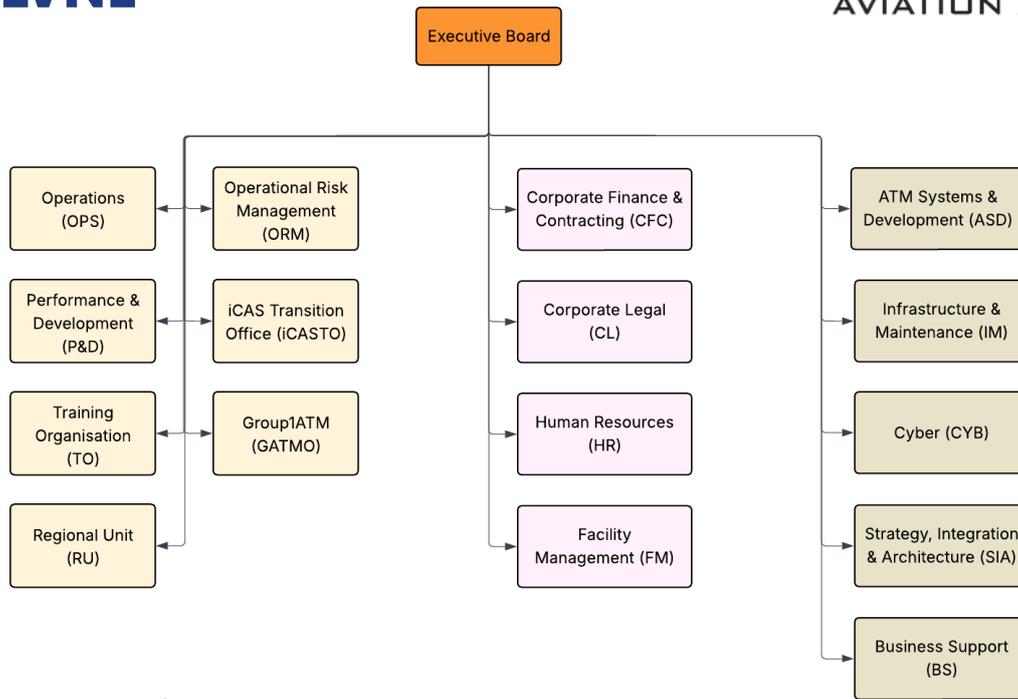


Figure 11: Organogram of LVNL

When the DT scope is mentioned in 2.1.4. is positioned against the LVNL organogram in Figure 11, clear structural distinctions emerge. The organogram confirms the formal positioning and organisational weight of departments within LVNL's governance structure, while also enabling decomposition into underlying functional domains. Departments relevant to DT share a common set of characteristics. Their responsibilities are connected to the turnaround or outbound operation, either through direct involvement or in a supporting role. In these areas, aircraft readiness information is used in operational or analytical work, meaning that changes in turnaround execution can affect planning stability, monitoring activities, or oversight tasks. Relevance is strongest in departments whose activities influence LVNL's performance outcomes, particularly departure predictability, capacity utilisation, and safety. In addition, these departments operate in situations where uncertainty in the turnaround or early outbound phase reduces foresight and coordination. These described conditions are therefore operationalised into a set of selection criteria that identify departments where DT has potential value:

1. **Operational Linkage:** The department have a direct role in the turnaround or outbound operations.
2. **Decision Dependency:** The department operational, analytical decisions, or control actions are influenced by aircraft readiness, TOBT, or related turnaround data.
3. **Performance Contribution:** The department's function contributes to LVNL's operational or strategic performance outcomes that are influenced by turnaround data.
4. **Operational Opportunity:** The department's effectiveness, foresight, or coordination improve if access to real-time turnaround data were introduced (e.g., PEGT or pushback-ready).

Each department was assessed against these four questions. These four questions were systematically applied to the department's core function and scored. A positive score (✓) indicates that the question is structurally applicable to the department's core function, while

a negative score (X) indicates that it is not. The results of this assessment are summarised in the department selection matrix.

### Selection Matrix

<b>Department</b>	<b>Q1: Direct role in the turnaround or outbound process?</b>	<b>Q2: Decisions influenced by aircraft readiness, TOBT, or turnaround data</b>	<b>Q3: Contribute to LVNL's operational or strategic performance</b>	<b>Q4. Department improve if access to real-time turnaround predictability were introduced</b>
ATM Systems & Development	X	X	✓	✓
Business Support	X	X	X	X
Corporate Finance & Contracting	X	X	X	X
Corporate Legal	X	X	X	X
Cyber	X	X	✓	X
Facility Management	X	X	X	X
Group1ATM	X	X	✓	X
Human Resources	X	X	X	X
iCAS Transition Office	X	X	✓	✓
Infrastructure & Maintenance	X	X	✓	✓
Operations	✓	✓	✓	✓
Operational Risk Management	X	✓	✓	✓
Performance & Development	X	✓	✓	✓
Regional Unit	X	X	✓	✓
Strategy, Integration & Architecture	X	X	✓	✓
Training Organization	X	X	✓	X

Table 6. Selection Matrix Department-Level

The selection matrix (Table 6) shows that DT relevance at LVNL is not evenly distributed, with the greatest scores in three departments: Operations, Operational Risk Management (ORM), and Performance & Development (P&D). Operations is directly involved in outbound execution and sequencing. Hereby, deviations that affect ground-handling progress immediately affect operational decisions, workload, and departure stability. ORM and P&D do not perform

turnaround tasks; instead, they rely on turnaround information to analyse operational performance, assess risks, and evaluate predictability and safety outcomes. Activities across all three departments are situated or influenced by the AIBT–AOBT window. This also accounts for why these departments generally score well in the matrix and are the main organisational targets for DT-derived information.

### 1. Primary Operational Targets

**Operations (4/4):** Operations emerges as the primary DT stakeholder and scores positively on all four criteria, reflecting its central role in outbound execution. According to Appendix II, Operations is responsible for traffic management, outbound sequencing, and the start-up and pushback clearances. These activities are directly dependent on aircraft readiness.

### 2. High Analytical Targets

**Operational Risk Management (3/4):** ORM scores positively on decision dependency, performance contribution, and operational opportunity, but not on direct operational linkage. Appendix II describes ORM as responsible for monitoring operational safety and analysing systemic risks rather than executing traffic flows. While ORM does not act during the turnaround itself, its assessments rely on accurate reconstruction of operational timelines.

**Performance & Development (P&D) (3/4):** P&D shows a similar pattern to ORM. As outlined in Appendix II, P&D focuses on development and strategic evaluation of operational efficiency and predictability. These functions depend on reliable timestamps to assess capacity utilisation, delay propagation, and adherence to A-CDM principles. Although P&D is not operationally active during the turnaround, inaccuracies in TOBT and related milestones undermine the validity of performance metrics.

#### 4.3.2. Function-Level Stakeholder Identification

At the function level, DT relevance is further refined by recognising that not all functions within a department interact with turnaround, readiness information, or outbound performance in the same way. The same four selection criteria applied at department level are therefore reused to ensure conceptual consistency and traceability of the stakeholder identification.

The same assessment approach applied in Table 6 is extended to the function level. Each department identified in Section 4.3.1 is decomposed into its existing functions, and each function is evaluated against the same set of criteria. The criteria are applied to each function's core responsibilities to determine structural relevance. A positive score (✓) indicates that the criterion is applicable to the function's mandate, while a negative score (X) indicates that it is not.

## Selection Matrix

<b>Department</b>	<b>Sub-Department / Functional Unit</b>	<b>Q1: Direct role in the turnaround or outbound process?</b>	<b>Q2: Decisions influenced by aircraft readiness, TOBT, or turnaround data</b>	<b>Q3: Contribute to LVNL's operational or strategic performance</b>	<b>Q4. Department improve if access to real-time turnaround predictability were introduced</b>
<b>OPS</b>	Outbound Planning (VLA-OPL)	✓	✓	✓	✓
	Ground Control (GC)	✓	✓	✓	✓
	Tower (TWR)	X	X	X	X
	Operational Support & Development (OSD)	X	✓	✓	X
	Procedures & Systems (P&S)	X	✓	X	X
<b>P&amp;D</b>	Capacity Management & Analytics (CMA)	X	✓	✓	✓
	Air Traffic Management Procedures (ATMP)	X	X	X	X
	Strategy (STRAT)	X	X	✓	X
	Business Support (BS)	X	X	X	X
<b>ORM</b>	Safety	X	✓	✓	✓
	Quality	X	X	✓	✓

Table 7. Selection Matrix Function-Level

Table 7 extends the department-level stakeholder analysis by assessing DT relevance at the function level. While departments provide organisational boundaries, operational value from DT data materialises at the level of concrete functions where decisions are made, actions are executed, or performance is evaluated. The table therefore decomposes the OPS, P&D, and ORM departments into their respective functional units. This approach reveals how DT relevance is distributed internally within departments and clarifies which functions constitute the actual points of impact for DT.

The results demonstrate that, as with the department-level analysis, DT relevance at the function level is unevenly distributed. Strong alignment is concentrated in a limited number of

functions whose responsibilities are either directly embedded in outbound execution or structurally dependent on aircraft readiness and turnaround predictability. These include Outbound Planning and Ground Control within OPS, Capacity Management & Analytics (CMA) within P&D, and ORM-safety. Other functions score lower because their mandates are temporally or functionally decoupled from the turnaround and early outbound phase, despite being part of operational departments.

### 1. Primary Stakeholders

**Outbound Planning (4/4):** Outbound Planning is responsible for constructing and maintaining the departure sequence, which relies heavily on TOBT. Because DT provides objective data, particularly through PEGT, it directly supports the planner's ability to enhance quality and anticipate earlier. This alignment between DT and the function's core operational need explains its full relevance score.

**Ground Control (4/4):** Ground Control also aligns strongly with DT relevance. While it does not determine the departure sequence, Ground Control is directly responsible for pushback coordination and movement during the early outbound phase. These tasks require accurate confirmation on when aircraft are physically ready to leave the stand. This explains why Ground Control checks all criteria despite the core function of Outbound Planning.

### 2. Secondary Stakeholders

**Capacity Management & Analytics (3/4):** CMA demonstrates strong DT relevance through its reliance on turnaround data to evaluate capacity utilisation and analyse it. Although CMA does not exercise direct operational control, it systematically incorporates operational data into its analytical and evaluative processes. DT data enhances the accuracy and timeliness of performance analysis and forecasting.

**ORM – Safety (3/4):** The function within ORM-safety aligns closely with DT relevance because its safety assessments rely on execution and readiness data. Although ORM activities formally begin once an aircraft starts moving, DT data remains essential for contextualising safety performance and compliance.

The stakeholder analysis identifies where turnaround information could be used within LVNL, but not how it is interpreted, trusted, or tailored to role-specific operational needs. The following section therefore presents qualitative results that connect the quantitative findings to operational acceptance and applicability among stakeholders.

#### 4.4. Qualitative Results of Thematic Coding

In total, seven participants involved in the turnaround, outbound departure process, and DT development were included in the interview findings. At LVNL, the results reflect perspectives from outbound planning, ground control, CMA, and ORM. At Schiphol, the findings include perspectives from staff involved in developing and applying Deep Turnaround data. In both organisations, participants worked in different functional domains, allowing the results to reflect diverse operational and organisational perspectives. More detailed characteristics of the participants are provided in Table 8.

Participant	Function	Affiliation	Area of expertise
L1	Outbound Planner	LVNL	Departure sequencing
L2	Ground Controller	LVNL	Ground movement control, pushback operations
L3	Head of CMA	LVNL	Capacity management, performance analysis
L4	Safety Expert of ORM	LVNL	Operational safety, risk management
S1	Data Scientist	Schiphol	Deep Turnaround analytics, event detection
S2	Data Scientist	Schiphol	Predictive modelling, turnaround data analysis
S3	Data Owner	Schiphol	Data governance
S4	Product Director	Schiphol	Product management

Table 8. Interview participants, coded with the first letter of their company (L = LVNL, S = Schiphol)

### Themes

The thematic analysis yielded 201 initial codes, which were iteratively clustered into 6 themes. These themes represent recurring patterns in how readiness information is generated, interpreted, and acted upon in outbound operations, as well as the conditions under which DT-derived information is considered operationally meaningful.

#### 1. Milestone Reliability and Manual Intervention

TOBT was consistently identified as a problematic milestone in terms of reliability and effects, noting its vulnerability to human resistance and operational consequences. The core issue, repeatedly mentioned across interviews, was not the absence of TOBT data but its inconsistent and inaccurate update patterns across different ground handlers. Hereby, ground handlers were described as often resisting TOBT updates out of fear of losing departure slots or being resequenced to later slots. This results in Outbound Planners performing manual validation and corrective interventions. Uncertainty is further amplified in reduced visibility or obstructed visual conditions, where pushback readiness cannot be independently confirmed, leading to increased reliance on incomplete or delayed milestone information.

#### 2. Planning Stability vs Dynamic Data Updates

Outbound planning was described as sensitive to frequent changes in readiness times, with a preference for stable planning inputs. Stability was described as important for maintaining situational awareness and managing workload, particularly close to AOBT horizons. TOBT was

described as becoming available earlier than PEGT and as being updated less frequently throughout the turnaround process. Frequent readiness updates were described as difficult to accommodate operationally without filtering or validation. Participants therefore described PEGT as functioning as a supporting or backend signal, used to validate or adjust TOBT rather than directly replacing it.

### **3. Technical vs Operational Readiness Indication**

DT-derived events, AEGT, and pushback tug connected were frequently cited as clear, observable, and technically valid indicators of readiness progression. However, these events do not constitute clearance from air traffic control (ATC) or full cockpit readiness. This misalignment highlights the distinction between technical readiness, as detected by DT, and operational readiness, including clearance. DT was framed as a “movement monitor”, not an authoriser. Its value lies in confirming whether the aircraft is physically able to initiate pushback, not whether it should.

### **4. Safety Monitoring and Automated Trigger**

Participants consistently identified pushback as a safety-critical phase within outbound operations. Interviewees described recurring incidents involving pushback without clearance, deviations from issued commands, and execution based on incorrect clearances. In addition to interviews, archival safety records indicate that between January 2021 and September 2025, a total of 707 such incidents were recorded during the pushback phase, averaging approximately 15.7 incidents per month (see Appendix IV).

This incident frequency underscores the operational challenge of maintaining situational awareness during peak traffic periods and monitoring command obedience. In this context, DT is perceived not as a control mechanism but as a safety net that supports early detection of deviations and contributes to post-operational analysis. DT’s capacity to detect aircraft movement adds value for both ground control and Operational Risk Management (ORM) functions. However, participants cautioned against overreliance on automated triggers. False positives were described as disruptive, and missed detections were deemed safety-relevant, highlighting the need for confidence thresholds and supplementary visual validation. DT is therefore most effective when implemented as an early-warning and deviation detection tool.

Participants emphasised that Pushback clearance is issued verbally and is not directly recorded as a timestamp in VEMMIS. However, lane changes of flight strips in EFS are systematically logged with exact timestamps.

### **5. Socio-Technical Barriers in Trust and Validation**

Interview findings indicate that effective integration of DT into live operations depends on procedural clarity, shared interpretation norms, and organisational trust. This trust dimension becomes critical when DT-derived timestamps conflict with TOBT. In the absence of clear rules on precedence, participants described the situation as “two clocks ticking,” undermining confidence in both data sources and complicating operational decision-making.

Physical constraints within the control tower limit the feasibility of adding new screens, making the Electronic Flight Strips (EFS) the only realistic interface for DT integration. However, DT information cannot be presented uniformly across functions. Differences in operational roles

require tailored data presentation, with strict control over the amount of information displayed. Both outbound planners and ground controllers consistently emphasised the need to work with a single leading timestamp. Presenting multiple timestamps on EFS was described as reducing clarity and increasing cognitive load. Displaying TOBT and PEGT as parallel timestamps would require controllers to arbitrate between the two, increasing interpretive effort and the risk of misinterpretation. Participants repeatedly linked this concern to a preference for PEGT functioning as a conditional filter on TOBT rather than as an additional timestamp.

From the CMA perspective, DT was primarily valued for post-operational analysis, performance assessment, and enforcement activities. Interviewees stressed that the reliability of DT data is critical, as inaccuracies would propagate into analytical assumptions and undermine the quality of downstream advisory outputs.

### 6. Technical Constraints and Coverage Boundaries

DT data availability was described as non-uniform across the airport, with camera coverage prioritised at high-volume passenger stands and less consistent availability in other operational areas. DT is designed around its region of interest, which currently detects only events on the stand. However, this region of interest can be technically expanded to detect events outside the stand, such as pushback directions.

DT detection was described as snapshot-based, with a detection latency of 5-10 seconds. Caused by the snapshot interval of 5 seconds, during which specific movement can occur between capture moments. An event can therefore be detected with a maximum latency of 10 seconds. In addition, detection accuracy is high for identifying movement, while small preparatory movements or shocks are detectable without necessarily representing readiness to move.

### Synthesis of Qualitative Results

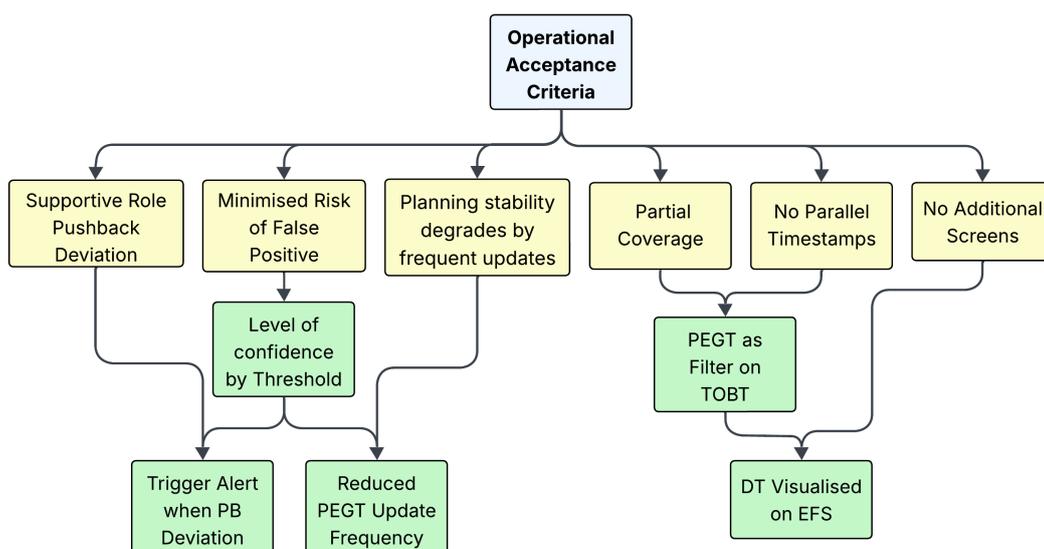


Figure 12. Operational Acceptance Conditions

Figure 12 summarises the qualitative themes by linking interview concerns to operational acceptance conditions for integrating DT. The upper section highlights the main constraints identified across six themes, while the lower section shows how these constraints define acceptable operational use. First, the distinction between technical and operational readiness positions DT as a monitoring and verification tool, not an authorising system. DT events indicate physical movement but do not replace ATC clearance, so DT is limited to deviation detection and safety support. Second, safety concerns and the risk of false alerts require a defined level of confidence, set through threshold values that determine when DT outputs can trigger alerts or influence interpretation. Third, planning stability requirements affect how DT predictions are presented: frequent PEGT updates are filtered, damped, and a threshold is applied, so PEGT serves only as a conditional signal rather than a continuously visible timestamp. Finally, trust and interface constraints require a single leading timestamp. DT is integrated within EFS, parallel timestamps are avoided, and no additional screens are used.

Together, the figure demonstrates how multiple qualitative themes are not independent but interact to define the specific conditions under which DT is considered operationally acceptable.

## 5. Findings and Recommendations

This chapter presents the key findings combining quantitative analysis with stakeholder perspectives. These findings are translated into recommendations on how turnaround information can be safely and effectively applied within existing outbound operations at LVNL.

### 5.1. Key Findings

This section presents the key findings of the quantitative and qualitative results in relation with the literature review.

#### 5.1.1. From DT-data Properties to Operational Usability

DT event data is analytically rich but not directly usable as an operational planning input for DMAN sequencing. Operational usability emerges only after processing raw DT observations into the Turnaround Insights CDM dataset, where event-level data are translated into structured and interpretable timestamps. Within this dataset, PEGT represents the primary indicator of DT's predictive capability and therefore constitutes the main source of operational value.

Importantly, the findings confirm that DT does not replace existing A-CDM milestones but functions as a complementary validation and forecasting layer. This directly addresses a recurring concern raised in the interviews: DT is not perceived as a replacement, but as an augmentation that improves milestone accuracy.

#### 5.1.2. PEGT and TOBT Accuracy and Update Behaviour

The combined quantitative, qualitative results, and literature analysis demonstrate that PEGT and TOBT represent fundamentally different types of readiness information. TOBT is available early in the turnaround and remains relatively stable, but its accuracy improves only marginally during execution. In the final 12 minutes before AOBT, TOBT maintains persistent uncertainty near departure. PEGT becomes progressively more accurate as the turnaround advances and 30 minutes before AEGT, PEGT outperforms TOBT in terms of MAE. PEGT errors show a narrower distribution and shorter tail, while TOBT errors exhibit wider distribution and higher exposure to extreme deviations. This ultimately suggests that PEGT is not only more accurate than TOBT but also more precise between 30-0 minutes before AEGT.

PEGT update behaviour is characterised by frequent incremental updates, with 53.04% of all PEGT updates occurring in the final 10 minutes before AEGT. TOBT update behaviour is characterised by long periods of inactivity followed by discrete manual corrections driven by human factors. PEGT's frequent update behaviour leads to increased risk of reduced stability in terms of planning. This underscores that operational value depends not only on accuracy but also on effective integration and filtering.

#### 5.1.3. Boundary Conditions of Deep Turnaround

DT detects physical aircraft and tug movement but does not observe ATC clearances or controller commands. DT data must therefore be interpreted in relation to clearance and command data to create relevance of operational state. DT data are spatially and technically bounded and are unlikely to achieve full coverage on AAS. Consequently, this leads to structurally non-uniform data generation, reducing the consistency of DT data. DT does not

resolve or replace decision authority within outbound operations and responsibility for clearance, sequencing, and safety remains with ATC. Finally, trust in data quality, validation, and accountability is a foundational requirement before any operational use.

#### **5.1.4. Qualitative Findings and Stakeholder Identification**

DT data is operationally relevant primarily for functions whose decisions depend on the AIBT-AOBT window or on events that occur immediately thereafter. Mapping the DT observation scope to the A-CDM milestone chain identifies the period between aircraft positioning and pushback initiation (approximately M7/8 AIBT to M15 AOBT) as the most relevant.

Four LVNL functions are structurally determined to any form of turnaround dependency within this window and therefore determined as stakeholders:

- Outbound Planning
- Ground Control
- Operational Risk Management (ORM)
- Capacity Management & Analytics (CMA)

While these functions are active in and around the turnaround window, they experience and manage different forms of uncertainty related to readiness, movement, safety, and performance. DT does not provide a uniform value across LVNL but supports function-specific needs at the operational interface.

#### **Findings for Outbound Planning**

Outbound planning relies primarily on TOBT, and inaccurate or late updates propagate directly into missed TSATs, resequencing, and downstream delays. Outbound planners compensate for this uncertainty by increasing monitoring, manual validation, and corrective interventions, underscoring the increase in workload. This can ultimately be resolved by a more accurate timestamp for planning and is logically linked to DT to be introduced in DMAN.

Outbound planners do not seek additional screens or timestamps on their interface. Presenting PEGT alongside TOBT on EFS as a parallel timestamp would therefore be directly excluded as a single source of truth is needed. Therefore, PEGT must act as a correcting filter on TOBT. If a pushback is connected, it is currently not visible to an outbound planner in any form. Mostly in deteriorated visibility conditions, this leads to unjustified pushback clearance and ultimately increased TSAT volatility. The pushback events category in the turnaround events data set is structurally detecting whether a pushback is connected and, therefore, provides an opportunity to be integrated into EFS as a checkbox.

#### **Findings for Ground Control**

The transition of responsibilities between outbound planning and ground control occurs when an aircraft approaches its TSAT window. Therefore, outbound planning and ground control are both beneficial for physically confirming whether a pushback is actually connected. Like outbound planning, this confirmation of the pushback connection is identical and derived from pushback event categories, and creates the opportunity to be integrated into EFS.

The safety analysis data show recurring incidents of pushback without clearance and deviating pushback execution. Subsequently, this substantiates the need for improvement in terms of safety-net mechanisms during the pushback phase. The DT aircraft event category reliably detects aircraft movement on the stand with a maximum latency of 5–10 seconds. A certain level of confidence must be met before sending a trigger alert to ground control on EFS to avoid false positives. This is determined by the exceedance of a threshold value and function strictly as decision support, not as an automated intervention mechanism. This mechanism to alert ground controllers is technically possible by combining the DT data with the VEMMIS database to improve safety.

Pushback clearance and command are issued verbally via radiotelephony and are not directly recorded in the VEMMIS database as a timestamp. Within EFS, ground controllers manage three operational lanes. The left lane represents aircraft awaiting pushback clearance; after receiving it, the strip is transferred to either the middle or right lane, depending on the operational situation. The moment a flight strip is transferred between lanes is systematically logged in VEMMIS, including an exact timestamp and flight identifier. As a result, a trigger for ground control can be derived by combining DT aircraft movement events with lane-change registrations.

### **Findings for Operational Risk Management (ORM)**

The analysis scope of ORM starts at the moment of rolling and DT can primarily be used by for post-operational analysis of pushback activities. DT's aircraft movement events provide validated evidence of actual stand behaviour. Hereby, enabling analysis of pushback execution deviations that are not accurately captured by other cameras or incident reports. Consequently, ORM is positioned as an analytical user of DT data, where value depends on data consistency, traceability, and governance.

### **Findings for Capacity Management & Analysis (CMA)**

CMA can primarily use turnaround data for post-operational performance analysis. CMA relies on consistent and validated timestamps to explain delay formation, assess predictability, and evaluate performance outcomes. DT is therefore valued primarily as a source of truth that complements or corrects A-CDM milestones.

PEGT adds limited value for CMA's core function. Analytical usefulness depends less on early prediction and more on data completeness, traceability, and stable definitions. The widespread use of additional data, powered by DT events and CDM data, can support a more reliable analysis of capacity and improve performance monitoring.

#### **5.1.5. Compatibility of DT-derived Signals with DMAN Logic**

Although PEGT shows greater accuracy, this advantage cannot be directly translated into without accounting for DMAN's calculation cycles. DMAN is designed to reduce sensitivity to updates as a flight approaches its TSAT, thereby preserving planning stability. Before semi-stable (>TOBT-40min), TOBT provides a sufficiently stable planning reference for initial sequencing. PEGT would, in this phase, increase recalculation and unnecessary resequencing without improving planning stability.

A shift occurs in the semi-stable planning phase of TOBT, from TOBT-40 min to TOBT-5 min. PEGT accuracy advantages emerge between TOBT-30 min and TOBT-5 min, which coincides with the increased operational impact of late TOBT deviations. Any TOBT update that is earlier or advancing beyond TSAT is a direct trigger for resequencing. In particular, earlier TOBT updates require recalculation of TSAT, TTOT, and priority positions. TOBT therefore converts a predicted readiness signal into a binding capacity claim, which destabilises the sequence by starting multiple resequencing of other flights. As a result, earlier updates based on PEGT propagate through DMAN as disruption events and could only be done with explicit certainty. This necessitates a reduced, one-sided update approach to limit the loss of slot capacity.

PEGT must be damped to preserve planning stability. This is achieved by applying a confidence threshold to the difference between PEGT and TOBT, so TOBT is updated only when PEGT indicates a sufficiently large and reliable delay. Small or uncertain deviations are ignored to avoid unnecessary resequencing. The threshold therefore balances improved accuracy against sequencing stability. Updates are strictly one-sided: only positive PEGT-TOBT differences are permitted, ensuring delay-only corrections.

In the final phase of Stable TSAT-5 min (AutoFreeze), TOBT updates become structurally incompatible. Any TOBT update within this window breaks the freeze protection on TTOT and ASAT, triggering the recalculation and sequencing of a flight. Therefore, PEGT cannot update TOBT during the stable phase, as this would contradict the stability objective of DMAN. This results in PEGT being operationally compatible with DMAN only in semi-stable planning phases.

## 5.2. Recommendations

Based on the combined quantitative and qualitative findings, the following recommendations define how DT-derived information can be integrated into existing LVNL operations in a controlled manner that improves accuracy and early detection of deviation. All recommendations should be implemented urgently in terms to benefit from DT.

### 5.2.1. Adoption of PEGT Filter on TOBT in DMAN

This recommendation directly follows from Findings 5.1.2, 5.1.4, and 5.1.5 which define the conditions under which PEGT should be operationally integrated without destabilising DMAN planning.

#### Phase 1: Before semi-stable planning (> TOBT-40 min)

- TOBT remains the sole readiness reference.
- PEGT is not used for operational updates.

#### Phase 2a: Semi-stable planning (TOBT-40 min to TOBT -30 min)

- TOBT remains the sole readiness reference.
- PEGT is not used for operational updates.

#### Phase 2b: Semi-stable Planning (TOBT-30 min to TOBT-5min)

PEGT should be used to update TOBT only under constrained conditions:

1. If PEGT is not available  
Then keep TOBT unchanged
2. If PEGT is available  
And  $(\text{PEGT}-\text{TOBT}) \geq X$  minutes (certainty threshold)  
Then update TOBT according to PEGT
3. If  $(\text{PEGT}-\text{TOBT}) < 0$   
Then reject the update unconditionally

#### Phase 3: Stable / AutoFreeze phase (<TOBT-5 min)

- Neglect all PEGT updates, and no further TOBT updates with PEGT are permitted

### 5.2.2. Pushback Connection Checkbox on EFS

This recommendation is grounded in Findings 5.1.1 and 5.1.3, which identified that DT-derived event confirmations are operationally acceptable only when used as contextual indicators rather than authoritative clearance signals.

Implement a pushback-connected indicator on the Electronic Flight Strip (EFS) for outbound planning and ground control, based on DT-detected pushback connection events.

The indicator shall be embedded directly within the EFS as a non-actionable visual confirmation (checkbox) to support existing outbound planning and ground control workflows. The indicator must not trigger automatic system actions.

### 5.2.3. Trigger Alert for Ground Control for Pushback Control

This recommendation follows from Findings 5.1.1, 5.1.3, and 5.1.4 which demonstrated that DT can reliably detect deviations between physical pushback execution and procedural clearance, provided that alerts are constrained to safety-net functionality and do not interfere with controller authority.

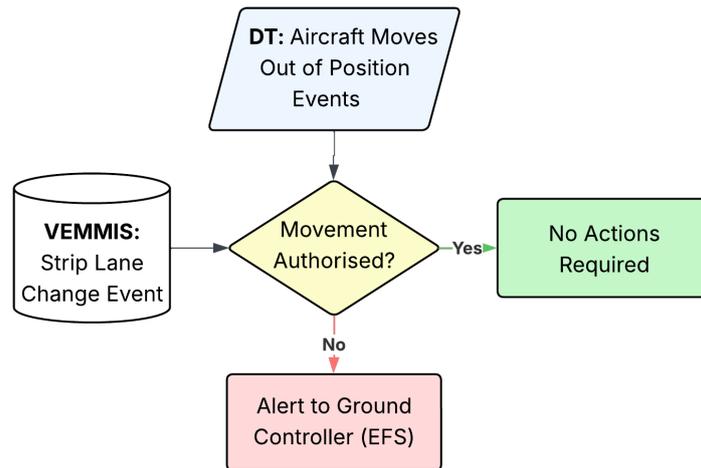


Figure 13. Pushback-without-clearance Safety Net Design

Implement a pushback-without-clearance safety net by integrating DT aircraft movement events with the VEMMIS database strip lane change event, as visualised in Figure 13. When DT detects aircraft movement out of position, and no corresponding pushback clearance is found, a trigger alert should be generated for Ground Control within EFS with the corresponding flight strip. This alert must be advisory only, serving to draw attention to a potential deviation. No control action may be automated, and the controller retains full authority to assess and resolve the situation.

### 5.2.4. Use of DT Data for Analytical Support in CMA and ORM

This recommendation is derived from Findings 5.1.3 and 5.1.4, which showed that DT’s spatially partial coverage and confidence-based timestamps limit its suitability for live operational control but make it well suited for post-operational analysis, performance monitoring, and safety assessment. It is recommended that CMA integrate DT turnaround event timestamps into its analytical databases to replace assumption-based interpretations of the ground process.

For ORM, DT data should be used for post-operational safety and risk analysis on pushback without clearance and deviating from clearance.

## 6. Conclusion

This thesis aimed to determine how turnaround information generated by Deep Turnaround (DT) can support LVNL at Amsterdam Airport Schiphol. Furthermore, it seeks to identify which departments and functions may benefit from this information. The study addressed the insufficient accuracy of turnaround timestamps used in outbound operations, which was shown to be structurally linked to reliance on manually maintained Target Off-Block Times (TOBT).

To achieve this aim, the following main research question was formulated and investigated:

*“Which departments and functions at LVNL can benefit from turnaround-generated timestamps produced by Deep Turnaround, associated with operational opportunities, and how can this information support traffic management decision-making at Amsterdam Airport Schiphol?”*

This main question was answered through desk research, document analysis, quantitative analysis of turnaround timestamps, and expert interviews, allowing DT to be assessed within the operational and organisational context.

DT can support multiple LVNL departments and functions if DT data are tailored to specific roles and operational contexts. For outbound planning, Predicted Estimated Ground Time (PEGT) provides greater accuracy than TOBT during the later stages of aircraft turnaround, with the difference most pronounced approximately 30 minutes before Actual Off-Block Time (AOBT). However, the findings demonstrate that increased predictive accuracy does not automatically result in improved operational outcomes. Due to the structure of Departure Manager (DMAN) systems and the sensitivity of departure sequencing to late-stage changes, unrestricted use of PEGT may cause operational instability and increase resequencing volatility. Consequently, PEGT should be applied only when a defined certainty threshold is met, allowing for a moderated update frequency that balances accuracy with planning stability. PEGT can only be used within a specific planning horizon relative to TOBT, exclusively for delay-related adjustments, and is excluded during AutoFreeze phases near off-block.

DT provides direct operational value by confirming physical readiness. Pushback connection detection provides outbound planners with a reliable means to verify actual departure readiness and supports ground control in confirming pushback clearance. Visualised on EFS, this signal improves shared situational awareness, particularly under reduced visibility or obstructed stand conditions. For Ground Control, DT events such as aircraft moving out of position objectively confirm the initiation of pushback activities. Integrating VEMMIS data with DT events enables trigger alerts when an aircraft begins moving without pushback clearance, providing narrowly scoped safety nets without automating control decisions.

In contrast, analytical and supporting functions within LVNL, specifically Capacity Management & Analysis and Operational Risk Management, benefit primarily from DT as a validated ground-truth data source. Consistently detected turnaround events improve post-operational analysis, delay attribution, and safety analysis by reducing reliance on manually determined milestones. In this role, DT focuses on enhancing learning, evaluation, and accountability rather than on real-time control.

In conclusion, this research shows that the problem of insufficient accuracy of turnaround-related timestamps in outbound operations can be mitigated by DT. DT improves timestamp accuracy by providing independently generated readiness information that is independent of manual TOBT updates. However, TOBT cannot be replaced, as it remains the structural input for A-CDM and DMAN sequencing and stability. The problem is therefore resolved in practice by using DT to condition TOBT: validating, supporting delay-related adjustments within defined planning horizons, and confirming physical pushback readiness. When applied under these constraints, DT improves decision-making without destabilising outbound operations. The remaining challenge is organisational, in defining when and how DT must be physically integrated into the LVNL environment and into the defined departments and functions.

## 7. Future Work

The analytical potential of Deep Turnaround (DT) data in supporting outbound planning at LVNL has been demonstrated. However, several areas warrant further investigation.

Systematic logging of DT outputs over time is necessary to ensure consistency in analysis and application. Research should identify a feasible, scalable database solution that provides consistent storage and integrates with DMAN, EFS, and VEMMIS. Further studies should evaluate integrating Predicted Estimated Ground Time (PEGT) into Departure Manager (DMAN) logic to maintain planning stability. Simulation-based testing is recommended to assess the impact of PEGT updates on sequencing behaviour and runway capacity. Additionally, defining a certainty threshold for PEGT use requires investigation to achieve an optimal balance between accuracy and operational stability.

Further research should establish appropriate thresholds for alert triggers based on DT, aiming to reduce false positives during unauthorized pushback events. Technical integration studies are advised to enable direct visualization of “Pushback Connected” indicators on EFS. Expanding the use of DT event logs in relation to the critical path could facilitate predictive modelling, performance reviews, and incident analysis. Additionally, include airport terminal data on gate-open or gate-close verification to provide a more robust indication of an outbound flight's readiness.

Future work should analyse pushback incident patterns across all stands at AAS to identify hotspots with the highest incident frequency. Collaboration with the Deep Turnaround Team is necessary to determine whether to expanding the region of interest is relevant. This approach would enable a more sophisticated analysis of pushback incidents, including directional deviations.

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## Appendix I: LVNL Department Descriptions

Department	Functionality
ATM Systems & Development (ASD)	Strategy, Integration & Architecture (SIA) develops and designs the overall architecture of the Air Traffic Management (ATM) system to ensure it is compliant, sustainable, and safe for both civil and military operations. The department integrates new systems and guarantees that all development processes meet legal, safety, and capacity requirements.
Business Support (BS)	The Business Support (BS) team is the operational core of the Performance & Development department, managing both routine administrative processes and major change programs. It ensures smooth coordination of the AIRAC cycle and provides structural and project management support across all departmental activities.
Corporate Finance & Contracting (CFC)	The CFC department ensures lawful, efficient, and sustainable purchasing and contract management to support LVNL's overall success. It operates transparently and collaboratively across the organization, emphasizing safety, quality, cost efficiency, and professional leadership in tendering processes.
Corporate Legal (CL)	The CL department safeguards the legal integrity of all LVNL activities by ensuring maximum legal certainty and balanced consideration of legal, financial, and operational interests. Its goal is to enable effective, consistent, and efficient decision-making across the organization.
Cyber (CYB)	The CYBER department manages LVNL's cybersecurity and safeguards its information systems and communication networks against deliberate disruptions. It operates through governance, tactical, and operational services, including cyber risk management, security operations (SOC/CSIRT), architecture, and advisory functions to ensure security-by-design and continuous protection across both IT and OT domains.
Facility Management (FM)	The FM department is responsible for maintaining and preserving LVNL's assets and infrastructure. It ensures that all operational, technical, and office facilities function reliably to support daily air traffic management activities.
Group1ATM (GATMO)	The 1ATM program aims to create a single integrated air traffic management organization for the lower Dutch airspace by transferring the 711 Squadron's tasks and staff to LVNL. It focuses on achieving civil compliance, regulatory approval, and technical integration with defence systems, targeting an initial integration date of October 1, 2026, pending final feasibility assessments.
Human Resources (HR)	The Human Resources department strengthens LVNL's success by attracting, supporting, and developing motivated and skilled employees. It focuses on creating a trustworthy and empowering

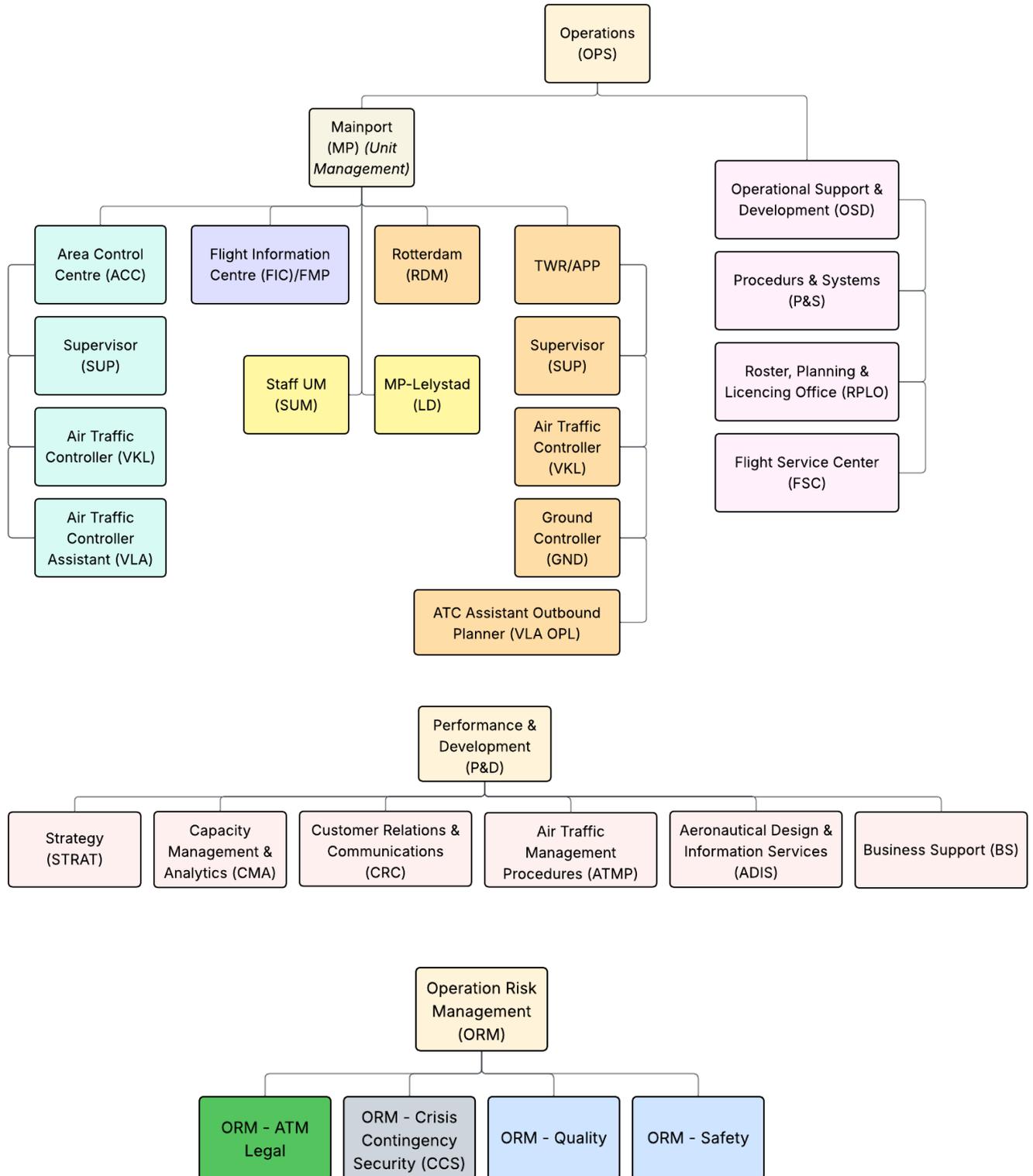
	work environment where both staff and leaders take responsibility for growth and continuous development.
iCAS Transition Office (iCASTO)	The iCASTO program manages the technical replacement of LVNL's current Amsterdam Advanced Air Traffic Control (AAA) system to meet future Single European Sky (SES) requirements. It oversees all software and system adaptations needed for implementing iCAS, in collaboration with the German air navigation service provider (DFS) and the Spanish supplier INDRA.
Infrastructure & Maintenance (IM)	Infrastructure & Maintenance (I&M) manages and develops all LVNL air traffic control systems and corporate IT infrastructure. The SWI-OT unit oversees all operational technology servers and workstations, transitioning from a project-based to a product-driven organization using standardized service platforms.
Operations (OPS)	The operation department ensures that safety remains LVNL's highest and non-negotiable priority, embedded throughout all organizational levels. It safeguards the continuity and quality of air traffic services while balancing stakeholder interests, supporting Schiphol's development, and maintaining transparent, efficient, and measurable operations.
Operational Risk Management (ORM)	Operational Risk Management (ORM) provides data-driven analysis to ensure optimal air traffic performance both now and in the future. Its work builds internal and external trust by offering factual, evidence-based insights into operational safety and efficiency.
Performance & Development (P&D)	The Performance & Development department shapes LVNL's strategic vision, policy, and innovation agenda while managing capacity, stakeholder relations, and communication. It ensures that ATM functions, procedures, and aeronautical information are safely, efficiently, and sustainably designed, maintained, and provided in compliance with regulations to support both air traffic controllers and aviators.
Strategy, Integration & Architecture (SIA)	The Strategy, Integration & Architecture (SIA) department designs and develops the architecture of the ATM system to ensure it is safe, sustainable, and compliant with all civil and military regulations. It integrates new systems and manages development processes to guarantee that the ATM machine meets all safety, capacity, and operational requirements.
Training Organisation (TO)	The Training Organisation (TO) manages all operational training within LVNL, from candidate recruitment and selection to the education and continuous development of licensed air traffic controllers. It also applies Human Factors expertise to optimize the interaction between people, machines, and procedures, ensuring safe and effective ATM system performance and future readiness.

## Appendix II: Turnaround Insights API Events

Event Group	Start Event	End Event
<i>Aircraft</i>	AircraftAppears	AircraftDisappears
<i>Aircraft Positioning</i>	AircraftStopsInPosition	AircraftMovesOutOfPosition
<i>Fuel Trucks</i>	FirstFuelTruckConnects	LastFuelTruckFinalizes
<i>Fuel Truck Presence</i>	FirstFuelTruckAppears	LastFuelTruckDisappears
<i>Pushback Connection</i>	TugIdleConnectedStarts	TugIdleConnectedEnds
<i>Tug Presence</i>	FirstTugAppears	LastTugDisappears
<i>Belt Loaders Presence</i>	FirstBeltLoaderAppears	LastBeltLoaderDisappears
<i>Belt Loader Operation (Unloading)</i>	BaxUnloadingStarts	BaxUnloadingStops
<i>Belt Loader Operation (Loading)</i>	BaxLoadingStarts	BaxLoadingStops
<i>High Loaders Presence</i>	FirstHighLoaderAppears	LastHighLoaderDisappears
<i>High Loader Operation (Cargo Doors)</i>	FirstCargoDoorOpens	LastCargoDoorCloses
<i>Cargo Freight</i>	CargoFreightLoads	CargoFreightUnloads
<i>Cargo Containers</i>	CargoContainerLoads	CargoContainerUnloads
<i>Oil Check Truck</i>	FirstOilCheckTruckAppears	LastOilCheckTruckDisappears
<i>Power Supply</i>	PowerConnects	PowerDisconnects
<i>Water/Toilet Service</i>	FirstWaterOrToiletTruckAppears	LastWaterOrToiletTruckDisappears
<i>Catering Truck Presence</i>	FirstCateringTruckAppears	LastCateringTruckDisappears
<i>Catering Lift Operation</i>	FirstCateringTruckCompletesAscent	LastCateringTruckCompletesDescent
<i>Passenger Bridge Operation</i>	FirstPaxBridgeConnects	LastPaxBridgeStopsInParkPosition
<i>Ambulift Presence</i>	FirstAmbuliftAppears	LastAmbuliftDisappears
<i>Ambulift Positioning</i>	FirstAmbuliftInPosition	LastAmbuliftOutOfPosition
<i>Front Passenger Stairs</i>	FrontPaxStairsConnects	FrontPaxStairsDisconnects
<i>Rear Passenger Stairs</i>	RearPaxStairsConnects	RearPaxStairsDisconnects
<i>Passenger Boarding</i>	PaxBoardStarts	PaxBoardStops
<i>Passenger Disembarking</i>	PaxDisembarkStarts	PaxDisembarkStops
<i>PIGS (Pre-Conditioned Air Hose)</i>	PigsConnected	PigsDisconnected
<i>Passenger Doors (Front Left)</i>	PaxDoorFirstFrontLeftOpen	PaxDoorFirstFrontLeftClosed
<i>Passenger Doors (Front Right)</i>	PaxDoorFirstFrontRightOpen	PaxDoorFirstFrontRightClosed
<i>Passenger Doors (Rear Left)</i>	PaxDoorFirstRearLeftOpen	PaxDoorFirstRearLeftClosed
<i>Passenger Doors (Rear Right)</i>	PaxDoorFirstRearRightOpen	PaxDoorFirstRearRightClosed
<i>Passenger Doors (Second Row Front Left)</i>	PaxDoorSecondFrontLeftOpen	PaxDoorSecondFrontLeftClosed
<i>Passenger Doors (Second Row Front Right)</i>	PaxDoorSecondFrontRightOpen	PaxDoorSecondFrontRightClosed
<i>Passenger Doors (Second Row Rear Left)</i>	PaxDoorSecondRearLeftOpen	PaxDoorSecondRearLeftClosed
<i>Passenger Doors (Second Row Rear Right)</i>	PaxDoorSecondRearRightOpen	PaxDoorSecondRearRightClosed
<i>Top Deck Doors (Front Left)</i>	PaxDoorTopFirstFrontLeftOpen	PaxDoorTopFirstFrontLeftClosed
<i>Top Deck Doors (Front Right)</i>	PaxDoorTopFirstFrontRightOpen	PaxDoorTopFirstFrontRightClosed

<i>Top Deck Doors (Rear Left)</i>	PaxDoorTopFirstRearLeftOpen	PaxDoorTopFirstRearLeftClosed
<i>Top Deck Doors (Rear Right)</i>	PaxDoorTopFirstRearRightOpen	PaxDoorTopFirstRearRightClosed
<i>Top Deck Second Row (Rear Left)</i>	PaxDoorTopSecondRearLeftOpen	PaxDoorTopSecondRearLeftClosed
<i>Top Deck Second Row (Rear Right)</i>	PaxDoorTopSecondRearRightOpen	PaxDoorTopSecondRearRightClosed

# Appendix III: OPS, P&D, ORM Organogram



## Appendix IV: Pushback Deviations from ATC Clearance Data

Total Amount of Deviations	Average/Month Deviations
707	15,7

Year/Month	Incidents of Pushback Deviations	Year/Month	Incidents of Pushback Deviations
2022-01	12	2023-01	10
2022-02	4	2023-02	13
2022-03	5	2023-03	27
2022-04	13	2023-04	22
2022-05	12	2023-05	28
2022-06	23	2023-06	24
2022-07	26	2023-07	28
2022-08	20	2023-08	36
2022-09	24	2023-09	39
2022-10	16	2023-10	25
2022-11	14	2023-11	19
2022-12	17	2023-12	21

Year/Month	Incidents of Pushback Deviations	Year/Month	Incidents of Pushback Deviations
2024-01	21	2025-01	5
2024-02	17	2025-02	7
2024-03	13	2025-03	11
2024-04	14	2025-04	8
2024-05	17	2025-05	10
2024-06	17	2025-06	4
2024-07	19	2025-07	7
2024-08	10	2025-08	9
2024-09	9	2025-09	8
2024-10	5	2025-10	
2024-11	9	2025-11	
2024-12	9	2025-12	

## Appendix V: Interview Transcript Data Scientist I

### **[Respondent]**

The AEGT is filled and there is a value. But AEGT is zero, or no value. And that can happen if a plane has entered. The turnaround is ongoing, but it has not yet gone out of order, so that value does not exist. It is only filled as the plane eventually goes out of order. Look, this one, the AEGT, is filled.

So that means that all activities are already done. If the plane is still at the apron and they are still completely busy, it is also zero here. So the AEGT has not yet been filled.

But the PEGT can be filled. If it is 30 minutes before TOBT, we have already made a prediction. So, there can be a value here. Upper and lower bounds, I'll skip that for a moment. Those are just kind of uncertainty margins. So predict the moment.

Then we have a number of things here. Is there a tug connected? A pushback truck? When is it connected? It says here. And this one is also initially at zero. Until it is filled. Until we see that it is connected.

### **[Interviewer]**

Fair enough. So in fact, this message contains all possible timestamps that exist.

### **[Respondent]**

Yes. And gradually, as things change on the apron, there are updates of this message.

### **[Interviewer – Researcher]**

And actually, what happens with that CDM API is the same message is sent several times. It may be sent again, but then actually further filled in. For those milestones.

### **[Respondent]**

It can be filled in and sometimes also updates. For example, the PEGT is written over several times. Yes.

### **[Interviewer]**

If we look back at the API and how we can get that back within the ATC organisation. In a global sense, can you explain what the best method is to get an API connection? Or maybe another form of communication?

### **[Respondent]**

We have an API. You can request it via the developer portal.

So what you have to do is set up a server or something in the cloud. It's probably preferred to do it in the cloud. Because then you have less to manage the hardware yourself. But where you run the script that maintains a permanent connection with the API. And from there you feed it into a database. And that can be a simple database, a Postgres-like database.

It can of course also be simpler. If you are more exploratory, you can store something in Python pickles, parquet files, I don't know what. That is of course also possible. But if you want to tackle something more robust, you have to put it in a database.

**[Interviewer]**

Do you also believe in that? That you think that's possible in the end?

**[Respondent]**

I would look at what you do with other data sources. To reinvent the wheel. Maybe there is a little more data, but it is not that much data. (...) I think something like 20 megabytes per day or something. (...) But not gigabytes per day.

**[Interviewer]**

One of the pain points is that not every stand has a camera. So then you're going to get the situation: some stands do have that data and the others don't. And how do you deal with that?

**[Respondent]**

Yes, that's where a lot of work is being done. Except for one area, which is a bit more difficult. Because of the buildings and things like that. But apart from that, almost all of the airport is being explored.

**[Respondent]**

I see the difficulty mainly in... after you have that data, to properly connect those use cases. And also to actually adjust the processes. (...) To actually let the new insight end up in different behaviour. (...) That is the most important.

**[Interviewer]**

I think the starting point is a clear plan.

**[Respondent]**

Yes, how the tool is positioned in daily practice. (...) We have said: okay, a quarter for TOBT, check the PEGT values. If there is a delay, then you go after it. Is this correct? Yes, update your TOBT. Is it not correct? Ignore it and move on with your daily work. (...) But even then we find out that it is still difficult.

**[Interviewer]**

The ultimate value case is: reduce runway expiry. Reduce it a bit with the PEGT. What happens if a flight does not meet its TOBT, and it tells it too late, then there is a gap in the runway planning. (...) For that flight it is a problem, because it immediately gets 15 minutes (...) if you miss your TOBT — or your TSAT I have to say.

**[Respondent]**

But that runway slot is not used. If that happens once, no problem. But if it happens five times in a row, that means five holes have been made in the planning. (...) Then you have that whole period to the end of your peak, then you have ten minutes of delay. So that accumulates. (...) It's not that PEGT is terribly accurate, but TOBT is very inaccurate. And PEGT is nothing more than a tool for the ground handler to point out to update the TOBT. So I think that's very useful.

**[Respondent]**

Maybe there is a way on which the ATC organisation proactively is going to contact the ground handler to ask if the TOBT is still correct. (...) Someone gets a certain role for that: TOBT validation.

But I can imagine that if the ATC organisation is going to overrule TOBT with the help of PEGT, that it might lead to discussions and hassle again.

## Appendix VI: Interview Transcript Data Scientist II

### **[Respondent]**

If you really only have the nosewheel, then we're not going to make a trigger right away. The aircraft has to be more visible so that there is enough confidence from the algorithm to make that trigger in one go.

So you have to remember that you have 5 to 10 seconds of inaccuracy in timing. The event itself is very accurate. If the aircraft is there, then it is close to 100% accurate. But the timing is a little less accurate.

### **[Interviewer]**

So that latency comes from the snapshot interval?

### **[Respondent]**

Yes. We take a snapshot every five seconds. If the aircraft just starts moving between two snapshots, you might miss it in the first one and then capture it in the next.

So if it coincidentally aligns badly, you see it five seconds later. But then you definitely have it.

### **[Respondent]**

As soon as the camera indicates movement of the aircraft, and it is large enough, the algorithm will immediately say that the aircraft is no longer in position.

But it depends on which frame it falls on. So the accuracy is again around five to ten seconds.

### **[Interviewer]**

Is that something that could lead to false triggers? For example, very small movements during pushback preparation?

### **[Respondent]**

We use probability thresholds. If the model is very certain that the aircraft is in position, and then suddenly becomes a bit uncertain, we do not issue an event.

Only if it goes from very certain to very certain in the opposite direction do we issue the event immediately.

If the model is uncertain, we wait for more frames.

### **[Respondent]**

So you can have a situation where the model briefly oscillates, but that does not immediately lead to an operational trigger. That logic is there to prevent false alerts.

### **[Interviewer]**

Do you monitor how often that latency or uncertainty actually occurs in live operations?

### **[Respondent]**

We do not monitor that on live data. We measure it on validation data.

If it would occur very frequently, it would be a concern. If it happens very rarely, then it can be considered negligible. That distinction is important.

**[Respondent]**

The key question is not whether the system is perfect, but whether it gives ground control the possibility to intervene in situations that are not intended.

The decision should always remain with the ground controller, not with the algorithm.

**[Interviewer]**

So the idea is not automated intervention, but decision support?

**[Respondent]**

Exactly. The idea is to provide an alert so that ground control can intervene if necessary.

That intervention can be direct, for example contacting the pushback driver.

But that also means you have to be careful: if you give faulty information, you can disrupt operations. That is something you want to avoid at all costs.

**[Respondent]**

So the integration is not only technical. You also have to think about how this fits into procedures, responsibilities, and safety roles.

After live use, the same data can also be used for post-operational analysis by other departments.

**[Respondent]**

The essence is that the data creates possibilities, but whether and how those possibilities are used depends on organisational choices.

You need a clear use case and a clear role definition before you put this into operations.

## Appendix VII: Interview Transcript Data Owner

### **[Respondent]**

Within LVNL, Deep Turnaround is still relatively unknown. I spoke to someone recently who thought turnaround data was only about open or closed hatches. In reality, it goes much further than that.

For Operational Risk Management, the relevant moment starts when the aircraft begins to move. The turnaround itself is not the focus; the moment of rolling is.

### **[Interviewer]**

So the operational relevance begins at aircraft movement, not earlier milestones?

### **[Respondent]**

Yes. Pushback readiness is derived from AEGT. That indicates the pushback truck is connected. It does not come from the cockpit.

That also means we do not know whether the cabin or cockpit is fully ready. Technically, the aircraft appears ready, but operationally that is not always the case.

### **[Interviewer]**

So clearance status is not part of that signal?

### **[Respondent]**

No, clearances are not included. That is an important limitation.

If you could link pushback readiness with clearance information, that would be very valuable, especially for safety analysis. But that linkage does not exist today.

### **[Respondent]**

At outbound planning, the discussion is mainly about PEGT versus TOBT. PEGT becomes more accurate as time progresses, but it updates much more frequently than TOBT. If PEGT updates too often, we see very strange outputs in DMAN. DMAN is not accuracy-driven first; it is stability-driven.

### **[Interviewer]**

So frequent PEGT updates conflict with DMAN logic?

### **[Respondent]**

Yes. TOBT is updated maybe twice on average. PEGT can update around five times.

DMAN works with a rolling window and a freeze horizon. Once you get close to that horizon, inputs should remain stable. PEGT updates inside that window can destabilise sequencing.

### **[Respondent]**

Outbound planners have clearly stated that they do not want multiple timestamps.

They want one leading time, binary logic: ready or not ready.

Showing both TOBT and PEGT at the same time was explicitly rejected.

### **[Interviewer]**

So PEGT should not directly replace TOBT in DMAN?

**[Respondent]**

Not as-is. PEGT needs filtering or damping.

You could let PEGT “walk” forward and only ingest updates that pass a stability threshold.

Oscillations of a minute forward or backward could be ignored.

That kind of gating would be necessary before using PEGT in DMAN.

**[Respondent]**

In the short term, the real value of PEGT is not in DMAN.

It is in situational awareness, early warning of TOBT non-adherence, and simple indications in the tower.

**[Respondent]**

EFS is the key operational interface. Controllers work from electronic flight strips.

What they want is something simple: a checkbox, a green or red indicator.

They currently rely on looking outside to judge readiness. That costs time and adds workload.

**[Interviewer]**

Is full DT coverage required for this to work?

**[Respondent]**

No. One hundred percent coverage is unrealistic and unnecessary.

Near-complete coverage on passenger stands is sufficient.

Cargo and general aviation can be treated differently because the volumes are much lower.

You should start where predictability gains are largest and avoid an all-or-nothing approach.

**[Respondent]**

The main constraint is not technical. It is organisational.

Data only creates value if procedures, roles, and responsibilities are aligned.

Without that, even good data will not change operational behaviour.

## Appendix VIII: Interview Transcript Product Director

### **[Respondent]**

We see that a lot of users look at the data, but they don't really know what to do with it yet. They log in to the dashboard, but the question remains: how does this data actually change daily operations?

That uncertainty is one of the main barriers to adoption.

### **[Respondent]**

Before DT data can be used operationally, trust has to be built.

Users want to be sure the data is reliable, validated, and consistent before they act on it.

Without that trust, the data remains observational rather than operational.

### **[Interviewer]**

Does that affect how PEGT is currently perceived?

### **[Respondent]**

Yes. PEGT updates very frequently as the turnaround progresses.

From a product perspective that is logical, but from an ATM perspective it creates instability.

Operational systems prioritise predictability over precision.

### **[Respondent]**

Controllers and planners consistently indicate that they want one dominant time value.

They do not want to interpret multiple timestamps in parallel.

If you show both TOBT and PEGT, you increase cognitive load and operational workload.

### **[Respondent]**

Frequent updates trigger resequencing.

Resequencing increases workload, especially during peak periods.

That is why stability is often preferred over marginal gains in accuracy.

### **[Interviewer]**

So PEGT cannot directly replace TOBT?

### **[Respondent]**

Not without filtering.

If PEGT is used, it needs damping or gating logic so that only meaningful changes are passed on.

Otherwise, planning systems react too often and lose stability.

### **[Respondent]**

At the moment, the highest operational value is in simple detections.

For example, pushback connected or pushback visible.

These signals are easy to interpret and immediately actionable.

### **[Respondent]**

Not all stands have camera coverage yet.

That creates a mixed operational picture where some aircraft have DT data and others do not.

This makes full operational integration difficult until coverage is nearly complete.

**[Respondent]**

For passenger operations, coverage is being prioritised because the impact is highest there. Full benefits only really emerge once coverage reaches a critical mass.

**[Interviewer]**

Does incomplete coverage affect acceptance?

**[Respondent]**

Yes. Users are hesitant to rely on a system that only works part of the time. They prefer consistency, even if that consistency is less accurate.

**[Respondent]**

DT data is increasingly used as a single source of truth in discussions about performance. It is used to resolve disputes about delays and on-time performance.

**[Respondent]**

This also creates resistance.

Ground handlers sometimes perceive DT as a monitoring or enforcement tool.

There is fear that the data will be used against them rather than to support operations.

**[Respondent]**

Under new governance models, the use of DT data will become mandatory.

This shifts DT from a voluntary support tool to a required operational input.

That transition requires careful change management.

**[Respondent]**

Reluctance to update TOBT is a known issue.

Actors fear that updating times will cause cascading delays across the network.

As a result, inaccurate times are sometimes left unchanged.

**[Respondent]**

The long-term value of DT is improved network predictability.

Earlier insight into ground delays allows downstream stakeholders to adjust earlier.

But many of these benefits depend on full rollout and organisational alignment.

## Appendix IX: Interview Transcript Outbound Planning

**[Respondent]**

Predictability is the big one. And if I have to be specific: it's the TOBT, and especially how it gets updated.

When it's not updated on time or it's just optimistic we're basically sequencing on an old picture.

Then you're mostly reacting, which creates unnecessary workload.

**[Interviewer]**

So you're building a sequence, but the inputs keep moving.

**[Respondent]**

Exactly. You're trying to keep rhythm towards the runway, and then suddenly an aircraft isn't actually ready.

It happens more often than people think. You can solve it, but it disrupts the sequence.

**[Interviewer]**

Is that mainly a system issue or human behaviour?

**[Respondent]**

Both, but the human side is big.

People hesitate to push the TOBT later. There's a fear of losing a slot or being judged, so they leave it and hope it works out.

For us, early honesty is what matters. I'd rather have a realistic time early than a nice time that turns out wrong.

**[Interviewer]**

Where do you see the biggest potential of DT-derived data?

**[Respondent]**

Straight into TOBT reliability.

If delays are visible earlier and updated without hesitation, I can anticipate instead of react.

If I know ten minutes earlier that a flight will be late, I can already adjust the sequence.

**[Respondent]**

When TOBT is wrong, the impact is high—especially during outbound peaks.

You expect a steady flow, and then you get gaps because an aircraft that should depart simply isn't ready.

That disrupts runway rhythm and reduces capacity.

**[Interviewer]**

Would showing early warnings help?

**[Respondent]**

Only if it improves the accuracy of the time I already use.

If it's just another alert or extra symbol, it becomes noise.  
I don't care about more timestamps. I care about a plan that becomes more trustworthy.

**[Interviewer]**

What about showing both TOBT and PEGT?

**[Respondent]**

Two times on the strip is asking for confusion.  
We need one leading time we can trust.  
If the system knows better, it should just show better quietly.

**[Respondent]**

Pushback readiness is very important.  
"Ready" doesn't always mean ready. A pilot can call, but the tug isn't there.  
If clearance is given and nothing moves for a few minutes, that's wasted space in the sequence and it delays others.  
A clear signal that movement is actually possible would prevent that.

**[Interviewer]**

So minimal interface change?

**[Respondent]**

Yes. Simple. No extra screens.  
Just a reliable time and a clear indication that the aircraft can move.  
Everything else should run in the background.

**[Respondent]**

If everyone looks at the same objective progress data, it becomes harder to keep pretending a time is realistic.  
That could reduce hesitation but in the end, what matters is that the input is trustworthy.

## Appendix X: Interview Transcript ORM

**[Respondent]**

From our perspective, the relevance really starts when the aircraft begins to roll. As long as it is standing still, there is nothing operationally in hand for us. The moment of movement is where safety becomes relevant.

**[Interviewer]**

So the process does not start at preparation, but at actual movement?

**[Respondent]**

Yes. Route preparation or readiness before that cannot be seen from the outside. What matters for us is the rolling moment. That is when the aircraft enters our safety domain.

**[Respondent]**

Our main task is operational safety. That includes traffic on the ground, aircraft movement, and safe transitions between controlled phases. Human factors, miscommunication, and inconsistencies are a major part of the risk picture.

**[Interviewer]**

Do you see value in camera-based information for that phase?

**[Respondent]**

Eh yes. Especially when traffic is close to each other during pushback. Visual confirmation is very valuable. Radar data alone has uncertainty, for example due to transponder position or merging of radar sources. Distance accuracy is not always reliable at short range.

**[Respondent]**

Camera images could help verify situations where aircraft move without finishing a pushback, or where pushback is executed in the wrong direction. Those are safety-relevant events for us.

**[Interviewer]**

So the interest is not efficiency, but risk detection?

**[Respondent]**

Exactly. What is interesting is movement without clearance, incomplete pushback, or unexpected motion. That is where safety risks emerge.

**[Respondent]**

At the moment, most of our analysis is post-operational.  
We analyse incidents after they occur, in terms of apron incursions during the pushback phase.

**[Interviewer]**

Do you have an indication of how often these events occur or data?

**[Respondent]**

Yes. Looking at our incident records, pushback-phase events occur roughly ten times per month.

That includes wrong-direction pushbacks, unfinished pushbacks, and other deviations.

**[Respondent]**

In the future, this kind of data could also act as a safety net.

Not to control operations, but to provide alerts when something deviates from what is expected.

Comparable to other safety nets we already have for runway or go-around protection.

**[Interviewer]**

So not an automated intervention?

**[Respondent]**

No.

It would be an alerting mechanism.

The decision always remains with the controller.

**[Respondent]**

Data only becomes valuable if it supports safe decision-making.

It should never replace operational judgement, but it can help highlight abnormal situations.