

Quantile-based Machine Learning Predictions of Luggage Arrival Time at Airport Reclaim Areas

Authors

EUROCONTROL Innovation Hub: Paolino De Falco, Pablo Gasco, Ivan Baruta

Munich Airport: Hanna Wulkow

paolino.de-falco@eurocontrol.int

- Overview of the PRELUDE project
- Machine learning modelling approach
- Model results
- Comparison with current operational model at Munich airports
- Next steps & potential developments

PRELUDE: one of the recent EATIN initiatives



Initiatives

- PRELUDE (PREdiction of LUggage DELivery time) project
- EATIN (EUROCONTROL Air Transport Innovation Network) initiative, complementary to SESAR
 - Focuses on short term innovation linked to operational challenges
 - Operational stakeholders submit new ideas which go through a selection process
 - Objective: ensure that stakeholders can benefit from solutions once they are developed and validated

Context

- Usually, passengers wait for their luggage at the claiming area without knowing when it will be delivered
- Can we improve passenger experience by showing prediction of luggage delivery time?
- Can we improve belt allocation process and passenger management in the luggage claim area?



Partners



Kick-off / Start of scoping phase

End of scoping phase / Data sharing

End of model development

Model handover

Sept 2024

April 2025

October 2025

- Model development: historical timestamps of first and last bags arrival time on the belt
- Timestamps are released manually by ground handlers
- First bag timestamps are not always “fully realistic”
- Predicting the arrival time of the first bag might be suboptimal for passenger experience
- Need of systematic overestimation of luggage arrival time
- **Quantile machine learning** allows to tune the level of overestimation



Sorting luggage area at Munich Airport, November 2024

Quantile regression model



- *Pinball* loss function enables the estimation of conditional quantiles of the target variable
- Train a set of ML models according to specific quantile values
- Example: **70th quantile model**
 - A prediction of 10:00am means there is **70% probability** that a **single event** will occur at 10:00am or earlier
 - Overall, **~70% of predictions** will be overestimated

- Example: comparison across quantiles (target value: 10:00am)

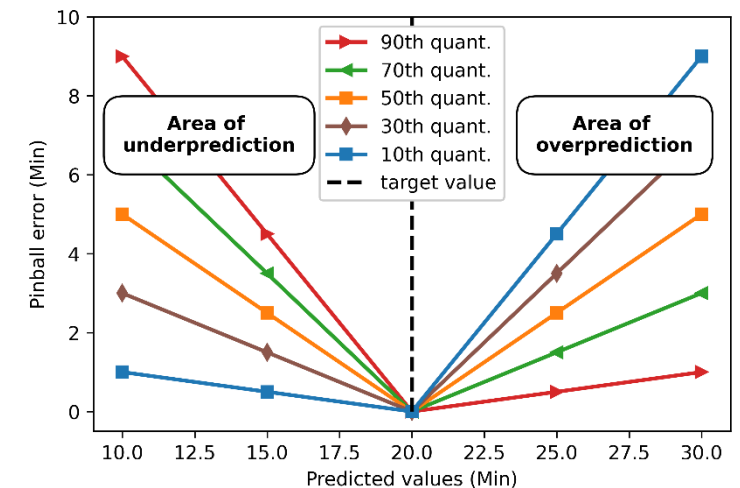
50th quantile model: 10:00am

60th quantile model: 10:02am

70th quantile model: 10:05am

- Higher quantile values systematically overestimate the model's target

- 1st bag timestamp issue
- Positively influence passenger perception when bags arrive earlier than displayed predicted time



Pinball loss function for a single observation

Two sets of models



CatBoost algorithm

Input features (data from 2024 & 2025)	Description	Type
hour, weekDay, month	Computed at AIBT	Cat
numBags	Number normal bags	Num
numSpecialBags	Number special bags	Num
numPax	Number of passengers	Num
aircraftType	IATA Code	Cat
aircraftOperator	IATA Code	Cat
groundHandler	Ground handler identifier	Cat
adep	Dep. airport (IATA code)	Cat
standPosition	Stand position	Cat
schengen	Referred to dep. airport	Cat (Y/N)
stand	Stand identifier	Cat
delay	AIBT - SIBT	Num

Model targets

Model 1: First bag arrival time – Actual In Block Time (AIBT) → “1st bag model”

Model 2: Last bag arrival time – First bag arrival time → “Loading model”



Prediction of last bag arrival time

Results & comparison with operational model



Quantile	Mean Absolute Error - MAE (min)		Mean Error (min)	
	1 st bag model	Loading model	1 st bag model	Loading model
50	6.1	4.0	-0.1	-1.7
70	7.6	4.6	4.1	0.6
90	11.7	8.0	10.1	6.1

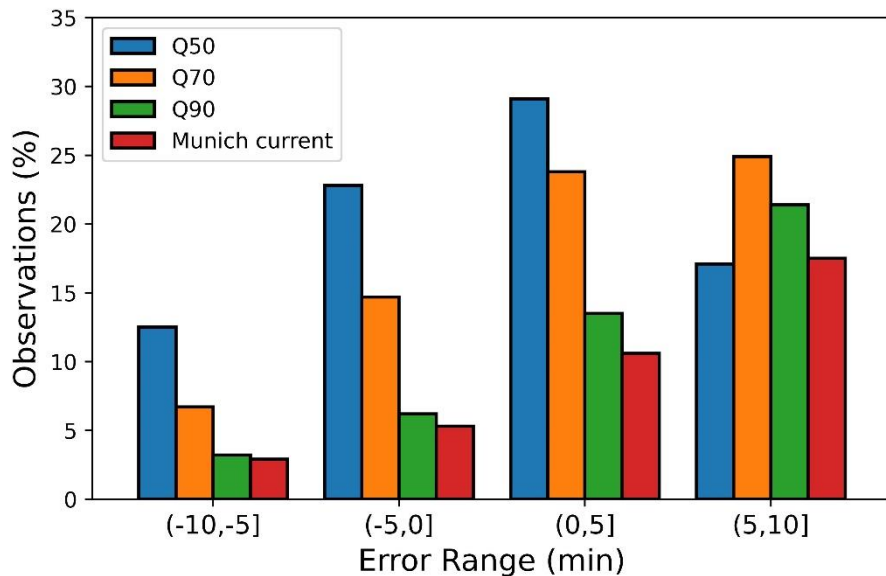
$$MAE = \frac{1}{n} \sum_{i=1}^N |\hat{y}_i - y_i|$$

$$ME = \frac{1}{n} \sum_{i=1}^N \hat{y}_i - y_i$$

$\hat{y}_i$ = predicted value

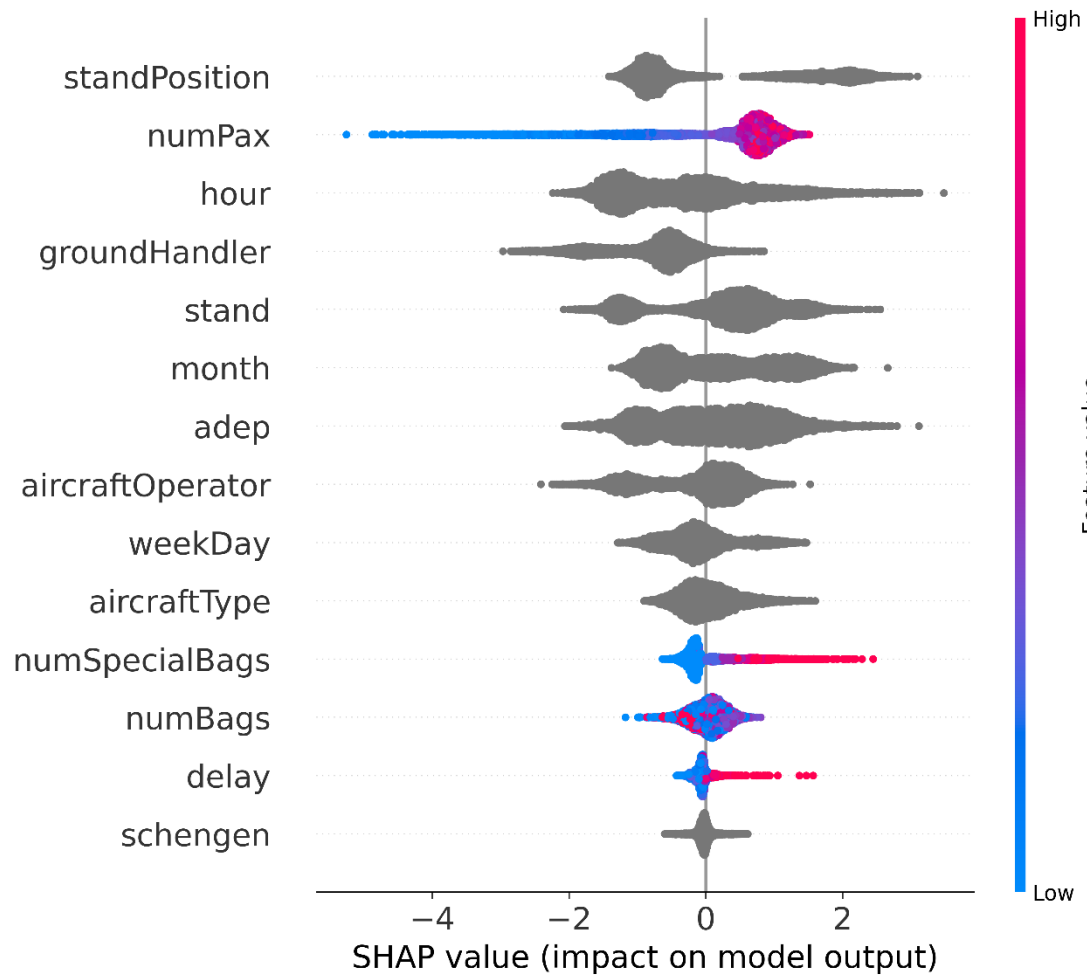
y_i = target value

error = predicted - target

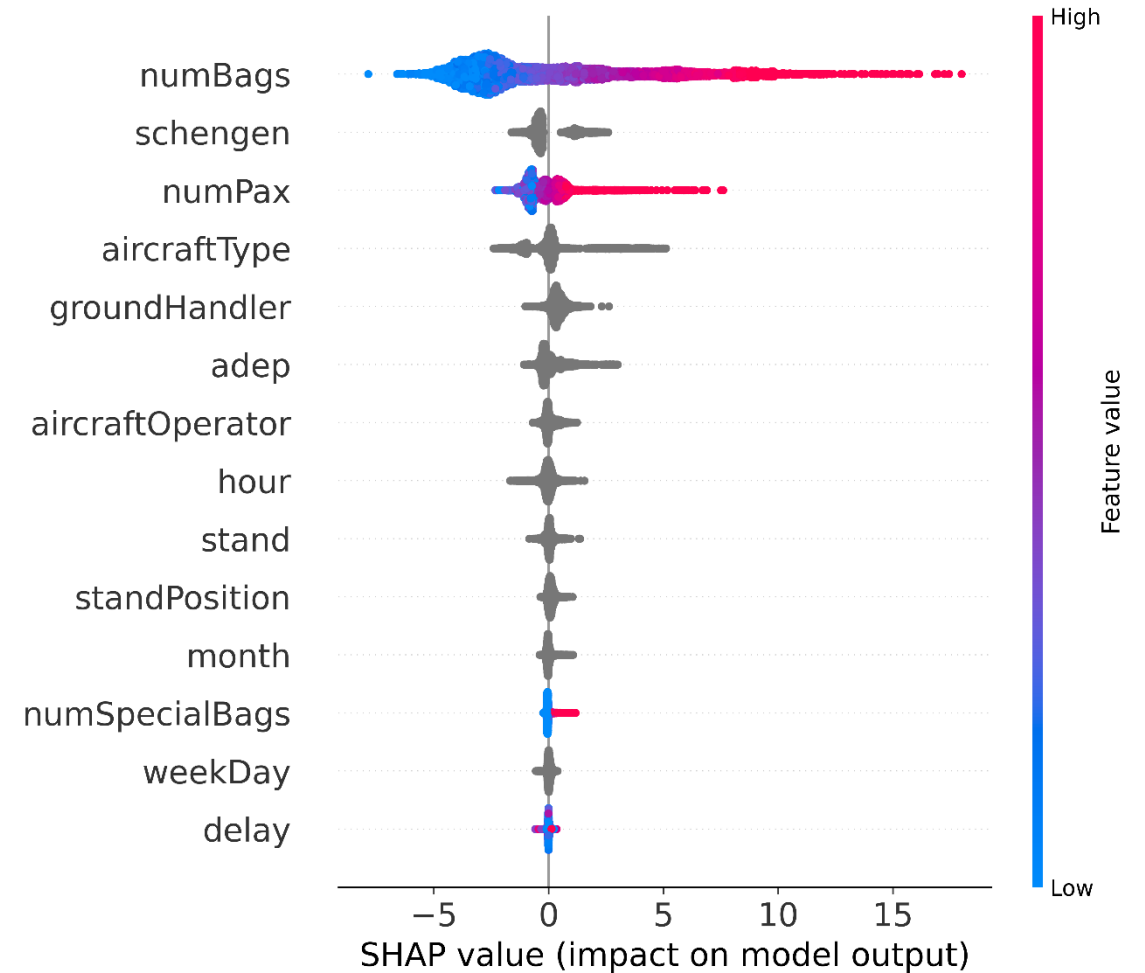


Observations within +/- 10 minute error (min)	
Q50	81.5%
Q70	70.1%
Q90	44.4%
Munich current	36.2%

Features importance: SHAP analysis



First bag model



Loading model

Potential benefits



Passenger satisfaction

- Keep friends or family informed
- Notify taxi drivers
- Use waiting time productively for personal activities
- Plan next travel more effectively (bus, taxi, train)

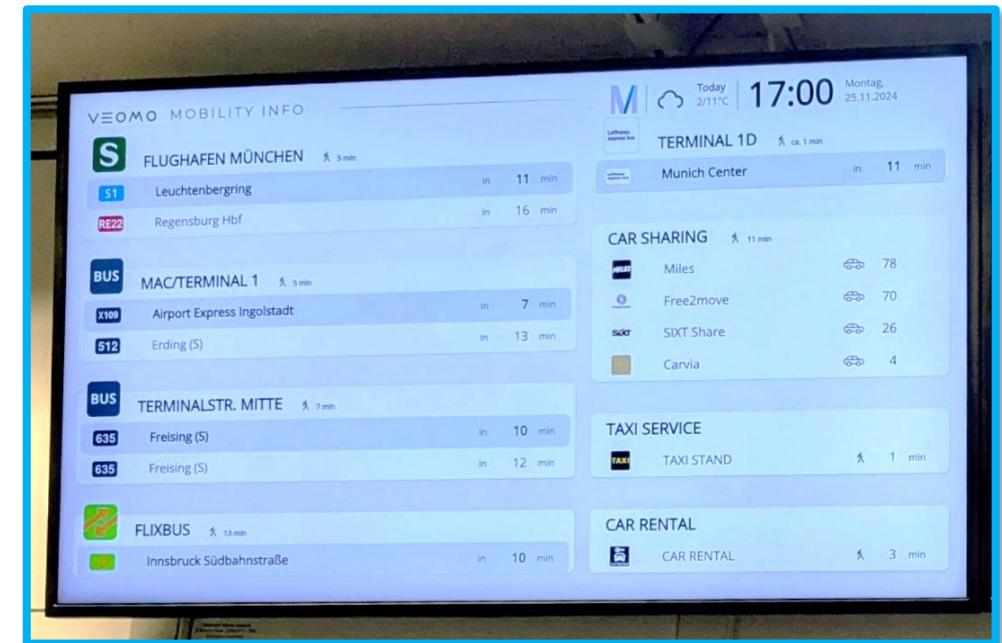
Airports

- Improve service to passengers
- Turn waiting time into shopping time
- Enhance passenger management in the reclaim area

Multimodal or intermodal transport operators

- Optimise connections (tactical management of connecting passengers)

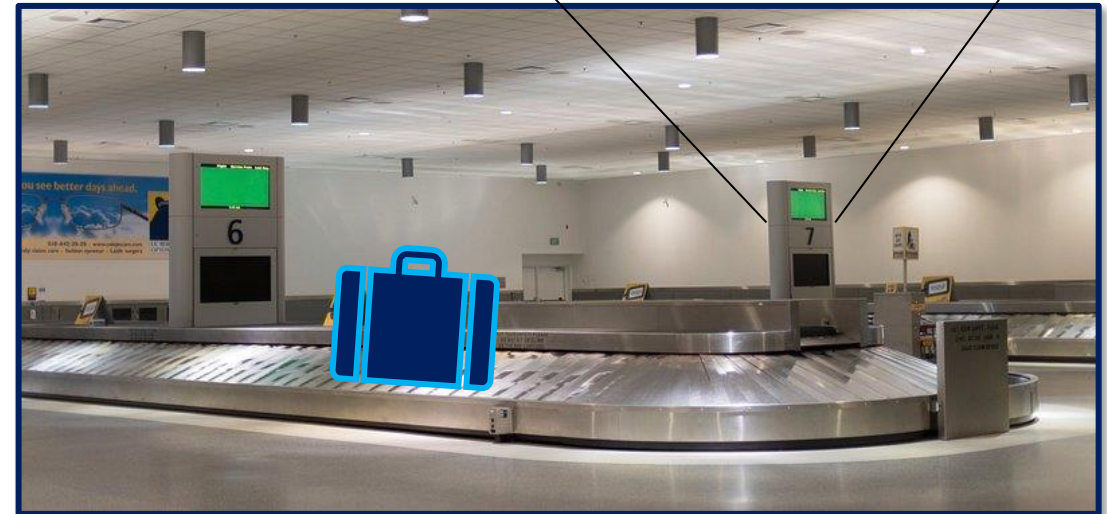
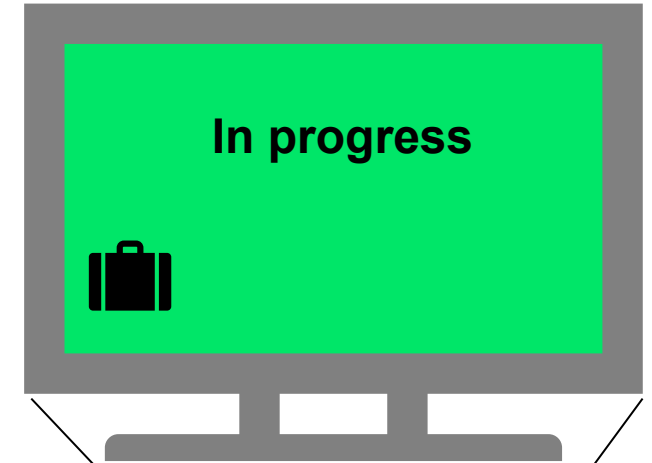
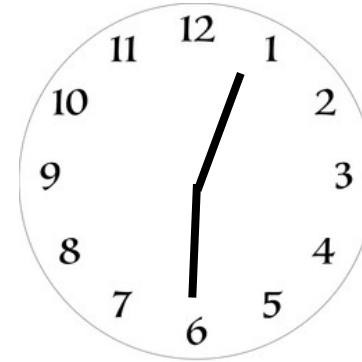
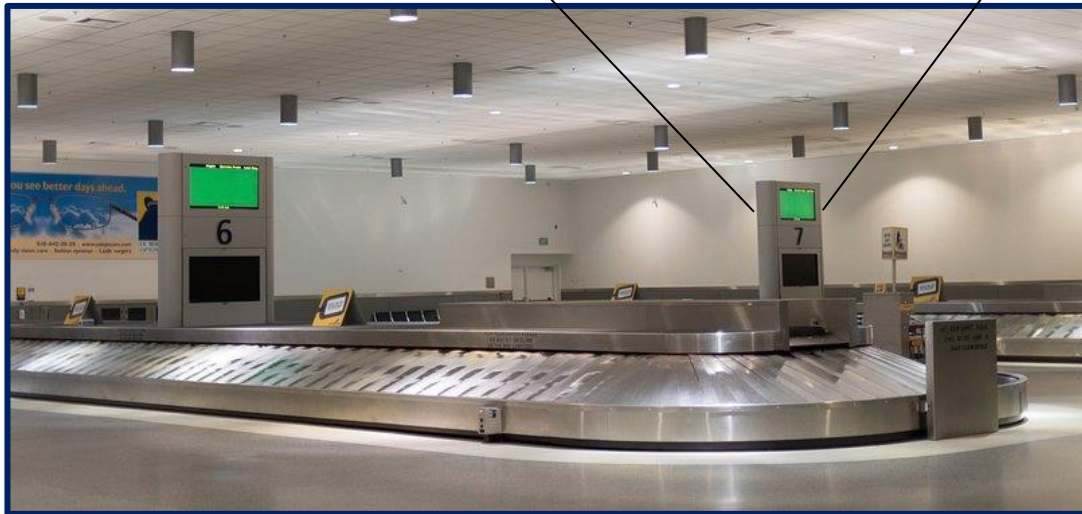
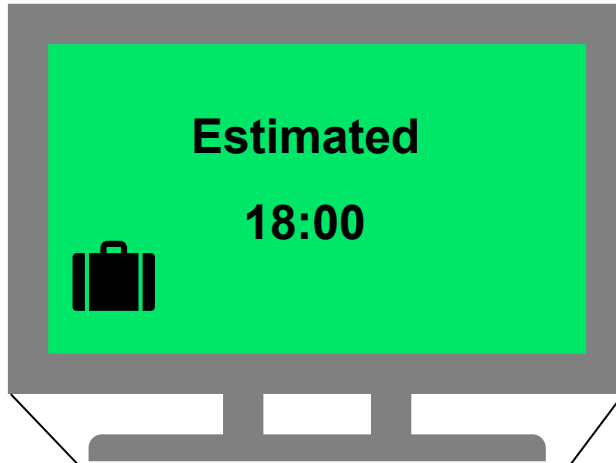
Luggage reclaim area at Munich Airport, November 2024



Displaying model output to passengers



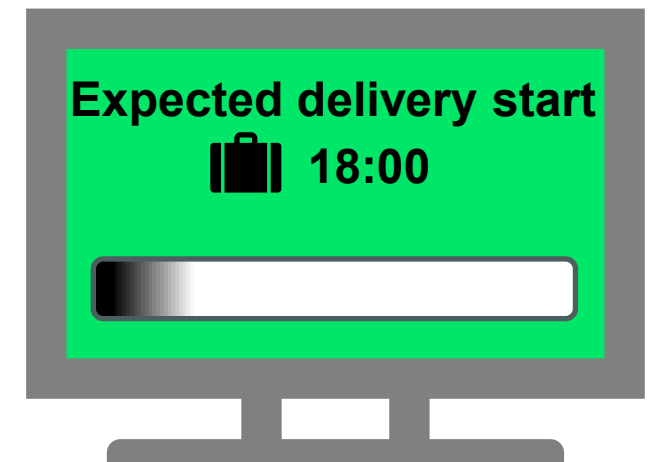
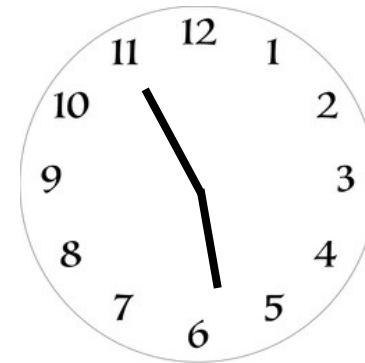
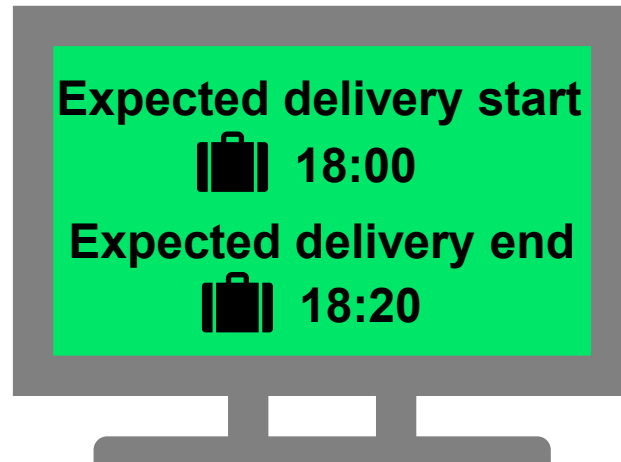
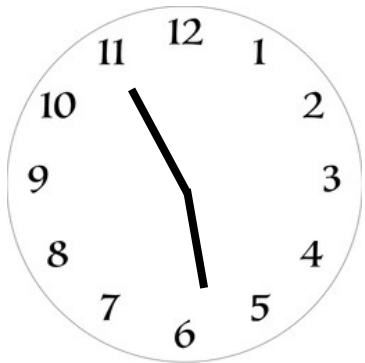
Current approach at Munich Airport



Displaying model output to passengers



Other potential approaches

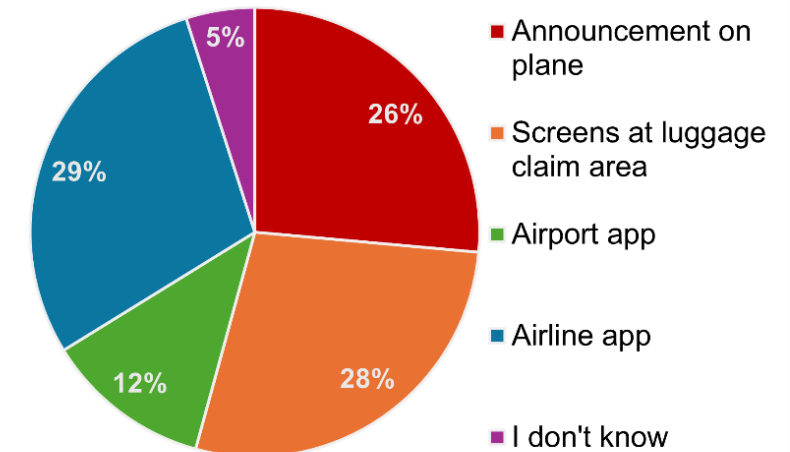


- Future implementation is still under discussion
- Difficult to forecast whether information on last bag arrival time will positively impact passengers' satisfaction
- Possibility to conduct live trials combined with passengers' survey (A/B testing)

Further developments



- Predictions are available upon arrival of inbound flight (AIBT)
- Potential to extend prediction horizon using an estimation of In-Block Time
- Possible focus on belt allocation process
 - Current practice: fixed luggage delivery duration
- Solution has been handed over to Munich Airport (models, code & documentation)
- Validation: live trial with passenger surveys
- Within PRELUDE, similar activities are taking place with SEA Milan, Dusseldorf & Aeroporti di Roma (ADR)
- You might soon see PRELUDE predictions in action! 😊



When and how passengers prefer to visualise the predictions