BOOST

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BAGGAGE OPERATIONS

AUTOMATED LOADING

A roadmap from manual dependence to intelligent, load-unit based operations for future success in baggage handling.

AVINOR | brussels airport the heart of Europe | Heathrow | Incheon Airport | AMS Schiphol

June 2026

01

THE CASE FOR CHANGE

What is the core problem of the baggage handling process, and why is innovation needed?

LOADING PARADOX: where baggage operation fails to move forward

Loading carries the highest physical burden but remains the least automated step. For many airports, this combination is no longer suitable.

DRIVERS FOR CHANGE

720 bags lifted per shift
10 TON baggage lifted per shift

The highest cause of physical burden and worker injury across BOOST airports

0- 10 % of loading is currently automated

The least automated stage in the entire baggage chain – complexity of baggage and container shapes limits automation

av. 10 per 1000 mishandled bags

Loading one of the largest contributing causes

THE URGENCY FOR CHANGE

The operation is outgrowing manual loading

Baggage operations are becoming more dynamic and less predictable

- *Flight volumes are rising with sharper peak loads*
- *Last-minute bags more frequent and harder to absorb*
- *Execution variability between teams and shifts is increasing*

At the same time:

- *The workforce cannot carry the burden. Shortages are structural, not temporary and staffing alone is not a solution.*
- *The physical strain for workers that load baggage is no longer acceptable at scale! .*

THE CASE FOR CHANGE

THE FUTURE OPERATION DEMANDS A NEW LOADING MODEL

Four key shifts are defining the future operating model of baggage handling. This requires more than optimization alone. Automated loading delivers the capability, while system orchestration enables it to scale.

MAKES AUTOMATION POSSIBLE

1 From flight-based to load-unit oriented processing

Bags are grouped early into pre-defined containers – Load Unit Devices (ULDs) or Airport Load Devices (ALDs) - decoupled from individual flight schedules. This enables earlier processing, greater buffer flexibility, fewer mishandled bags, and a consistent predictable unit that automation can rely on.

→ **Predictability is what makes automation possible**

2 Automation takes on the heavy lifting

Robotics and automated load cells perform the act of loading bags into load units. Flexible load cells will create smart environments where people and machines work side by side - consistently, at scale and with minimal physical burden. People's role shift from lifting baggage to supervising automation

→ **Automation replaces variability with performance**

MAKES IT SCALABLE

3 Evolving role of baggage handlers and operators

Handlers shift to new skilled roles. For example supervision, exception management and system overview

→ **Workforce evolution enables the system**

4 End-to-end orchestration across the journey

Digital control coordinates data, systems, logistics, bags and load units across the entire process

→ **From isolated steps to one coordinated system**

02

THE AMBITION

What is automated loading, and what do we want to achieve in the baggage handling process?

THE AMBITION

AUTOMATED LOADING AS OPERATIONAL CAPABILITY

DEFINITION

"Automated Loading uses robots to load bags into load units in a controlled and consistent way. People support the robotic cells by supervising operational productivity and handling exceptions with stable, load-unit based flows. The system can automate up to 95% of in-gauge baggage. It reduces the need for manual handling and delivers consistent performance at scale.

It gives airports, airlines, and handlers more control over the loading process as it's independent of individual experience or physical effort. At the same time, it enables staff to focus on safer, more meaningful work."

*Automated loading is **not just a technology upgrade**, but an operational capability enhancement*

WHAT WE MUST ACHIEVE

- ✓ **A foundation for Load Unit-based logistics** achieving near full automation of in-gauge baggage
- ✓ **Consistent, reliable and scalable capacity** across operations, supporting predictable long-term costs
- ✓ **Fewer damaged and mishandled bags**. Improving quality beyond today’s av. 10 per 1,000
- ✓ **Resilient operations** less dependent on workforce variability and managing last-minute bags effectively
- ✓ **Safer, more meaningful work** for operators during and after transition

WHY THIS MATTERS

We develop robotic loading as the core capability, enabling load unit–based operations and creating the foundation for continuous flow operations

THE AMBITION

HOW AUTOMATED LOADING INTEGRATES INTO THE BAGGAGE PROCESS

It focuses on the moment bags leave the BHS and are placed into the load unit – by a robot, supported by people

BHS*
BHS feeds bags into the loading zone.
Upstream flow

BAGS
Bag identification, orientation and tracking are required for the loading process to function

ROBOT
Automated handling and placement into load unit

ORCHESTRATION LAYER*
The digital flow that decides on the coordination logic

AGV LOAD UNIT* TRANSPORT = physical flow that transports individual load units

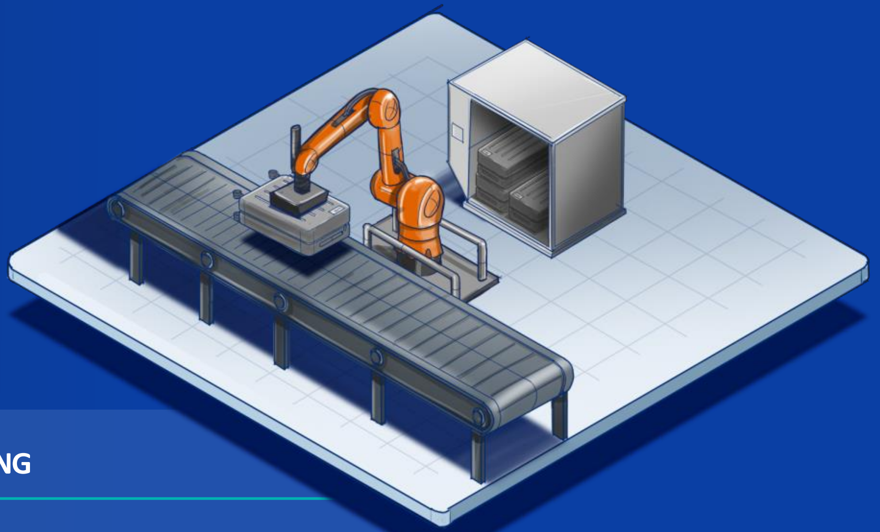
LOAD UNIT
Process of the ULD or ALD being filled. Full ULDs are the output of the loading cell

PEOPLE
Role transition to future-proof staff – supervision
& exception handling

*Not in scope, but connected to the wider system

THE AMBITION

DESIGN FOR SCALE



HOW WE DESIGN IT

1. Automated by default

Standard flows go through the robot without manual planning. People intervene by exception only.

2. In control of the process

Full visibility and clear ownership at every step of the baggage process.

3. Flexible and scalable

Works across airport sizes (large hubs to regional), layouts (retrofit to new-build) and volumes (one load unit to many).

4. Collaborative by design

Open data interfaces and shared standards. Interoperability is a requirement, not a future aspiration.

HOW WE KNOW IT'S WORKING

Automation rate *Of standard, in-gauge flow*	**95%**
Fill rate per load unit	**> 90%**
Automatable bags *Of total in-gauge volume (hard & soft shell)*	**>85%**
Mishandled bags	**< 5 per 1,000**
Manual top-up interventions	**Exception based, not continuous**
Handler role transition	**Supervisory role in place at go-live**

03

OPERATIONAL CONCEPTS

How do we move from a robotic loading capability to system-wide performance?

TWO OPERATIONAL CONCEPTS SHAPE TODAY'S ENTRY POINT INTO AUTOMATED BAGGAGE LOADING

Airports typically begin automation from one of two established loading concepts

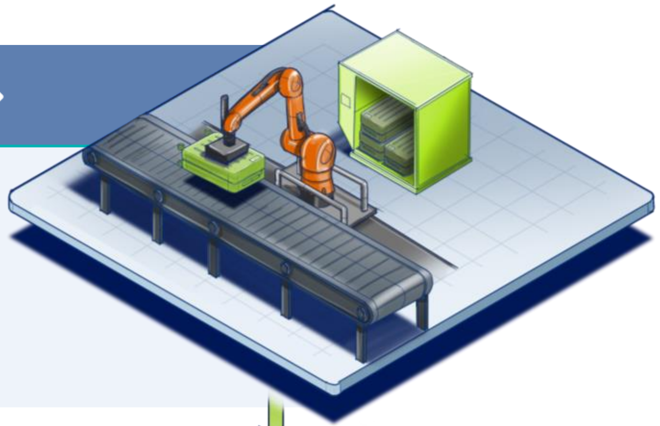
BATCH-BASED LOADING

Practical use cases of batch-based? Click here. →

Uses early bag stores with sequential loading of one load unit at the time, ensuring robustness and *predictability*

- *Pre-sorted baggage > optimal loading quality*
- *High predictability and robustness*

Robot type: → precision loading robot
Load unit: → loads one unit at the time



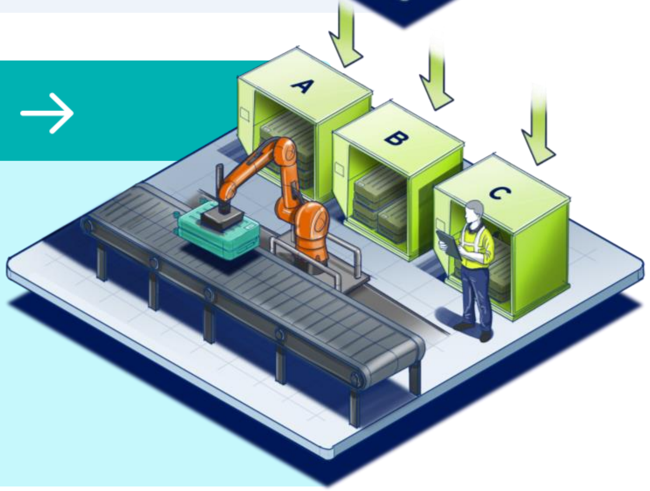
FLIGHT-BASED LOADING

Practical use cases of flight based? Click here. →

Focuses on just-in-time loading per flight with multiple load units loaded parallel, reducing space for early bag stores

- *Unsorted baggage > dynamic allocation*
- *Increased flexibility but higher complexity*

Robot type: → sorting / allocation robot
Load unit: → loads multiple units in parallel



Both concepts enable automated loading today – but require different levels of operational maturity, system integration and scalability

CHOOSING THE RIGHT LOADING CONCEPT DEPENDS ON YOUR OPERATION

The goal is not to choose one model. But to enable the right model or mix per operation

BATCH-BASED LOADING

Best suited for:

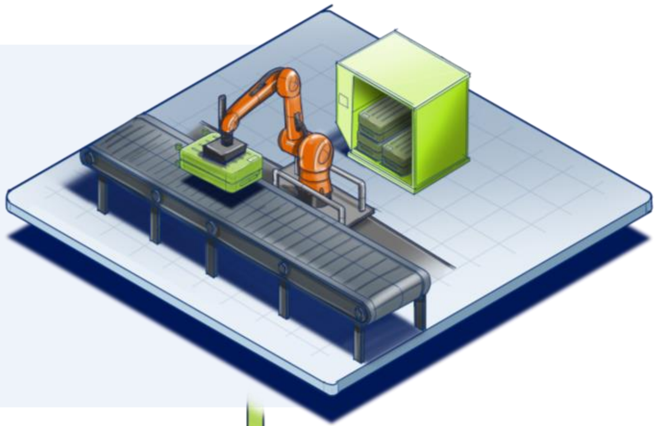
- Stable operations with predictable patterns
- Available buffer space
- Lower complexity, higher robustness

Strength:

- ✓ High predictability for stable fill rates
- ✓ Strong fill rate performance
- ✓ Efficient use of machine
- ✓ Proven and scalable today

Limitations:

- ! Limited system integration
- ! Last minute baggage prevents achieving a fully loaded flight



FLIGHT-BASED LOADING

Best suited for:

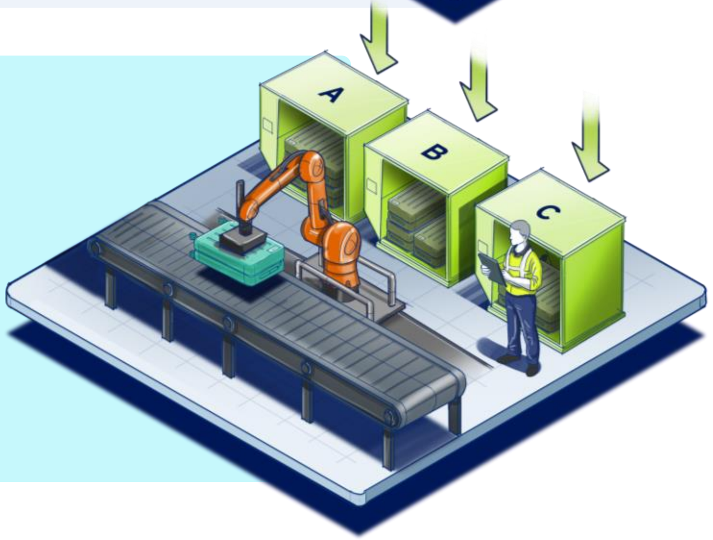
- Dynamic operations demanding flight separation
- Limited buffer capacity
- Need for flexibility, e.g. last-minute bags

Strength:

- ✓ Enables significant automation
- ✓ Higher compatibility with existing processes

Limitations:

- ! Higher process & orchestration complexity
- ! High number of load units required for operations



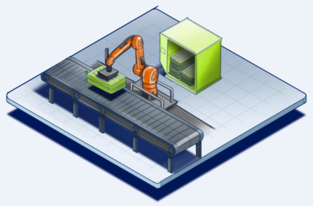
OPERATIONAL CONCEPTS

MATURITY PATH TOWARD CONTINUOUS FLOW OPERATIONS

BATCH-BASED LOADING

CONCEPT | PROOF OF CONCEPT | PROOF OF OPERATION | **PROOF OF SCALE** | DEPLOY

Proven & scaling (TRL 6–8)



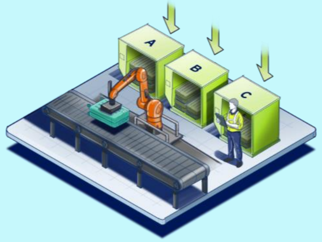
OPERATIONAL INSIGHTS:

- Fill rate standardization is complex
- Close to human performance: av. 15 % remain manual
- Hybrid operations required in transition
- Dependent on buffer capacity & flight peaks

FLIGHT-BASED LOADING

CONCEPT | **PROOF OF CONCEPT** | PROOF OF OPERATION | PROOF OF SCALE | DEPLOY

Piloting & validation (TRL 4–6)



OPERATIONAL INSIGHTS:

- Optimisation human interface and intervention is required
- Optimises loading cells, not end-to-end-baggage flow
- Buffer configuration is critical
- Strong business case potential

CONTINUOUS FLOW OPERATIONS

CONCEPT | PROOF OF CONCEPT | PROOF OF OPERATION | PROOF OF SCALE | DEPLOY

To unlock further maturity, operational readiness is required in ...

Emerging operating model (TRL 2-3)

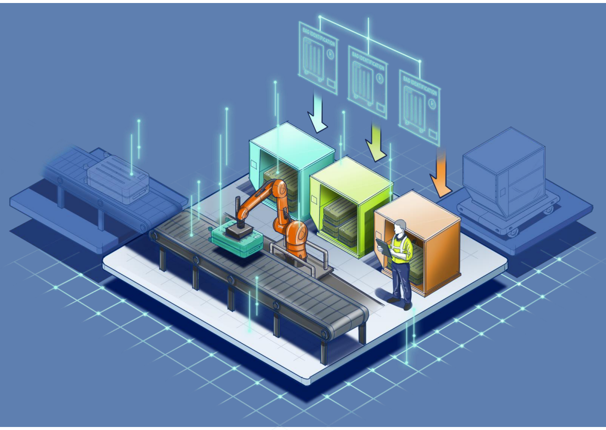
Reliable automated loading operation
batch or/and flight based
(operational capability)

\+

Stable system integration
(BHS, AGVs software connectivity)

\+

Real-time orchestration
(dynamic flow coordination)



Continuous flow operations become achievable once automated loading is operationally proven and reliable at scale.

OPERATIONAL CONCEPTS

WHY BOOST MOVES TOWARD CONTINUOUS FLOW OPERATIONS

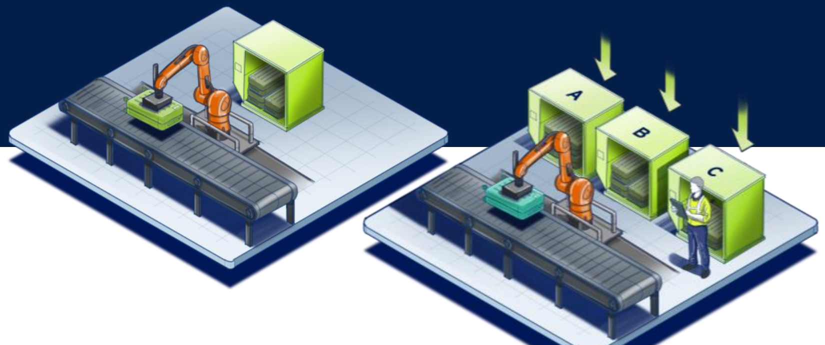
As automated loading matures, the focus shifts from automating individual processes to optimising baggage flow across the operation

LIMITATIONS OF CURRENT AUTOMATED LOADING

- Limited space in baggage halls
- Flight-based operations drive peaks and idle time
- Growing dependence on buffers and storage
- Automation remains locally optimized rather than system flow
- Increasing pressure on throughput and flexibility
- Limited scalability at high-volume hubs

WHY OPERATIONS MUST EVOLVE

- Need for making best use of space
- Need for helping people and equipment work more efficiently
- Need for optimised end-to-end baggage flows
- Need for handling more bags without expanding facilities
- Need for managing growing operational complexity
- Need for deploying resources where they are needed most



“Our operational challenge is no longer machine automation, it is coordinating the entire baggage flow dynamically.”
— Dennis van Kleef, Schiphol

OPERATIONAL CONCEPTS

CONTINUOUS FLOW OPERATIONS: THE NEXT STAGE BEYOND AUTOMATED LOADING

Continuous flow operations dynamically coordinate baggage, equipment and resources across the entire baggage operation

WHAT IT ENABLES

BETTER USE OF AVAILABLE CAPACITY

- Dynamic balancing of bags and available loading capacity

HIGHER USE OF ASSETS

- Continuous execution reduces idle time and peak dependency

FLEXIBLE BAG ALLOCATION

- Load units assigned dynamically based on system conditions

LESS DEPENDENT ON FLIGHT SCHEDULES

- More adaptive and resilient operations

SCALABLE GROWTH

- Higher throughput without proportional infrastructure expansion

WHAT IT REQUIRES

1. **PROVEN ROBOTIC LOADING CONCEPT**
   Execution of loading in a continuous environment
2. **FLEXIBLE LU MOVEMENT VIA AGVS**
   Flexible, decoupled transport of load units
3. **ORCHESTRATION SOFTWARE**
   Real-time coordination of flows, resources & priorities
4. **SMARTER UPSTREAM SYSTEMS + DECISION INTELLIGENCE**
   BHS feeding optimized, flexible baggage streams

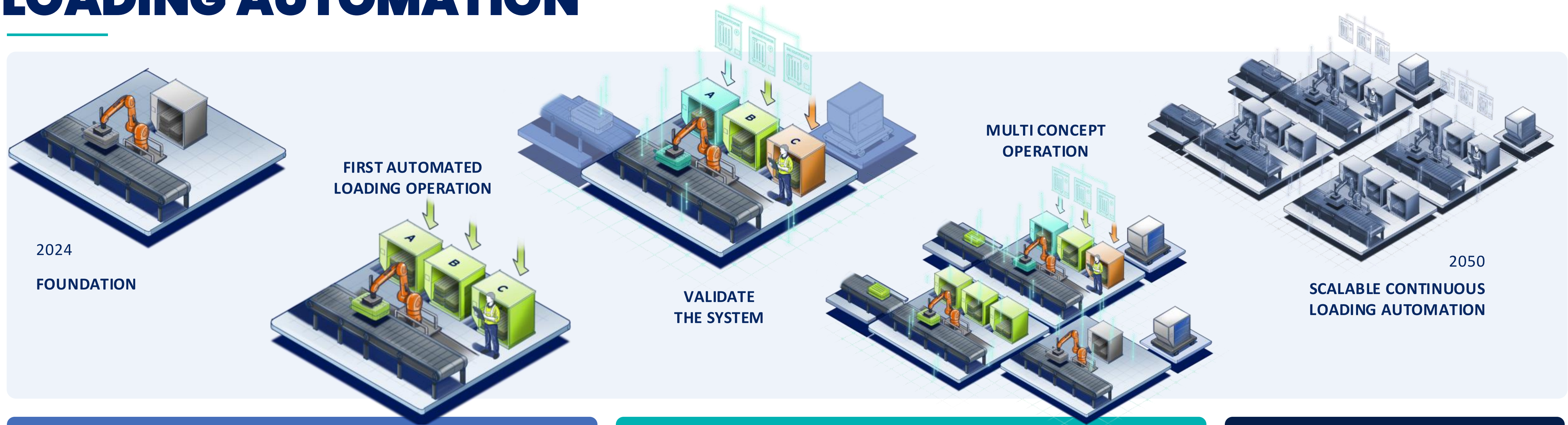
Continuous flow operations represent the **next maturity stage:** from optimising individual loading processes to unlocking the performance of the entire baggage eco-system

04

THE ROADMAP

How do we move from pilots to scalable operations?

FROM OPTIMIZE, HYBRID TO SCALABLE CONTINUOUS LOADING AUTOMATION



OPTIMIZE

FOUNDATION

Setting the baseline for automation by

- Define tech & operational needs
- Align systems, workforce & infrastructure

FIRST AUTOMATED LOADING OPERATION

Introducing automated loading into operations

- Robotic loading cells
  batch – scaling
  flight – first pilots
- Focus on performance, reliability, and learning

HYBRID

VALIDATE THE SYSTEM

Proving the new operating model

- Introduce partial LU-based flow
- Validate end-to-end processes (batch and/or flight)
- Test human-automation interaction in real operations

MULTI CONCEPT OPERATION

Automated loading as system capability

- Batch, flight and hybrid models co-exist
- interface robotic loading with transport, orchestration and control

END STATE

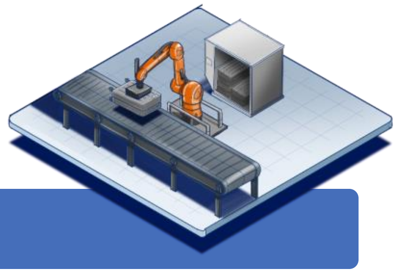
SCALABLE CONTINUOUS LOADING AUTOMATION

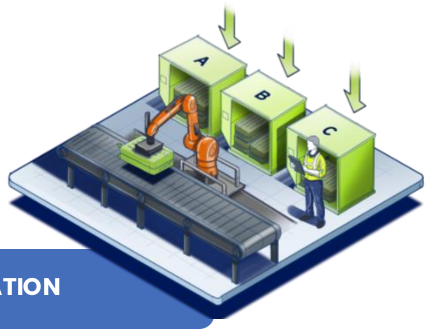
System-wide performance at scale

- 95% of baggage autonomously loaded
- Airport deploy optimal combination of loading

ROADMAP

OPTIMIZE





	2025 - 2028 FOUNDATION	2028-2030 FIRST AUTOMATED LOADING OPERATION
Process Design & improvement	**Define the operating model** • Define bag preparation standards & automatable definitions • Define segregation rules & exception handling logic • Build business case & operational value model (ROI)	**Make the process work into practice** • Define continuous loading, flow control & operator handovers. • Set the Load Unit management, buffering, & staging logic • Clear allocation of responsibilities and human hand-over points

Product
Technology, systems & data)
	Define the system
	• Define automation tech requirements & architecture (robotics, sensing, safety, data)
	• Set system & data integration principles
	• Start supplier collaboration:
	  ◦ Batch: scaling proven solutions
	  ◦ Flight: early sorting-robot prototypes & pilots
		Deploy and validate
		• Deploy 1st robotic load cells
		  ◦ Batch: move into deployment
		  ◦ Flight: first live pilots & data collection
		• Integrate core systems (BMS, tracking , LU status)
		• Define and apply modular robotic loading designs (adaptable lay-outs, grippers, LU configurations)
		• Validate performance, reliability, and interfaces

People Workforce & organisation readiness	**Operational philosophy & impact** • Flow and responsibilities human vs automation • Set future workforce principles • Initial workforce impact assessment (co-design, role transition, mapping)	**Prepare workforce transitions** • Prepare training & human–robot readiness • Define staffing models & new roles • Establish safety framework & compliance

What's achieved:

- ✓ A defined and operational loading model
- ✓ First automated loading in a live environment
- ✓ Alignment between process, product, and people

Next step

- From pilot success to scalable operation

ROADMAP

HYBRID

BOOST

2030-2040

VALIDATE THE SYSTEM

2040 - 2050

MULTI-CONCEPT OPERATION

Process
Design & improvement

Validate operational concepts

- Validate end-to-end loading process & exception handling
- Test human–automation interaction in real operations
- Refine SOPs and workflows

Operate across concepts

- Standardise workflows across batch, flight and hybrid models
- Enable parallel operation across concepts and cells
- System-wide performance management

Product
Technology, systems & data)

Validate system performance

- Validate robot performance and system workflows
- Optimise algorithms, interfaces, and control logic
    - Batch: optimise fill rate consistency & execution speed
    - Flight: validate dynamic allocation and reliability at scale
- Stabilise system integration

Enable multi-concept, system capability

- Support batch, flight and hybrid within one architecture
- Enable multi-cell and multi-concept operations
    - Batch: scale proven configurations
    - Flight: stabilise and scale
- Monitoring, diagnostics, and reliability engineering
- Interface robotic loading with AGV-transport, orchestration and control into one system

People
Workforce & organisation readiness

Workforce change

- Recruitment for robotics data & maintenance roles
- Engagement with handlers & airlines
- Train operators in real scenarios
- Introduction of support roles (tech leads & champions)

Change & adoption for scale

- Scale workforce organisational capabilities & expertise (robotics, data, maintenance)
- Strengthen cross-functional collaborations
- Build in-house expertise and ownership

What's achieved:

- ✓ Validated performance in real operations
- ✓ Automated loading is established as a system capability
- ✓ Stable interaction across process, product, people
- ✓ Operational confidence in human–automation workflows

Next step

SCALABLE CONTINUOUS LOADING AUTOMATION

- 95% of baggage autonomously loaded
- Airports deploy optimal combinations per context
- System-wide optimisation enabled by integrated control

LESSONS LEARNED FROM OUR INNOVATION PROJECTS

Across pilots, BOOST airports and member airlines are seeing same challenges returning

Robotics performance depends on tech readiness

Robot software and hardware are still evolving to consistently meet required operational performance and capacity levels.

→ Continue advancing robotics software and hardware
→ Design robust exception handling

Workforce transition is underestimated

Late change management slows adoption in automation

→ Start from day one
→ Co-design roles with handlers and operators

Integration requires stronger collaboration

Scaling depends on alignment across systems and vendors

→ Align on interfaces and requirements early
→ Engage vendors in open collaboration

Future scalability must be built in early

Current deployment risks limit future operations

→ Include LU-based standards and interfaces in current deployments
→ Avoid locking into non-scalable designs

05

THE ROADMAP INTO PRACTICE

Which pilots have been tested, and what have we learned?

7 ROBOTS FOR AUTOMATED BAG LOADING INTO ULDS

GOAL

After forming batches of baggage of the same segregation, automatically loading these batches into ULDs in order to improve working conditions.

SCOPE & METHOD

After developing and testing multiple prototypes of batching robots, together with the supplier, in the E-hall at Schiphol, 6 batching robots were implemented in the South hall baggage handling process. These have been operational for 15 years and have currently undergone EOL replacements. Also the E-hall prototype is being upgraded. Batching robots at Schiphol handle approximately 8-9% of all baggage loading.

METRIC

80-95%
Fill rate achieved

150/hr operational cap.
Bags loaded per hour

NIOSH lifting index <1
Physical strain

0-10%
Exception rate
(manual)

KEY LEARNING

- ✓ Robots load batches of in-gauge baggage that are sent by EBS from large to small.
- ✓ Batching robot is most efficient for high volume segregations and for early baggage.
- ! Limited development of suppliers due to low demand by airports.
- ! 1 on 1 operator remains required due to set-up of robot, to manually intervene and top-up.

READINESS VERDICT

State: → *Proof of scale*

Robotic batch loading is operationally feasible today and handles 8-9% of baggage at Schiphol. The technology is considered proven technology. Further improvements can be made by closing the gap in bag classification and exception handling protocols.

PROOF OF OPERATION BATCH-BASED

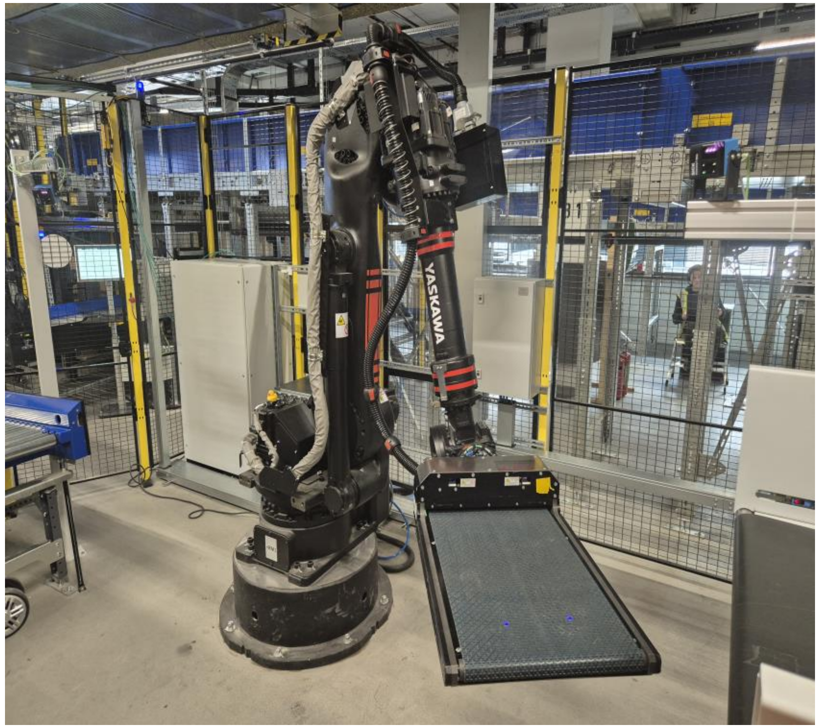
FIRST ROBOT FOR AUTOMATED BAG LOADING INTO CARTS AND ULDS

GOAL

Validate whether a robot system can reliably load standard bags into carts and different types of ULD's at operational speed and fill rate — in a live baggage hall environment.

SCOPE & METHOD

After extensive development and testing at the robot supplier's facilities, including factory acceptance testing, the complete system was installed in the new BHS at Terminal 1, Oslo Airport, as a proof of concept for operational testing. Performance will be evaluated during an operational trial period using live baggage flows and handling personnel. During and after the trials, the system will be further refined and developed to improve performance and meet the handler's needs and requirements.



METRIC

80-90 %
Fill rate achieved

260–300/hr
Bags loaded per hour

NIOSH lifting index <1
Physical strain

0-10%
Exception rate (manual)

KEY LEARNING

- This first robot at Oslo airport will load batches of standard bags buffered in the fully automatic central DBS
- In the early stage of using the robot in live operation, it will be used for early builds and for peak shaving of flights with high bag volume.
- To fully learn from user experience, the operational trials will closely be followed up by the project and by management
- Actual manning of the robot, and how the robot will be used as part of the overall handler's operation in the make-up area

READINESS VERDICT

State: → *Proof of concept evaluation*

As compared with testing at supplier's premises, as well as with test bags at Oslo airport, further improvements can be made on the KPI's; Capacity, filling degree, manual interventions and quality of bag loading. Also, adaptions and further developments from user's needs and requests will be worked on.

PROOF OF CONCEPT FLIGHT-BASED

AUTOMATED MAKE-UP UNIT LOADING MULTIPLE CONTAINERS

GOAL

Validate whether a robotic arm can reliably load standard in-gauge bags into multiple ULDs at operational speed and fill rate without forming batches in an early bag store.

SCOPE & METHOD

After validation in a factory environment using test baggage and containers, the set-up was installed in Baggage Hall South at Schiphol, as a proof of concept for operational testing. The goal is to evaluate performance under operational conditions, with handling personnel and live baggage flows. After proof of concept, further development such as automatic tracking, sorting into ULDs and baggage reconciliation will lead to a proof of operations.

METRIC

80-100%
Fill rate achieved

85-120/hr
Bags loaded per hour

NIOSH lifting index <1
Physical strain

7-14%
Exception rate
(manual)

KEY LEARNING

- ✓ Robot is able to simultaneously load multiple and all types of ULDs. Sorting currently by manual instruction.
- ✓ Mainly operational testing with "cold baggage" from EBS, since performance is under review.
- ! Performance (fill rate, capacity, exceptions) needs further improvements.
- ! Top-up by handler remains and may require additional lifting aid. Physical strain TBD.

READINESS VERDICT

State: → *Proof of concept evaluation*

First robot worldwide that can load baggage simultaneously into different load units. Further improvements in performance are required, before process and system integration will be started.

PROOF OF CONCEPT FLIGHT-BASED

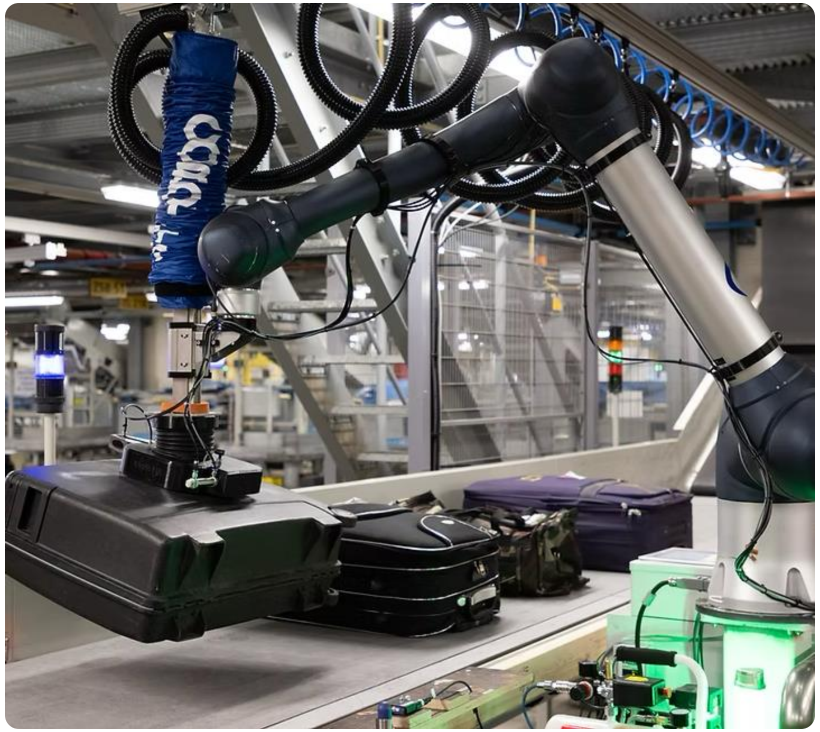
COLLABORATIVE ROBOT ARM LOADING BAGGAGE INTO CARTS

GOAL

Develop a robotic loading arm that operates collaboratively with operator to load baggage into loading units and can be retrofitted in existing baggage halls.

SCOPE & METHOD

After a proof of technology within an operational environment, 6 collaborative robots were installed in South hall at Schiphol as a proof of concept. In this operational environment the robots were further improved by developing vision technology, loading algorithms and the user interfaces.



METRIC

80-90% **Fill rate achieved**	**120-180/hr** **Bags loaded per hour**	**NIOSH lifting index <1** **Physical strain**	**0-5%** **Exception rate** (manual)

KEY LEARNING

- Pick-up rate of baggage items was high (95%+), resulting in a low exception rate.
- Dependence of manual baggage reconciliation by handling staff.
- Due to design of arm and suction gripper, robot was unable to load into ULDs or carts with roof.
- Project stopped due to process and system integration issues, resulting in limited support of stakeholders.

READINESS VERDICT

Automated loading into baggage carts was successfully demonstrated, but loading of ULDs was not achieved. Challenges in system integration, baggage reconciliation, and handling peak volumes resulted in BHS sorter recirculation. While not viable for Schiphol's operation, the concept showed promising potential for collaborative robotics in baggage handling and deserves further testing.

06

BOOST COLLABORATION

How do we accelerate baggage innovation together?

BOOST BAGGAGE

Automated loading is not a single solution, it is a shared capability the industry must build together.

BOOST brings airports, airlines, and partners together to accelerate baggage innovation.

WHAT WE DO

- Develop and validate automated loading in real operations
- Share what works — and what doesn't — across the industry
- Accelerate the transition from pilots to scalable solutions

WE DO THIS THROUGH:

- Joint pilots with open sharing of results
- Cross-airport collaboration on common challenges
- Practical outputs: blueprints, tools, and learnings

THE RESULT

- Safer, more efficient baggage operations that benefit workers and passengers alike.

BOOST

ACCELERATING BAGGAGE INNOVATION, TOGETHER

Dennis van Kleef
Manager Baggage Development
Amsterdam Airport Schiphol

Yorick Buys
Head of Baggage
Brussels Airport

Jamie Ratcliffe
Baggage Development Manager
Heathrow Airport

Do-Young Chun
Executive Director of BHS Group
Incheon Airport

Steffen Hamre Gavem
Dep. manager technology & baggage
Avinor

Wopke Dost & Romy van Kessel
Program lead & management
nlmtd

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