

# Fiduciary Carton Tracking in Processing Facilities without an ASRS

Final Report – Milestone 5

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## 1.0 Abstract

Across its processing network, JBS stores frozen and chilled meat cartons in coldstores, where reliably identifying and locating each carton remains a significant operational challenge. Earlier trials of RFID and other electronic tagging at JBS were undermined by signal attenuation from the high water content and dense stacking of meat and by potential interference with metal-detection equipment. This project investigated whether visible-light-based identification and positioning – proven in earlier University of Adelaide research – could deliver accurate carton and pallet tracking in a coldstore that has no Automated Storage and Retrieval System (ASRS).

A proof-of-concept system was designed, built and trialled at JBS Bordertown. It combined a new high-capacity carton label (a fiducial marker paired with a data region), a fixed Pallet Reader, retroreflective rack tags, a forklift-mounted camera, a Honeywell CK65 handheld application, and a Raspberry Pi server hosting a central database with automated daily reporting.

On-site trials on 25 May 2026 confirmed the approach. The Pallet Reader reliably registered two- and four-sided pallets and detected duplicate scans and removed cartons; the CK65 application supported carton search, addition, removal, pallet transfer and shipping with built-in validation; and the forklift camera (more than 2,700 images) correctly identified pallets and their source and destination rack locations across multiple bays, columns and rack levels. The label design supports up to 500 million unique identifiers.

The project demonstrates a practical, interference-resistant alternative to RFID for carton traceability in coldstores. For industry, it offers a pathway to improved stock rotation, faster carton retrieval, fewer despatch errors and stronger export shelf-life compliance in the many facilities that operate without an ASRS.

## 2.0 Executive summary

JBS Australia, in partnership with the University of Adelaide and with co-funding from AMPC, undertook this research to solve a long-standing problem in meat coldstores: accurately identifying and locating individual cartons and pallets in facilities that do not have an Automated Storage and Retrieval System (ASRS). Carton-level visibility underpins stock rotation, on-time despatch, export shelf-life compliance and order-fulfilment accuracy. The primary audience is red meat processors operating conventional (non-ASRS) coldstores, for whom RFID has repeatedly proven unreliable. The results will guide JBS's next phase of development and inform the wider industry on a deployable, interference-resistant tracking approach.

**Objectives.** The project aimed to develop and demonstrate a proof-of-concept, visible-light-based carton tracking system, including carton and rack fiducials, scanning hardware and software, a forklift vision system, a carton-location database and search, carton storage-removal information flow, an offline database, and carton-age reporting. All objectives were achieved and demonstrated on site.

**Methodology.** The University of Adelaide, as lead contractor, designed and built the system; JBS Bordertown hosted installation and trials. Custom labels were applied to cartons and retroreflective tags to racking; a fixed Pallet Reader registered pallets; a forklift-mounted camera captured pick-up and put-down events; a CK65 handheld supported floor operations; and a Raspberry Pi server maintained the database and generated daily reports.

**Results / key findings.** On-site trials on 25 May 2026 validated every core function. The Pallet Reader reliably registered two- and four-sided pallets and detected duplicates and removed cartons; the CK65 application performed carton search, add, remove, transfer and ship with validation and multi-orientation label reading; and the forklift camera (2,700+ images) identified pallets and their source and destination rack locations across ground and first-rack levels, multiple bays and columns. The new label supports up to 500 million unique identifiers.

**Benefits to industry.** The system offers processors a practical alternative to RFID for carton traceability in coldstores, supporting better stock rotation (oldest-first picking), faster retrieval, fewer despatch errors and stronger export shelf-life compliance – particularly valuable for the many facilities without an ASRS.

**Future research, extension, adoption and recommendations.** Recommended next steps are to enable continuous-rotation scanning at the Pallet Reader, extend the forklift camera to additional rack levels, improve label detection under reflective plastic wrapping, integrate the system with JBS production and despatch systems, and conduct broader operational trials toward a deployment-ready solution.

## 3.0 Introduction

Across JBS locations, both frozen and chilled meat cartons are stored in coldstores. Being able to identify and locate every carton across the JBS network represents a substantial operational opportunity, supporting accurate stock rotation, timely order fulfilment, adherence to shipment deadlines and compliance with export shelf-life requirements. In facilities without an Automated Storage and Retrieval System (ASRS), this visibility is largely manual and error-prone, and the challenge grows as volumes and product complexity increase.

JBS has previously investigated RFID and other electronic tagging technologies, but these trials did not achieve the required performance. The key barriers have been signal attenuation caused by the high density and water content of stacked meat, and potential interference with metal-detection equipment in the coldstore environment.

The central question for this project was therefore whether a non-radio-frequency approach could deliver reliable, accurate carton and pallet tracking under real coldstore conditions. The University of Adelaide has developed indoor positioning systems based on visible-light technology that are not affected by radio-frequency interference and can identify and locate targets reliably over several metres. This project tested the practical application of that research to carton and pallet tracking at JBS Bordertown.

The primary audience is JBS operations and the wider red meat processing industry, particularly processors operating conventional coldstores without an ASRS. The results provide JBS with the evidence base to plan a next development phase and offer the industry a validated, cost-effective and interference-resistant alternative to RFID.

## 4.0 Project objectives

As specified in the Research Agreement, the University of Adelaide was engaged to develop and demonstrate a proof-of-concept design for a robust carton tracking system and an indicative operating interface. The specific objectives were to develop and validate:

- ◆ carton fiducials (labels);
- ◆ coldstore racking fiducials;
- ◆ carton scanning hardware and software;
- ◆ a forklift onboard vision system and software;
- ◆ a carton-location recall database and search capability;
- ◆ a carton storage-removal information flow;
- ◆ an offline (standalone) database; and
- ◆ reporting of carton age.

Underpinning these was a single overarching aim: to develop a high-precision, interference-resistant indoor positioning and tracking system, based on visible-light technology, capable of tracking meat cartons within JBS coldstores while overcoming the limitations of RFID and other electronic tagging. All objectives were met and demonstrated during the on-site trial on 25 May 2026.

## 5.0 Methodology

The University of Adelaide acted as lead contractor, supported by JBS Bordertown management and technical and operational staff. The system was designed as an integrated proof-of-concept comprising customised carton labels, a Pallet Reader, retroreflective rack tags, a forklift-mounted camera, a CK65 handheld application, and a Raspberry Pi server with a central database and daily reporting. Its components and their operation are described below; full technical detail and figures are provided in the University of Adelaide Final Report at Appendix A.

### Carton label design

Two-dimensional barcodes (e.g. QR Code, Data Matrix) store data at high density but are not designed for pose estimation and require close-range scanning, whereas fiducial markers (e.g. AprilTag, ArUco) support pose estimation at greater distances but encode little data. The project developed a new label that combines at least one fiducial marker with at least one data region of known dimensions and relative position. Adapted to the space available on JBS cartons, the design stores up to 500 million unique identifiers and can be detected at longer range than an ordinary Data Matrix or QR code, enabling reliable scanning by the forklift camera.

### Pallet Reader

The Pallet Reader is a fixed, camera-based station that registers pallets carrying labels on two or four sides. The pallet is rotated on a turntable so each labelled face is presented about 1.0–1.4 m from the camera. For each face the Reader captures a timestamp and every carton ID and computes each carton's row and column position from 3D spatial information, then transmits the data to the server. It provides real-time feedback (scanned-carton counts and duplicate-scan alerts), reads partially damaged labels, and includes integrated LED lighting for low-light conditions.

### Rack tags

Each rack location is identified by a customised 100 mm retroreflective tag incorporating an AprilTag marker (AT41h12 family), mounted on a 100 × 130 mm board sized for the Bordertown rack structure. Each tag is shared by the upper and lower levels of a rack section, with five bays per row, allowing the forklift camera to determine rack positions and support pallet-location tracking.

### Forklift camera system

A camera mounted on the side of the forklift mast, using custom 3D-printed brackets, scans carton labels when a pallet is picked up and reads rack tags to determine the locations from which pallets are collected and where they are placed. Detected events are converted into pallet-movement records and transmitted to the server.

### CK65 handheld application

A mobile application on the Honeywell CK65 handheld lets operators perform carton and pallet tasks on the floor, using the device camera to scan labels and communicating with the server over Wi-Fi in real time. It provides five

functions – Scan Carton, Search Carton, Add Carton, Remove Carton and Ship Pallet – with a secondary confirmation step on critical actions and built-in consistency checks that reject invalid operations to protect data integrity.

## Server, database and network

A Raspberry Pi 5, connected to a Teltonika RUT241 router, acts as the central server. Over the router's Wi-Fi network it communicates with the Pallet Reader, CK65 device and forklift camera, hosts the carton and pallet database, processes device requests, and applies transaction-handling and validation logic to maintain database consistency.

## System startup and daily reporting

Powering on the Reader launches the Server, Forklift and Reader programs via three desktop shortcuts, activating the complete system and allowing all components to be connected, monitored and managed from the Reader's monitor. The server automatically generates a daily Carton Activity Report summarising carton status, inventory exceptions, chilled-area inventory density, storage-duration breakdown and aged cartons. A sample report is provided at Appendix D.

# 6.0 Results

The integrated prototype was trialled at JBS Bordertown on 25 May 2026, with AMPC representatives Stuart Shaw and Koentadi Hadinoto attending in person to review progress. All core functions operated successfully. Results for each subsystem are summarised below and in Table 1; the full set of test cases and supporting images is provided in the University of Adelaide Final Report at Appendix A.

## Pallet Reader

Despite the small label size, the Pallet Reader detected and registered labels reliably. Ten test cases were completed successfully: system startup and inter-component communication; registration of a two-sided pallet (Pallet 101) and a four-sided pallet (Pallet 102); updating an existing pallet record after reconfiguration; detection of duplicate side scans and duplicate pallet scans; detection of carton removal (the removed carton was re-stated to "Buffered" and its prior pallet preserved as a negative reference for traceability); cancellation of an active scan; safe system shutdown; and full data persistence after restart.

## CK65 handheld application

The CK65 application detected and decoded labels under a range of practical conditions. Nine test cases were completed successfully: carton search (including correct "No Data", "Wrong Pallet", "Wrong Side" and "Carton Found" responses with column and row coordinates); carton-label scanning; adding a new carton to a pallet; moving a carton between pallets; removing a carton; rejecting removal of an unregistered carton; shipping a pallet; rejecting a shipment containing cartons from different pallets; and reliable label detection at inverted, 90-degree and 45-degree orientations.

## Forklift camera system

More than 2,700 images were captured and processed. Seven scenarios were demonstrated: picking up a pallet from the Reader area; placing a pallet at ground level (location 0007); moving a pallet from ground level to the first rack level (1007); moving a pallet from the first rack level to ground level (0006); moving a pallet between bays (to 1006); picking up a pallet from the first rack level at a different bay; and tracking a small (nine-carton) pallet at a different rack column (1005). In each case the system detected pick-up and put-down events, identified the pallet from its carton labels, determined source and destination locations from the rack tags, and generated a pallet-movement packet for transmission to the server.

## Server and daily reporting

The server maintained a live carton and pallet database, processed requests from all three devices and applied consistency checks throughout. It generated a daily Carton Activity Report covering carton status, inventory exceptions, chilled-area density, storage duration and aged cartons (sample at Appendix D).

**Table 1.** Summary of on-site trial results, JBS Bordertown, 25 May 2026.

Subsystem	Functions / test cases demonstrated	Result
Pallet Reader	10 cases: registration (2- and 4-sided), record update, duplicate-scan and removal detection, cancel, shutdown, data persistence	All passed
CK65 handheld	9 cases: search, scan, add, move, remove, ship, invalid-operation rejection, multi-orientation reading	All passed
Forklift camera	7 scenarios across ground and first-rack levels, multiple bays and columns (2,700+ images)	All passed
Server & reporting	Live database with consistency checks; automated daily Carton Activity Report	Demonstrated

## 7.0 Discussion

The trial confirmed the feasibility of visible-light identification and positioning for carton and pallet tracking in a coldstore. The prototype performed the full set of core functions – pallet registration, carton handling, forklift movement tracking, database management and reporting – and clearly demonstrated the value of combining multiple information sources (carton labels, rack tags, pallet records and forklift events) for identification and consistency checking. AMPC’s representatives noted the maturity of the integrated solution and the quality and consistency of the data captured across the Reader, CK65 and forklift systems.

The trial also identified practical opportunities for the next phase. Pallet Reader operation currently requires some operator adjustment to align each face on the turntable; the workflow could be streamlined by enabling detection

while the pallet rotates continuously, for example by increasing LED illumination while reducing camera exposure, or by adding cameras at different viewing angles. The forklift camera system was demonstrated for two rack levels; extending it to additional levels requires adjustments to camera positioning and location-identification logic. Multiple layers of plastic wrap can produce localised reflections that temporarily reduce label visibility; this can be mitigated by scanning during the wrapping process (for the Reader) and by testing a wider range of viewing angles (for the forklift camera).

A number of consistency-checking functions beyond the original project scope were added during development. While not required by the proposal, these materially improve the system's practical robustness and its readiness for operational use.

## 8.0 Conclusions

The project successfully demonstrated the feasibility of using visible-light identification and positioning to track cartons and pallets in a JBS coldstore. An integrated proof-of-concept was delivered, comprising the carton labels, Pallet Reader, rack tags, forklift camera system, CK65 application, server, database, network, startup software and daily reporting.

The Pallet Reader reliably registered two- and four-sided pallets and updated the database; the CK65 application supported carton search, scanning, addition, removal, pallet transfer, shipping and validation; and the forklift camera detected pick-up and put-down events and identified pallets and rack locations across the rack levels, bays, columns and pallet configurations tested. The server integrated information from all devices, maintained database consistency and generated operational reports. User manuals for the Pallet Reader and the CK65 handheld were also delivered.

The project has therefore achieved its primary objective of developing and validating a visible-light-based prototype for carton and pallet tracking, establishing a strong technical foundation and a clear pathway for the next development phase.

## 9.0 Recommendations

**Practical application.** Progress the prototype toward an operational pilot at JBS Bordertown, integrating the carton-tracking database with JBS production and despatch systems to deliver oldest-first stock rotation, faster retrieval and reduced despatch errors.

**Future RD&E.** Enable continuous-rotation scanning at the Pallet Reader; extend the forklift camera system to additional rack levels; and improve label detection under reflective plastic wrapping through illumination, camera-placement and viewing-angle refinements.

**Adoption and extension.** Conduct broader operational trials across additional cartons, racks and forklifts, and share findings with the wider red meat processing industry, given the approach's relevance to the many facilities operating without an ASRS.

## 10.0 Project outputs

The project delivered the following outputs:

- ◆ An integrated proof-of-concept carton and pallet tracking system installed and demonstrated at JBS Bordertown, comprising the Pallet Reader, forklift camera system, CK65 application, Raspberry Pi server, database and network.
- ◆ A new high-capacity carton label design (fiducial marker plus data region) supporting up to 500 million unique identifiers, and a custom retroreflective rack-tag design.
- ◆ Daily Carton Activity Reporting software and a sample report.
- ◆ A User Manual for the Carton Tracking Pallet Reader.
- ◆ A User Manual for the Carton Tracking Mobile Application (Honeywell CK65).
- ◆ An on-site system demonstration and review with AMPC (Stuart Shaw and Koentadi Hadinoto) on 25 May 2026.
- ◆ The University of Adelaide Final Report documenting the system design, methodology and trial results.

## 11.0 Bibliography

[1] University of Adelaide, prior research on visible-light-based indoor positioning systems (cited as reference [1] in the University of Adelaide Final Report). Full bibliographic details are provided in that report at Appendix A.

## 12.0 Appendices

The following supporting documentation (Appendix A-D) is provided as accompanying appendices to this report. The University of Adelaide Final Report (Appendix A) contains the complete technical description, all test-case results and supporting figures referenced in the main body.

### Appendix A – University of Adelaide Final Report

“Positioning System for Carton Tracking in Logistics Environments – Final Report”, prepared by Siu-Wai Ho (University of Adelaide), 21 June 2026. Provided as a separate attachment.

### Appendix B – Carton Tracking Pallet Reader User Manual

Operating manual for the Pallet Reader, covering the interface, scanning workflow, button reference, position calculation, data output and error handling. Provided as a separate attachment.

### Appendix C – Carton Tracking Mobile Application (CK65) User Manual

Operating manual for the Honeywell CK65 application, covering the interface and the Search, Add, Remove and Ship functions, with error handling. Provided as a separate attachment.

### Appendix D – Sample Daily Carton Activity Report

Sample Carton Activity Report generated by the server at JBS Bordertown on 29 May 2026, including the carton status summary, inventory exception log, chilled-area inventory density map, inventory duration breakdown and aged-carton list. Provided as a separate attachment.

## Appendix E – Forklift Camera System and New Label Images

Images captured by the forklift camera system during the on-site trial, illustrating carton-label and rack-fiducial detection under operational conditions, together with images of the new reduced-size carton labels. Provided as a separate attachment.



Figure 1 – Forklift camera image showing carton pallet with labels visible through plastic wrapping.



Figure 2 – Forklift camera image showing rack fiducial tags detected at depth within the cold store aisle.



Figure 3 – New reduced size labels on the cartons.



Figure 4 – New reduced size labels on the cartons.



Figure 5 – Pallet Reader scanning pallet on the turntable.



Figure 6 – CK65 handheld scanning cartons.