Smart Inventory Pallets - Requirements Specification Document

Version: 2.0
Project: Smart Inventory Pallets for Beverage Distribution Warehouses
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Course: Embedded Systems Project

Document Information

Field	Value
Document Type	Requirements Specification
Version	2.0
Status	Updated with NFC Integration
Previous Version	1.0
Changes	Added NFC vehicle identification requirements

1. Introduction

1.1 Purpose

This document specifies the functional and non-functional requirements for the Smart Inventory Pallets system. The system aims to automate inventory tracking in beverage distribution warehouses using embedded IoT devices with NFC vehicle identification integrated with existing SaaS platforms.

1.2 Scope

The Smart Inventory Pallets system covers:

- Automated weight measurement using load cells
- **NFC-based vehicle identification and tracking**
- Real-time inventory calculation based on weight changes
- **Vehicle-specific transaction logging and analytics**
- ESP32-based embedded device for local processing
- WiFi connectivity for cloud data transmission
- Integration with existing SaaS platform for beverage distribution
- **Enhanced dashboard with vehicle tracking capabilities**
- Real-time dashboard updates and reporting

1.3 Document Conventions

- **SHALL/MUST**: Mandatory requirement
- **SHOULD**: Highly recommended requirement
- **MAY/COULD**: Optional requirement
- **FR**: Functional Requirement
- **NFR**: Non-Functional Requirement
- **NEW**: Requirements added in version 2.0

1.4 Intended Audience

- Project supervisor and academic reviewers
- Development team (student)
- Future maintainers and developers
- End users (warehouse staff and delivery drivers)

2. Overall Description

2.1 Product Perspective

The Smart Inventory Pallets system is an embedded IoT solution that extends the existing SaaS platform for beverage distribution. It operates as a complementary system that automates manual inventory tracking processes currently performed by warehouse clerks, **while providing vehicle identification and tracking capabilities for enhanced accountability and analytics**.

2.2 Product Functions

- **Automated Weight Monitoring**: Continuous monitoring of pallet weight using load cells
- **Inventory Calculation**: Real-time calculation of bottle/product quantities based on weight
- **NEW - Vehicle Identification**: NFC-based identification of delivery vehicles and drivers
- **NEW - Transaction Tracking**: Vehicle-specific loading/unloading transaction logging
- **Data Transmission**: Wireless transmission of inventory and vehicle data to cloud platform
- **Local Display**: Real-time status display on embedded device with vehicle information
- **Cloud Integration**: Seamless integration with existing SaaS dashboard
- **NEW - Vehicle Analytics**: Performance tracking and route optimization data

2.3 User Classes and Characteristics

- **Warehouse Staff**: Primary users who load/unload vehicles and monitor inventory
- **NEW - Delivery Drivers**: Direct users who scan NFC cards for vehicle identification
- **Warehouse Managers**: Users who review reports and monitor overall inventory and vehicle performance
- **System Administrators**: Technical users responsible for system maintenance and vehicle card management
- **NEW - Fleet Managers**: Users who monitor vehicle performance and route efficiency

2.4 Operating Environment

- **Physical Environment**: Industrial warehouse setting with temperature variations
- **Network Environment**: WiFi network with internet connectivity
- **Power Environment**: Mains power with optional battery backup
- **Mechanical Environment**: Subject to loading/unloading vibrations and weight changes
- **NEW - NFC Environment**: Close-proximity NFC communication for vehicle identification

3. Functional Requirements

3.1 Weight Measurement System (FR-WM)

FR-WM-001: Load Cell Integration

- The system SHALL integrate with 20kg capacity load cells to measure pallet weight
- The system SHALL use HX711 amplifier for accurate weight signal conditioning
- The system SHALL support calibration procedures for accurate weight measurement

FR-WM-002: Real-time Weight Monitoring

- The system SHALL continuously monitor pallet weight at configurable intervals
- The system SHALL detect weight changes greater than a configurable threshold
- The system SHALL filter out vibrations and temporary weight fluctuations

FR-WM-003: Weight Data Processing

- The system SHALL calculate net product weight by subtracting pallet tare weight
- The system SHALL convert weight measurements to product quantities using configurable unit weights
- The system SHALL maintain weight measurement history for analysis
- **NEW - The system SHALL associate weight changes with specific vehicle transactions**

3.2 NEW - NFC Vehicle Identification System (FR-NFC)

FR-NFC-001: NFC Hardware Integration

- The system SHALL integrate with NFC reader module (PN532 or RC522) compatible with ESP32
- The system SHALL support 13.56MHz NFC communication protocol
- The system SHALL detect NFC cards within 2-5cm proximity range

FR-NFC-002: Vehicle Card Management

- The system SHALL read unique NFC card UIDs for vehicle identification
- The system SHALL support NFC card registration and vehicle assignment
- The system SHALL maintain local database of authorized vehicle cards
- The system SHALL detect and reject unauthorized or unknown cards

FR-NFC-003: Transaction Initiation

- The system SHALL initiate inventory transactions upon valid NFC card detection

- The system SHALL associate all subsequent weight changes with the identified vehicle
- The system SHALL support both loading and unloading transaction types
- The system SHALL automatically end transactions based on configurable timeout or manual confirmation

FR-NFC-004: Vehicle Authentication

- The system SHALL authenticate vehicle cards against authorized vehicle database
- The system SHALL log all NFC card scan attempts (successful and failed)
- The system SHALL provide immediate feedback for card recognition status
- The system SHALL support emergency override procedures for system access

3.3 Display and User Interface (FR-UI)

FR-UI-001: Local Display

- The system SHALL display current weight measurements on an integrated screen
- The system SHALL show calculated product quantities in real-time
- The system SHALL display system status and connectivity information
- **NEW - The system SHALL show current vehicle identification and transaction status**

FR-UI-002: Status Indicators

- The system SHALL provide visual indicators for system operational status
- The system SHALL display error conditions and alerts
- The system SHALL show network connectivity status
- **NEW - The system SHALL indicate NFC reader status and card detection events**

FR-UI-003: NEW - Vehicle Transaction Interface

- The system SHALL display vehicle-specific transaction information
- The system SHALL show transaction history for current session
- The system SHALL provide clear indication of loading vs unloading operations
- The system SHALL display transaction completion status and summary

3.4 Data Communication (FR-DC)

FR-DC-001: WiFi Connectivity

- The system SHALL connect to wireless networks using WPA2/WPA3 security protocols
- The system SHALL automatically reconnect to known networks after connectivity loss
- The system SHALL support network configuration through user interface

FR-DC-002: Cloud Data Transmission

- The system SHALL transmit weight and inventory data to cloud platform via HTTP/HTTPS
- **NEW - The system SHALL transmit vehicle identification and transaction data**
- The system SHALL send data in JSON format with standardized data structures
- The system SHALL include timestamp and device identification in all transmissions

- **NEW - The system SHALL include vehicle ID and transaction context in all data packets**

FR-DC-003: Offline Operation

- The system SHALL continue local operation when network connectivity is unavailable
- The system SHALL store unsent data locally during network outages
- **NEW - The system SHALL cache vehicle authentication data for offline operation**
- The system SHALL automatically sync stored data when connectivity is restored

3.5 SaaS Platform Integration (FR-SI)

FR-SI-001: API Integration

- The system SHALL integrate with existing SaaS platform through RESTful APIs
- The system SHALL authenticate with cloud services using secure protocols
- The system SHALL handle API responses and error conditions appropriately
- **NEW - The system SHALL support vehicle management APIs for registration and updates**

FR-SI-002: Real-time Updates

- The system SHALL enable real-time inventory updates on SaaS dashboard
- **NEW - The system SHALL provide real-time vehicle tracking and transaction updates**
- The system SHALL support configurable update intervals based on weight changes
- The system SHALL provide inventory change notifications to the SaaS platform
- **NEW - The system SHALL send vehicle performance and analytics data**

FR-SI-003: Data Synchronization

- The system SHALL maintain data consistency between local device and cloud platform
- The system SHALL resolve data conflicts using timestamp-based resolution
- The system SHALL support bulk data synchronization for initial setup
- **NEW - The system SHALL synchronize vehicle database and transaction history**

3.6 NEW - Vehicle Management and Analytics (FR-VM)

FR-VM-001: Vehicle Registration

- The system SHALL support registration of new vehicles through admin interface
- The system SHALL assign unique identifiers to vehicle NFC cards
- The system SHALL maintain vehicle profile information (ID, type, capacity, driver)
- The system SHALL support vehicle card replacement and reactivation procedures

FR-VM-002: Transaction Tracking

- The system SHALL log all vehicle transactions with complete audit trail
- The system SHALL calculate loading/unloading quantities per vehicle
- The system SHALL track transaction duration and efficiency metrics

- The system SHALL detect and flag unusual transaction patterns

FR-VM-003: Vehicle Performance Analytics

- The system SHALL calculate vehicle utilization and efficiency metrics
- The system SHALL track average loading/unloading times per vehicle
- The system SHALL generate vehicle-specific performance reports
- The system SHALL support comparative analysis between vehicles

3.7 Configuration and Calibration (FR-CC)

FR-CC-001: System Configuration

- The system SHALL support configuration of product-specific weight parameters
- The system SHALL allow configuration of network settings and cloud endpoints
- The system SHALL provide factory reset functionality
- **NEW - The system SHALL support NFC reader configuration and sensitivity adjustment**

FR-CC-002: Load Cell Calibration

- The system SHALL support guided calibration procedures using known weights
- The system SHALL store calibration parameters in non-volatile memory
- The system SHALL detect and alert for calibration drift or errors

FR-CC-003: NEW - Vehicle System Configuration

- The system SHALL support configuration of vehicle transaction timeouts
- The system SHALL allow customization of vehicle identification procedures
- The system SHALL support configuration of vehicle-specific weight limits and alerts

4. Non-Functional Requirements

4.1 Performance Requirements (NFR-P)

NFR-P-001: Weight Measurement Accuracy

- The system SHALL achieve weight measurement accuracy within ±50 grams
- The system SHALL maintain accuracy across operating temperature range
- The system SHALL provide consistent measurements under normal warehouse conditions

NFR-P-002: Response Time

- The system SHALL display weight changes within 500 milliseconds of detection
- **NEW - The system SHALL respond to NFC card detection within 200 milliseconds**
- The system SHALL transmit critical data to cloud within 2 seconds
- The system SHALL respond to user interface interactions within 200 milliseconds

NFR-P-003: Data Processing Speed

- The system SHALL process weight data and calculate inventory quantities within 100 milliseconds
- **NEW - The system SHALL process vehicle identification and transaction data within 100 milliseconds**
- The system SHALL handle multiple simultaneous weight measurements efficiently
- The system SHALL maintain real-time performance under normal load conditions

NFR-P-004: NEW - NFC Performance

- The system SHALL achieve >95% NFC card detection success rate
- The system SHALL support NFC card reading within 2-5cm range consistently
- The system SHALL process NFC card authentication within 300 milliseconds

4.2 Reliability Requirements (NFR-R)

NFR-R-001: System Availability

- The system SHALL maintain 99% uptime during normal operating hours
- The system SHALL recover automatically from temporary power interruptions
- The system SHALL continue operation during brief network connectivity issues

NFR-R-002: Data Integrity

- The system SHALL ensure 100% accuracy in data transmission to cloud platform
- **NEW - The system SHALL ensure 100% accuracy in vehicle transaction logging**
- The system SHALL implement error detection and correction for critical data
- The system SHALL maintain audit trails for all inventory and vehicle transactions

NFR-R-003: Fault Tolerance

- The system SHALL detect and report sensor failures automatically
- **NEW - The system SHALL detect and report NFC reader failures**
- The system SHALL continue operation with degraded functionality during component failures
- The system SHALL provide graceful degradation rather than complete system failure

NFR-R-004: NEW - NFC Reliability

- The system SHALL maintain NFC functionality across temperature and humidity variations
- The system SHALL provide consistent card detection despite physical wear
- The system SHALL support card detection with various card orientations within range

4.3 Usability Requirements (NFR-U)

NFR-U-001: Ease of Use

- The system SHALL require minimal training for warehouse staff operation
- **NEW - The system SHALL require minimal training for delivery drivers to use NFC cards**

- The system SHALL provide intuitive user interface with clear visual indicators
- The system SHALL support operation by users with basic technical knowledge

NFR-U-002: Installation and Setup

- The system SHALL support installation by technical staff within 2 hours
- **NEW - The system SHALL support vehicle card registration within 5 minutes per vehicle**
- The system SHALL provide automated setup procedures where possible
- The system SHALL include comprehensive setup documentation

NFR-U-003: NEW - Vehicle User Experience

- The system SHALL provide clear feedback for successful/failed card scans
- The system SHALL support intuitive transaction flow for drivers
- The system SHALL provide multilingual support for driver interface

4.4 Security Requirements (NFR-S)

NFR-S-001: Data Security

- The system SHALL encrypt all data transmissions to cloud platform
- The system SHALL implement secure authentication for cloud services
- The system SHALL protect against unauthorized access to configuration settings
- **NEW - The system SHALL protect vehicle identification data with appropriate encryption**

NFR-S-002: Network Security

- The system SHALL support secure WiFi protocols (WPA2/WPA3)
- The system SHALL validate server certificates for cloud connections
- The system SHALL implement secure firmware update mechanisms

NFR-S-003: NEW - NFC Security

- The system SHALL implement secure NFC communication protocols
- The system SHALL protect against NFC eavesdropping and replay attacks
- The system SHALL support NFC card deactivation and blacklisting
- The system SHALL log all security events and unauthorized access attempts

4.5 Compatibility Requirements (NFR-C)

NFR-C-001: Hardware Compatibility

- The system SHALL be compatible with standard warehouse pallet sizes
- The system SHALL operate with common 20kg load cell specifications
- The system SHALL support standard power supply voltages (5V/12V)
- **NEW - The system SHALL be compatible with ISO 14443 Type A NFC cards**

NFR-C-002: Software Compatibility

- The system SHALL integrate with existing SaaS platform APIs without modifications
- The system SHALL support common WiFi router configurations
- The system SHALL maintain compatibility with standard JSON data formats
- **NEW - The system SHALL support standard NFC communication libraries**

NFR-C-003: NEW - NFC Compatibility

- The system SHALL support common NFC card types (NTAG, MIFARE Classic)
- The system SHALL be compatible with standard vehicle fleet management cards
- The system SHALL support card programming using standard NFC tools

4.6 Environmental Requirements (NFR-E)

NFR-E-001: Operating Conditions

- The system SHALL operate in temperature range of 0°C to 50°C
- The system SHALL function in humidity levels up to 85% non-condensing
- The system SHALL withstand typical warehouse dust and vibration levels
- **NEW - The system SHALL maintain NFC functionality across full operating temperature range**

NFR-E-002: Power Requirements

- The system SHALL operate on 5V DC power supply with ±5% tolerance
- The system SHALL consume less than 2 watts during normal operation
- **NEW - The system SHALL include NFC reader power consumption within total power budget**
- The system SHALL support optional battery backup for 8+ hours operation

NFR-E-003: NEW - Physical Durability

- The system SHALL withstand typical warehouse physical impacts
- The system SHALL protect NFC reader from dust and moisture
- The system SHALL support outdoor loading dock environments

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5. System Constraints

5.1 Hardware Constraints

- **Microcontroller**: ESP32-based development board with WiFi capability
- **Load Cells**: Maximum 20kg capacity with appropriate load distribution
- **NEW - NFC Reader**: PN532 or RC522 module compatible with ESP32
- **Display**: OLED or LCD display suitable for industrial environment
- **Power**: Standard 5V/12V power supply with optional battery backup

5.2 Software Constraints

- **Development Platform**: Arduino IDE or ESP-IDF for firmware development
- **Programming Language**: C/C++ for embedded firmware
- **Communication Protocol**: HTTP/HTTPS for cloud communication
- **NEW - NFC Protocol**: ISO 14443 Type A for NFC communication
- **Data Format**: JSON for data exchange with SaaS platform

5.3 Regulatory Constraints

- **Safety Standards**: Compliance with industrial equipment safety standards
- **Electromagnetic Compatibility**: FCC/CE compliance for wireless operation
- **NEW - NFC Compliance**: FCC Part 15 and ETSI EN 300 330 for NFC operation
- **Data Protection**: Compliance with applicable data privacy regulations

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6. Assumptions and Dependencies

6.1 Assumptions

- Existing SaaS platform provides stable APIs for integration
- **NEW - Existing SaaS platform can be extended to support vehicle tracking features**
- Warehouse WiFi network provides reliable internet connectivity
- Standard warehouse pallets support load cell integration
- Warehouse staff will receive basic training on system operation
- **NEW - Delivery drivers will receive basic training on NFC card usage**
- Product weights are consistent and known for accurate inventory calculation
- **NEW - Vehicle fleet uses standardized NFC cards or can adopt them**

6.2 Dependencies

- **Hardware Procurement**: Timely delivery of electronic components including NFC modules
- **SaaS Platform**: Availability of existing platform for integration testing
- **NEW - Vehicle Database**: Access to vehicle fleet information for card registration**
- **Network Infrastructure**: Functional WiFi network in warehouse environment
- **Power Supply**: Reliable electrical power or battery backup system
- **Technical Support**: Access to technical documentation and support resources

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7. NEW - Vehicle Integration Specifications

7.1 Vehicle Card Requirements

- **Card Type**: ISO 14443 Type A compatible NFC cards
- **Memory**: Minimum 96 bytes for vehicle identification data
- **Range**: 2-5cm detection range for reliable operation

- **Durability**: Industrial-grade cards suitable for warehouse environment

7.2 Vehicle Data Structure

```
{
 "vehicleId": "string",
 "cardUID": "string",
 "vehicleType": "truck|van|forklift",
 "capacity": "number",
 "driverName": "string",
 "registrationDate": "ISO8601",
 "lastMaintenance": "ISO8601",
 "status": "active|inactive|maintenance"
}
```

7.3 Transaction Data Structure

```
{
 "transactionId": "string",
 "vehicleId": "string",
 "palletId": "string",
 "transactionType": "loading|unloading",
 "startTime": "ISO8601",
 "endTime": "ISO8601",
 "initialWeight": "number",
 "finalWeight": "number",
 "quantityChange": "number",
 "location": "string"
}
```

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8. Acceptance Criteria

8.1 Functional Acceptance

- All functional requirements (FR-WM, FR-NFC, FR-UI, FR-DC, FR-SI, FR-VM, FR-CC) are implemented and tested
- **NEW - NFC vehicle identification system functions reliably with >95% accuracy**
- System successfully integrates with existing SaaS platform
- Real-time inventory updates are accurately reflected in dashboard
- **NEW - Vehicle tracking and transaction data is accurately captured and reported**
- Local display shows correct weight, inventory, and vehicle information

8.2 Performance Acceptance

- Weight measurement accuracy meets ±50g specification

- **NEW - NFC card detection meets <200ms response time specification**
- System response times meet specified performance targets
- Network connectivity and data transmission function reliably
- System maintains 99% uptime during testing period

8.3 Integration Acceptance

- Seamless integration with existing SaaS platform without disruption
- API calls function correctly with proper authentication
- **NEW - Vehicle management APIs function correctly for registration and tracking**
- Data synchronization maintains consistency between device and cloud
- Error handling and recovery procedures function as specified

8.4 NEW - Vehicle System Acceptance

- NFC vehicle identification works reliably across all test vehicles
- Vehicle transaction logging captures complete audit trail
- Vehicle analytics provide meaningful performance insights
- System supports vehicle card management lifecycle

9. Validation and Verification

9.1 Testing Strategy

- **Unit Testing**: Individual component functionality verification including NFC module
- **Integration Testing**: System-level operation and API integration with vehicle features
- **Performance Testing**: Load testing and response time validation including NFC performance
- **User Acceptance Testing**: End-user workflow validation with actual drivers
- **NEW - Vehicle Testing**: Comprehensive testing with multiple vehicles and scenarios

9.2 Test Environment

- **Development Environment**: Breadboard prototype with test weights and NFC cards
- **Integration Environment**: Test SaaS platform instance with vehicle management features
- **Production-like Environment**: Warehouse simulation with actual pallets and test vehicles
- **Field Testing**: Limited deployment in actual warehouse environment with real vehicles

9.3 NEW - Vehicle Testing Scenarios

- Multiple vehicle simultaneous operation
- Vehicle card replacement and reactivation
- Emergency access procedures
- Vehicle performance analytics validation
- Driver training and usability testing

10. Future Considerations

10.1 Scalability

- Support for multiple smart pallets in single warehouse
- Central management system for multiple devices and vehicles
- **NEW - Fleet management integration for multi-location operations**
- Enhanced analytics and reporting capabilities
- Integration with additional warehouse management systems

10.2 Enhancement Opportunities

- Advanced sensor integration for improved accuracy
- Machine learning for predictive inventory management
- **NEW - AI-powered vehicle route optimization**
- Mobile application for warehouse staff and drivers
- **NEW - Blockchain integration for immutable transaction records**
- Enhanced security and authentication mechanisms

11. Glossary

Term	Definition
Load Cell	Sensor that converts mechanical force/weight into electrical signal
HX711	24-bit analog-to-digital converter designed for load cell applications
ESP32	Microcontroller with integrated WiFi and Bluetooth capabilities
NFC	Near Field Communication - short-range wireless technology
PN532	NFC controller chip supporting multiple communication modes
RC522	RFID/NFC reader module operating at 13.56MHz
UID	Unique Identifier - unique code stored on NFC cards
SaaS	Software as a Service - cloud-based software delivery model
Tare Weight	Weight of empty pallet without products
JSON	JavaScript Object Notation - data interchange format
API	Application Programming Interface
MQTT	Message Queuing Telemetry Transport protocol
IoT	Internet of Things
ISO 14443	International standard for proximity cards used in NFC

Document Control:

- **File Location:** docs/requirements-specification-v2.md
- **Version History:** v1.0 (Basic system), v2.0 (Added NFC integration)
- **Related Documents:** Project Proposal, System Architecture Design
- **Change Impact:** Major enhancement - added vehicle identification and tracking capabilities