

# Smart TOTE Tracker – Hardware Design Requirements (Draft v0.1)

## Purpose

Define baseline hardware requirements for the Smart TOTE tracker so that it:

1. Supports Smart TOTE logistics use cases (location, environmental monitoring, security), and
  2. Is technically aligned with **FedEx-approved trackers** (e.g., SenseAware M4) to facilitate future FedEx assessment and use on AT&T/FedEx lanes.
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## 1. Power & Battery Design

### Battery type & capacity

- **REQ-1.1** – The device shall use a **rechargeable Li-ion / Li-polymer battery pack**.
- **REQ-1.2** – Total battery energy shall be  $\leq 100 \text{ Wh}$  (IATA limit for lithium batteries in equipment); target range **5–20 Wh** for typical use.
- **REQ-1.3** – The selected cell/pack shall have an existing **UN38.3 test report**, or the final pack shall be qualified to **UN Manual of Tests and Criteria, Section 38.3**.

### Battery protection & safety

- **REQ-1.4** – Battery pack shall integrate a **BMS** providing:
  - Over-charge, over-discharge, over-current, and short-circuit protection.
  - Temperature monitoring and charge/discharge cut-off outside safe limits.
- **REQ-1.5** – The device shall support **safe charging** via USB or docking interface, with charge current and temperature limits defined.

### Power consumption & operating modes

- **REQ-1.6** – The tracker shall provide:
  - **Active mode** (full sensing + connectivity).
  - **Power-save mode** (reduced reporting interval).
  - **Deep sleep mode** with  $\mu\text{A}$ -level quiescent current.
- **REQ-1.7** – All radios (cellular, Wi-Fi, BLE, GNSS TX) shall be capable of **full hardware shutdown** under flight/aircraft mode (see Section 2).

### Labeling

- **REQ-1.8** – Product labeling and datasheet shall clearly state:
  - Battery chemistry
  - Voltage, capacity and Wh rating
  - Reference to **UN38.3 test report ID**

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## 2. RF Subsystem & Flight / Aircraft Mode

### Radio technologies

- **REQ-2.1** – Cellular: support **LTE-M and/or NB-IoT** bands relevant for AT&T and global roaming (final band list TBD).
- **REQ-2.2** – GNSS: support **GPS** plus at least one additional constellation (Galileo/GLONASS/BeiDou).
- **REQ-2.3** – Short-range (optional but recommended): support **Bluetooth Low Energy (BLE)** and/or **Wi-Fi 2.4 GHz** for warehouse pairing and configuration.
- **REQ-2.4** – For each radio, the design shall specify:
  - Supported bands/frequencies

- Max conducted TX power (dBm)
- Antenna type and placement

## Aircraft / flight mode

- **REQ-2.5** – The device shall implement a robust **Aircraft Mode** that ensures **full radio suppression** during flight operations.
  - **REQ-2.6** – Aircraft Mode shall be triggered by a combination of:
    - **Barometric pressure / altitude** changes,
    - **Motion profile** (take-off/landing patterns), and/or
    - **Time-based rules**,
 with thresholds to be defined during system tuning.
  - **REQ-2.7** – When Aircraft Mode is active, all transmitters (cellular, Wi-Fi, BLE, GNSS TX) shall be **disabled via hardware control lines**, not only via software flags.
  - **REQ-2.8** – A **ground-test / lab mode** may allow radios during simulated flights, but:
    - It shall require physical access (e.g., USB + secure command), and
    - It shall not be possible to enable accidentally in production shipments.
  - **REQ-2.9** – The device shall log Aircraft Mode state transitions for audit and certification evidence.
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## 3. Sensing & Data Logging

### Environmental sensing

- **REQ-3.1** – Temperature sensor covering at least **-20 °C to +60 °C**, accuracy **±0.5 °C** or better in the **-10 to +40 °C** range.
- **REQ-3.2** – Relative humidity sensor with typical accuracy **±3–5 %RH** in cargo-relevant range.
- **REQ-3.3** – Barometric pressure sensor to support altitude estimation and Aircraft Mode; resolution and range suitable for ground to cruising altitude.
- **REQ-3.4** – Optional: light sensor to detect **door open / exposure events**.

### Motion & handling

- **REQ-3.5** – 3-axis accelerometer (and gyro, if justified) to detect:
  - Shock / impact events (e.g. up to 16 g or higher).
  - Tilt and orientation changes.
  - Vibration patterns.
- **REQ-3.6** – Thresholds for “shock” and “rough handling” events shall be configurable.

### Data logging & storage

- **REQ-3.7** – The device shall include non-volatile memory sufficient to log:
    - Full trip history (events + periodic samples) for **at least 30 days** at nominal sampling/reporting rates.
  - **REQ-3.8** – Sampling shall be **adaptive**:
    - Lower-frequency logging during normal conditions.
    - Higher-frequency logging around anomalies (shock, door open, temperature excursions).
  - **REQ-3.9** – All records shall be **timestamped** and include **battery state-of-charge** and key diagnostics to support future AI/battery analytics.
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## 4. Mechanical, Environmental & System Design

## Form factor & integration

- **REQ-4.1** – The tracker shall be mechanically compatible with the Smart TOTE design:
  - Mounting position predefined (lid, frame, or dedicated cavity).
  - Access for charging/replacement without disassembling the tote.
- **REQ-4.2** – Dimensions and weight targets will be defined with the mechanical team but should be comparable to current FedEx-approved trackers.

## Ruggedness & environmental

- **REQ-4.3** – Target IP54 or higher (dust-protected, splash-resistant).
- **REQ-4.4** – The device shall withstand cargo-typical:
  - Vibration and shock profiles (inspired by RTCA DO-160 categories).
  - Operating temperature range aligned with logistics use (e.g. -20 °C to +60 °C).
- **REQ-4.5** – Enclosure materials shall be suitable for air cargo (non-flammable per relevant standards, no sharp edges).

## User interface

- **REQ-4.6** – Minimal local indicators:
    - Status LED(s) for power, network, and Aircraft Mode.
    - Optional button for wake-up/pairing, with lockout to prevent misuse in transit.
  - **REQ-4.7** – Configuration shall primarily be done through **BLE/Wi-Fi or wired interface**, not via complex physical controls.
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## 5. Certification & Compliance Architecture

### Regulatory approvals

- **REQ-5.1** – The RF design shall use **pre-certified radio modules** (where possible) to simplify regulatory approvals.
- **REQ-5.2** – The final product shall be designed for:
  - FCC (and ISED/CE as required).
  - UN38.3 (battery).
- **REQ-5.3** – Where feasible, the design should anticipate **aviation EMC** requirements (e.g. RTCA DO-160 Section 21), and compliance with:
  - FAA AC 91.21D
  - EASA AMC1.CAT.GEN/MPA.140
    - similar to the SenseAware M4 positioning.

### Security & firmware

- **REQ-5.4** – The MCU shall support **secure boot and signed firmware updates**.
  - **REQ-5.5** – The system shall support **remote disable / lock** capability for lost or compromised devices.
  - **REQ-5.6** – All configuration interfaces (USB, BLE, Wi-Fi) shall have **authentication** and, where applicable, **encryption**.
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## 6. Documentation & Technical Package

To support FedEx and airline approval, the following documentation shall be produced as part of the design:

- **REQ-6.1 – Product specification sheet**, similar in structure to SenseAware M4, including:
  - Dimensions, weight, environmental ratings.
  - Radio technologies, bands, max TX power.

- Sensors and performance specs.
  - Battery details and UN38.3 reference.
  - Compliance and certification list.
  - **REQ-6.2 – System block diagram** and high-level schematic showing MCU, radios, sensors, power architecture, and Aircraft Mode control paths.
  - **REQ-6.3 – Antenna layout and RF notes** (isolation, placement, ground plane description).
  - **REQ-6.4 – Aircraft Mode description:**
    - State machine diagram.
    - Detection logic (pressure, motion, time).
    - Failsafe behavior.
  - **REQ-6.5 – Test reports** (or plans) for:
    - RF performance and emissions (per FCC/CE).
    - Battery safety (UN38.3).
    - Key environmental and vibration tests.
  - **REQ-6.6 – Safety & risk analysis** (basic FMEA) focusing on:
    - Battery failure modes.
    - RF/EMI issues in aircraft environment.
    - Firmware malfunction affecting Aircraft Mode.
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## 7. Implementation Roadmap & Open Issues

### Near-term actions

- **REQ-7.1** – Confirm battery chemistry and target Wh rating consistent with air-cargo and FedEx expectations.
- **REQ-7.2** – Finalize radio set (LTE-M/NB-IoT bands, BLE/Wi-Fi yes/no) based on AT&T and global requirements.
- **REQ-7.3** – Define Aircraft Mode triggers and thresholds in consultation with potential certifying bodies / FedEx assessment.

### Open questions for FedEx / partners

- **OQ-1** – Is RTCA DO-160 testing mandatory for initial FedEx approval, or is documented Aircraft Mode + FCC/UN38.3 sufficient for pilots?
- **OQ-2** – Are there **specific TX power or duty-cycle constraints** FedEx prefers for trackers?
- **OQ-3** – Any preference or prohibition regarding **altitude-based flight-mode algorithms** vs. time-based only?