

## Claims

1. **A system for autonomous medication inventory management in a healthcare facility**, comprising:
  - **a plurality of automated dispensing cabinets (ADCs)** each including a locked storage for medications and a local computer controlling access and tracking transactions;
  - **a central inventory management server** communicatively connected to the plurality of ADCs;
  - **a usage monitoring module** on the server configured to collect, from each ADC, data on medication dispensing and usage over time;
  - **an inventory optimization module** that automatically calculates and updates a **PAR level** or stock threshold for each medication at each ADC based on the collected usage data and one or more predictive algorithms, such that the PAR level is dynamically adjusted to reduce stockouts and overstock conditions;
  - **a restock generation module** that triggers restocking of an ADC when its inventory for a medication falls below the updated PAR level, the restock generation module being further configured to interface with a central pharmacy system or automated storage to initiate dispensing of the required medication for delivery to the ADC;
  - **wherein** the system thereby **optimizes inventory levels in each ADC in real time** without requiring manual PAR level review.
2. **The system of claim 1**, wherein the inventory optimization module takes into account **medication expiration dates** and usage rates, and if it detects that a quantity of a medication at a first ADC is unlikely to be used before expiration, it generates a **redeployment recommendation** to transfer that quantity to a second ADC or location with higher expected demand for that medication.
3. **The system of claim 1**, further comprising **an integration interface** to an electronic health record (EHR) system that provides an electronic medication administration record (eMAR), and an interface to an admission-discharge-transfer (ADT) system, the system being configured to **cross-verify each medication removal** from an ADC against a corresponding eMAR entry and patient status:
  - wherein upon a user removing a medication from an ADC for a specified patient, the system automatically checks if an active medication order exists for that patient in the EHR and if the patient is currently admitted or valid in the ADT system;
  - and **if no matching order or active patient status is found**, the system generates an **alert or notification** indicating a potential discrepancy in documentation or unauthorized removal.
4. **The system of claim 3**, wherein the system waits a predefined short interval for a delayed eMAR documentation, and automatically clears the alert if a matching administration record is entered within that interval, otherwise logging the event as an **undocumented removal** for follow-up.
5. **The system of claim 3**, wherein the alert is provided in real-time to one or more of: a user at the ADC via the cabinet's user interface, a pharmacy management console, and/or

a security or diversion oversight dashboard, thereby enabling immediate investigation or correction by staff.

6. **The system of claim 1**, further comprising an **anomaly detection module** that analyzes ADC transaction logs, user activity patterns, and discrepancy records to identify **anomalous events** suggesting potential medication misappropriation or process errors, the anomaly detection module being configured to:
  - assign an **anomaly score** or risk level to each detected event or pattern based on deviation from expected behavior;
  - automatically **classify** anomalies into categories including at least documentation discrepancies, inventory count discrepancies, and user behavior anomalies.
7. **The system of claim 6**, wherein the anomaly detection module employs **machine learning models** trained on historical data to improve accuracy of detecting diversion-related behavior, and wherein the module updates the anomaly score thresholds or model parameters over time based on feedback from confirmed investigations (such as marking an alert as false positive or confirmed diversion).
8. **The system of claim 6**, further comprising an **automated discrepancy resolution module** that applies a set of rules to **discrepancy events** (inventory count mismatches in an ADC):
  - if the anomaly score for a discrepancy is below a certain low threshold indicating a benign or explainable cause, the module automatically marks the discrepancy as **resolved** with a predefined reason code and adjusts inventory records accordingly;
  - if the anomaly score exceeds the threshold, the discrepancy remains open and is escalated for human review along with contextual data gathered about the event.
9. **The system of claim 8**, wherein the contextual data gathered for a discrepancy or anomaly includes one or more of: relevant ADC transactions (before/after the event), the identities of users involved, video or access logs from the time of the event (if available), related eMAR entries, and historical anomaly metrics for the same user or medication, thereby providing investigators a comprehensive view through the system's interface.
10. **The system of claim 6**, wherein the anomaly detection module identifies **patterns of behavior** by correlating multiple events, and in particular can detect when a single user is associated with a statistically abnormal frequency of certain events (such as frequent overrides, repeated undocumented withdrawals, or excessive wasting of controlled substances) and in response the system generates a **possible diversion alert** for that user.
11. **The system of claim 10**, wherein upon generating the possible diversion alert, the system is configured to **automatically restrict or suspend** the user's access to one or more ADCs if the risk is deemed critical (based on a configurable policy), and requires managerial override to restore access[12].
12. **The system of claim 1**, further comprising a **secure audit logging subsystem** that records all transactions and system events in an **immutable ledger** data structure:
  - wherein each log entry includes a timestamp, event details, and a cryptographic hash linking it to previous entries such that any attempt to modify or remove an entry is

detectable;

– and wherein the ledger can be implemented using a blockchain or append-only secure log technology to ensure **tamper-evident audit trails**.

13. **The system of claim 12**, wherein the secure audit logging subsystem stores entries related to controlled substance handling, including dispenses, returns, waste, discrepancies, and resolutions, and is configured to provide **verifiable evidence** of each event for regulatory compliance purposes.
14. **The system of claim 12**, further comprising a **compliance report generator** that automatically compiles data from the immutable ledger and other system records into a **compliance packet** (covering a specified reporting period), the compliance packet including aggregated and itemized information required by oversight bodies (such as DEA logs of all Schedule drug transactions, discrepancy resolution reports, etc.).
15. **The system of claim 14**, wherein the compliance report generator applies a **digital signature** to the compliance packet using a private cryptographic key associated with the hospital or responsible pharmacist, thereby sealing the report and enabling recipients to verify that the report has not been altered since generation.
16. **The system of claim 14**, wherein the compliance packet generation is **on-demand or scheduled**, and the system allows authorized users to initiate generation for an auditing period, after which the system outputs a human-readable file (PDF or similar) and/or a machine-readable dataset, both of which are signed or hash-verifiable.
17. **The system of claim 1**, wherein the central inventory management server further comprises an **integration manager module** configured for interfacing with external systems via application programming interfaces (APIs) or messaging protocols, the integration manager module including **self-healing logic** to handle communication failures:
  - if an API call to an external system fails or times out, the integration manager automatically retries the call or routes it to an alternate backup service;
  - if a connection to a data feed (for ADT or eMAR updates) is lost, the integration manager raises an alert and begins buffering relevant events, and upon restoration of the connection, flushes the buffered events in correct sequence to maintain data consistency.
18. **The system of claim 17**, wherein the integration manager module monitors the status of each external integration (through heartbeats or acknowledgments) and can proactively **reinitialize connections** or switch to a redundant interface if the primary interface has not responded for more than a predefined interval, thereby minimizing downtime of the data exchanges.
19. **The system of claim 17**, wherein the integration manager provides a **transaction queuing mechanism** such that any action that depends on an external system (including restock orders, verification of eMAR, etc.) is placed in a queue if the external dependency is unavailable, and the queued actions are automatically executed once the connection is restored, ensuring no data or command is permanently lost due to transient outages.

20. **The system of claim 1**, wherein the restock generation module (of the inventory optimization) is integrated with an **automated pharmacy storage and retrieval system** such that restocking tasks are sent directly as pick instructions to a robotic storage (carousel or equivalent):
- the system generates a digital pick list identifying medications and quantities to be loaded to a specific ADC;
  - the automated storage processes the pick list and dispenses or stages the items for delivery;
  - and upon delivery, the system verifies the restocked items by scanning or electronic acknowledgment, updating the ADC inventory counts accordingly.
21. **A method of managing medication inventory and usage in a hospital environment** using a computerized platform, comprising steps of:
- a. **Collecting usage data** from automated dispensing cabinets (ADCs) regarding medications dispensed, returned, and remaining stock levels;
  - b. **Analyzing the usage data** to determine usage trends for each medication at each ADC, and computing adjusted inventory par levels based on the trends and anticipated demand;
  - c. **Automatically updating configuration** of the ADCs with new par levels and triggering restock orders when current inventory falls below the updated threshold;
  - d. **Monitoring transactions** at the ADCs in real time and cross-referencing each transaction with electronic medication administration records and patient admission/discharge status;
  - e. **Identifying discrepancies or mismatches** when an ADC transaction lacks corresponding documentation or involves a patient not in appropriate status, and promptly alerting staff or logging an anomaly;
  - f. **Scoring anomalies** by severity or likelihood of drug diversion using an algorithm or trained model that considers patterns of behavior and historical data;
  - g. **Automatically resolving low-risk discrepancies** by applying predefined logic and marking them resolved in the system's records, while flagging higher-risk anomalies for human investigation;
  - h. **Recording all events** (including transactions, detected anomalies, and resolution actions) in an immutable log to maintain a secure audit trail;
  - i. **Generating a compliance report** at defined intervals by aggregating logged data for controlled substances and other regulated aspects, and digitally signing the report to certify its integrity;
  - j. **Maintaining integration** with external health IT systems and employing a self-healing interface mechanism that queues operations and retries connections to ensure continuous data flow despite temporary outages.
22. **The method of claim 21**, wherein step (b) (computing adjusted par levels) utilizes a **machine learning forecast** that takes as input historical dispensing patterns, ward-specific factors, and upcoming scheduled medication orders to output an optimal stock range, thereby continuously adapting stock thresholds to current needs.
23. **The method of claim 21**, wherein step (d) (monitoring transactions) further comprises capturing the identification of the user performing the ADC transaction and the exact

timestamp, and comparing those with shift schedules and user profiles, such that unusual timing (e.g., transactions outside of assigned shift hours) is also detected as a potential anomaly.

24. **The method of claim 21**, wherein step (g) (automatically resolving low-risk discrepancies) includes generating an **explanatory note** stored in the system for each auto-resolved discrepancy, the note describing the rationale (for example, “resolved by matching to transaction X, likely counting error by user, inventory adjusted by +1”) to maintain transparency for later audit.
  25. **The method of claim 21**, wherein step (i) (generating a compliance report) further comprises encrypting the report or the underlying audit log data when transmitting it or storing it, ensuring that sensitive information is protected, and wherein the digital signing is compliant with regulatory standards for electronic records and signatures in healthcare.
  26. **A non-transitory computer-readable medium** storing instructions which, when executed by one or more processors of a medication management server system, cause the system to perform the method according to any of claims 21-25.
  27. **A medication dispensing management apparatus**, comprising:
    - hardware and software means for **dispensing and tracking medications** at distributed locations (including automated cabinet devices);
    - means for **data communication** with electronic medical record and patient administration systems;
    - means for **computational analysis** of inventory and usage data;
    - and means for **secure logging and reporting**;
    - wherein the apparatus is configured to function in accordance with the system of claim 1, thereby providing an integrated solution for medication inventory optimization, discrepancy reduction, and compliance management.
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