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(Research Article)

A lean approach to eliminating manual search and identification waste in server repair operations using a GPS-assisted hybrid tracking system

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Abstract

This study developed a prototype hybrid tracking system intended to reduce manual search and identification waste in server repair operations. Unlike pure GPS-based systems, which are unreliable in indoor environments due to signal obstruction, the proposed system integrates GPS, Bluetooth, and Cellular (GSM/LTE) connectivity to provide practical indoor localization capability. The problem originated from the current repair workflow where technicians spend working hours searching for server machines and manually verifying identification numbers before actual repair work can begin. Using baseline data from one 8-hour work shift, the study found that out of 275 missing server machines, only 88 units were located while 187 units remained unfound—a retrieval rate of only 32.00%. The remaining 187 units often spilled into subsequent workdays, compounding the operational backlog. To address this problem, the study proposed a system that binds a hybrid tracker to a server machine through its unique serial number and allows the user to locate the machine using a command sent via a mobile application, triggering a fast-blinking RGB LED alert and an audible beep to eliminate manual search waste. The study employed a developmental-descriptive design and relied on frequency counts and percentage analysis. The findings confirm that the current process contains Lean-related waste—specifically motion and waiting—and that a hybrid tracking approach is a practical intervention for improving machine traceability in repair operations. The study is limited to prototype development and baseline analysis, but it provides a solid foundation for future implementation and time-based performance evaluation.

Keywords: Lean Operations; Server Repair; Hybrid Tracking System; GPS, Bluetooth; Machine Identification; Process Waste

1. Introduction

Lean operations focus on removing activities that do not add value to the work process. In repair operations, one persistent source of waste is the time and effort spent walking around, searching for the correct unit, and verifying its identity before actual repair work can begin. Lean literature classifies these activities as motion waste and waiting waste [1]. Based on the baseline data gathered in this study, 275 server machines were recorded as missing across three models. Within one 8-hour work shift, only 88 machines were found, while 187 machines remained unlocated. These figures confirm the presence of a substantial volume of non-value-adding activity that slows down repair throughput.

The challenge of tracking assets in complex operational environments is not unique to IT repair settings. Valero, Adan, and Cerrada [6] conducted a comprehensive review of RFID applications in the construction industry and demonstrated how location and identification technologies have successfully reduced search-related inefficiencies and improved resource traceability in environments that are similarly large-scale and spatially complex. Their findings underscore that the principle of using tracking systems to eliminate manual search waste is broadly applicable across industries where physical assets must be rapidly located and identified before work can proceed.

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Related studies reinforce this point within technology-driven settings. Lin et al. [3] demonstrated that barcode and RFID technologies can improve maintenance information handling and reduce identification errors. Yoo et al. [4] showed that real-time location systems can support day-to-day asset management in operational environments. Ahmed et al. [5] compared several seamless indoor and outdoor tracking approaches and highlighted the value of technology combinations for mixed environments. Hailu et al. [2] further stressed that indoor positioning presents distinct challenges compared to outdoor tracking, as signal behavior, environmental obstructions, and device model inn all affect system accuracy.

This study was motivated by the direct observation that technicians in the target repair operation spend measurable portions of their shift simply locating machines and manually confirming serial numbers before any value-adding work can begin. Since these activities contribute nothing directly to the repair outcome, they are classified as waste under Lean principles. The researcher explored a practical hybrid tracking solution that integrates GPS for outdoor and open-area positioning with Bluetooth and Cellular connectivity for indoor localization support.

The study asked one central research question: how can a hybrid tracking-based system help reduce manual search and identification waste in server repair operations? The study does not yet claim final performance gains through a controlled before-and-after time study, as exact per-unit search time records were unavailable. Instead, it uses existing operational data to quantify the current waste condition and to justify the development of the proposed prototype.

2. Methodology

This study employed a developmental-descriptive research design. The developmental component covered the design and construction of the GPS-assisted hybrid tracking system prototype, while the descriptive component focused on characterizing the current repair process condition using available baseline data. The study was bounded to a single repair operation facility where server machines are manually searched and identified prior to repair. The unit of analysis was the individual server machine, categorized into three model types: Model 4.0, Model 2.0, and Model 6.0.

The baseline data were drawn from a work-shift record documenting the number of missing server machines, the number of units located within an 8-hour shift, and the number of units remaining unresolved at the end of that shift. Because stopwatch-based or log-based per-unit search time records were not available, the study did not apply a time-and-motion methodology. Frequency counts and percentage rates were used instead, which were appropriate for describing the scale of the current problem given the available data.

Figure 1 GPS-Assisted Hybrid Tracking Device

2.1. Prototype Development and System Architecture

The prototype developed in this study is a GPS-assisted hybrid tracking device engineered to function effectively in both indoor and outdoor repair environments. The device integrates three distinct communication and positioning technologies: a GPS module for outdoor and open-area positioning, a Cellular module (GSM/LTE) with an embedded SIM card for wide-area network connectivity and remote command transmission, and a Bluetooth module for short-range indoor localization support. This multi-technology architecture directly addresses the well-documented limitation of GPS systems in indoor environments, where satellite signal reception is obstructed by structural materials [2].

The hardware specifications of the prototype are as follows. The device is powered by a 2400 mAh Sipos rechargeable battery, which supports charging via a standard Type-C connector at 5V/2A. Under active operational use, the battery provides sufficient power for daily shift operations; in sleep mode, it can sustain up to five days of standby operation. The device also features a multi-color RGB LED indicator that communicates battery status to the user immediately upon binding. Three blinks of the LED indicate the current charge level: green blinks indicate a full charge, blue blinks indicate approximately 50% remaining charge, and red blinks indicate a low battery level of approximately 20%, prompting the user to recharge the device before use.

The system workflow proceeds through three distinct phases: Binding, Locating, and Alerting. During the Binding phase, the tracker is physically attached to a server machine and registered to that machine's unique serial number through the companion mobile application. This creates a one-to-one digital association between the physical device and its corresponding server record in the database. During the Locating phase, when a technician needs to find a specific machine, they issue a Find command through the mobile application by referencing the machine's serial number. During the Alerting phase, the tracker responds to the received command by activating fast-blinking RGB LED lights and emitting an audible beep sound, allowing the technician to visually and audibly identify the machine's physical location without manual searching.

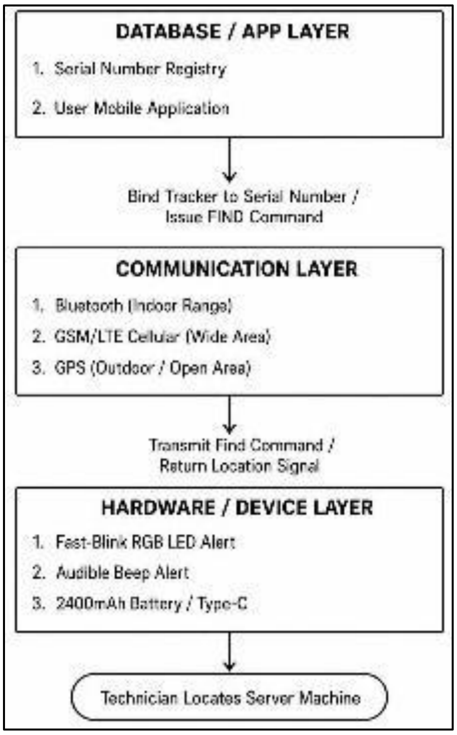

Figure 2 System Architecture and Workflow of the Proposed Hybrid Tracking System

As shown in the system architecture diagram, the workflow is organized across three functional layers. The Database and Application Layer manage the serial number registry and serves as the user interface through which the technician issues commands. The Communication Layer handles signal transmission across multiple channels, with Bluetooth providing localized indoor range, GSM/LTE enabling wide-area connectivity for remote tracking, and GPS supporting outdoor positioning. The Hardware and Device Layer is the physical tracker itself, which responds to received commands through its RGB LED and audible alert mechanisms. This layered architecture ensures that the system remains functional across different physical environments within the repair facility, whether in open warehouse spaces or enclosed server rooms.

Table 1 Input-Process-Output Model of the Proposed System

Input	Process	Output
GPS/Hybrid Tracker Server machine with unique serial number User command via mobile application	Bind tracker to machine serial number Send Find command via app Activate LED and audio alert	Real-time server location Audible and visual tracking alert Faster machine identification

The statistical treatment used in the study was limited to frequency counts and percentage analysis. The Found Rate was computed as the number of found units divided by the number of missing units, multiplied by 100. The Remaining Rate was computed as the number of remaining units divided by missing units, multiplied by 100. The Overall Retrieval Rate was the total found units divided by total missing units, multiplied by 100. These measures were appropriate for the present study's objective of describing the scale of the existing waste problem and justifying the proposed prototype.

3. Results and Discussion

This section presents the baseline results of the current server search condition and examines the findings through a Lean operations lens. Since the available data cover one 8-hour work shift, the discussion focuses on what the counts and percentages already reveal about systemic process inefficiency. The section does not assert final prototype performance gains; rather, it establishes the operational waste condition that the proposed hybrid tracking system is designed to address.

Table 2 Summary of Missing, Found, and Remaining Server Machines

Model	Missing	Found (8 HRS)	Remaining
4.0	138	28	110
2.0	57	26	31
6.0	80	34	46
Total	275	88	187

Table II presents the full baseline count of server machines across the three models. Model 4.0 had the highest volume of missing units at 138, followed by Model 6.0 with 80 and Model 2.0 with 57. After one complete 8-hour work shift, only 88 units in total were located, while 187 units remained unfound. This outcome demonstrates a significant deficit in machine visibility and traceability within the current process. A repair operation cannot sustain efficient throughput when the majority of required units must still be manually searched at shift end.

It is also important to note that the 187 unresolved units do not simply disappear at the end of the shift. In practice, these machines carry over into subsequent workdays, where search activities must be resumed before repair work can continue. This multi-day carryover creates a compounding bottleneck: each day that begins with an unresolved backlog of missing machines further delays repair scheduling, reduces technician productivity, and accumulates additional motion and waiting waste across the operation.

Table 3 Found and Remaining Rates per Model

Model	Found Rate	Remaining Rate
4.0	20.29%	79.71%
2.0	45.61%	54.39%
6.0	42.50%	57.50%
Overall	32.00%	68.00%

Table III translates the raw counts into proportional rates. Model 2.0 showed the highest retrieval rate at 45.61%, followed by Model 6.0 at 42.50%. Model 4.0

recorded the lowest found rate at only 20.29%, meaning that nearly four out of five missing units in that model were still unlocated after a full 8-hour shift. The overall found rate across all models was only 32.00%, while 68.00% of all missing machines remained unresolved. From a Lean standpoint, these figures represent clear evidence of motion waste—technicians moving through the repair area to search manually—and waiting waste—repair work that cannot begin until the correct machine is physically found and identified [1].

Table 4 Distribution of Unresolved Units After an 8-Hour Work Shift

Model	Remaining Units	Share of All Remaining
4.0	110	58.82%
2.0	31	16.58%
6.0	46	24.60%
Total	187	100.00%

Table IV reveals the concentration of the unresolved workload. Model 4.0 alone accounted for 58.82% of all remaining units at shift end, making it the dominant source of carryover waste. Model 6.0 contributed 24.60% and Model 2.0 contributed 16.58%. These proportions have practical implications for implementation prioritization: a deployment strategy that targets Model 4.0 machines first would yield the largest immediate reduction in unresolved backlog.

The baseline results support the relevance of the proposed hybrid tracking system. When a tracker is pre-bound to a server machine's serial number, the technician no longer needs to rely on memory, visual inspection, or verbal inquiry to locate the unit. A simple Find command through the mobile application triggers the device's LED and audio alert, guiding the technician directly to the machine. This workflow aligns with findings from Lin et al. [3] and Yoo et al. [4], who demonstrated that identification and location technologies reduce search steps and improve asset visibility. It also reflects the multi-technology integration approach recommended by Ahmed et al. [5] for environments that require both indoor and outdoor tracking capability.

3.1. Indoor Tracking Environment and System Limitations

One important limitation of any GPS-based tracking approach is its performance in indoor environments. Pure GPS systems rely on line-of-sight satellite signals, which are significantly attenuated or blocked entirely by building structures, metal server racks, and dense equipment layouts typical of repair and warehouse facilities [2]. A system relying solely on GPS would therefore be unreliable for the majority of server search scenarios, which occur indoors.

The proposed prototype addresses this limitation through its hybrid architecture. The Bluetooth module provides short-range indoor positioning by enabling proximity-based detection when the technician is within the same room or area as the target device. The GSM/LTE Cellular module supplements this by maintaining network connectivity even when GPS signals are unavailable, allowing the Find command and alert response to function through the cellular network instead. Together, these fallback mechanisms ensure that the system retains practical utility in the indoor server repair environment even when satellite positioning is not possible.

Nonetheless, residual limitations remain. In highly obstructed indoor environments with weak cellular coverage, localization accuracy may still be degraded. The current prototype has not yet been subjected to a controlled accuracy test across all areas of the target facility. These constraints represent meaningful avenues for future research, including indoor signal mapping, Bluetooth beacon triangulation for finer-grained positioning, and integration with the facility's Wi-Fi infrastructure for additional location layers. The present study acknowledges these limitations and positions them as the primary targets for the next phase of system development.

4. Conclusion

This study found that the current server repair operation contains a significant volume of manual search and identification waste. Out of 275 missing server machines, only 88 were located within one 8-hour work shift, yielding an overall retrieval rate of 32.00% and leaving 187 units unresolved. These unresolved units frequently carry over into subsequent workdays, creating a compounding operational bottleneck that delays repair scheduling and reduces technician productivity. The baseline findings confirm the presence of motion waste and waiting waste as defined by Lean operations principles [1].

To address this problem, the study developed a GPS-assisted hybrid tracking system prototype that integrates GPS, Bluetooth, and Cellular (GSM/LTE) connectivity to support both outdoor and indoor machine localization. The device binds to each server machine's unique serial number and responds to a Find command issued through a companion mobile application by activating fast-blinking RGB LED lights and an audible beep alert. The system's three-layer architecture—Database/Application, Communication, and Hardware—ensures that tracking capability is maintained across different physical environments within the repair facility, including indoor areas where pure GPS signals are unreliable.

The study concludes that a hybrid tracking-based approach is both technically feasible and operationally relevant for improving machine traceability in server repair operations. The current work is bounded to prototype development and baseline descriptive analysis. Future researchers are encouraged to measure actual per-unit search times before and after implementation, conduct field accuracy testing across all indoor zones of the facility, evaluate user experience among technicians and supervisors, and explore additional indoor positioning layers such as Wi-Fi triangulation or Bluetooth beacon arrays to improve localization precision.

Overall, this study provides a workable and technically grounded starting point for eliminating manual search waste in server repair operations through a Lean-aligned hybrid tracking solution. The baseline data and system architecture presented here give organizations a clear view of where waste is occurring and a concrete prototype framework for addressing it.

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