# Applicability of RTLS in the Manufacturing Industry

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**Abstract.** This study investigates the applicability, performance, and sustainability of Real-Time Locating Systems (RTLS) in production logistics, with a focus on the automotive industry. RTLS, as part of broader supply chain visibility and digitalization efforts, supports decision-making, risk management, agility, and inventory control. However, adoption challenges include budget constraints, electromagnetic interference, lack of standardization, and reluctance to share data. The paper specifically examines two RTLS technologies—Cargo Beacon (CB) and GEPS sensors—within a Scania production environment. An experimental research design, complemented by a systematic literature review, was employed. Quantitative data were collected through controlled and uncontrolled experiments to assess accuracy, precision, and lag time, while qualitative insights addressed sustainability and integration challenges. Performance analysis revealed that CB sensors, though precise (symmetrical distributions, low skewness), suffered from frequent sleep-mode interruptions, resulting in higher lag (average 43s) and significant RMSE in path tracking (4.02–4.61). In contrast, GEPS sensors demonstrated higher accuracy and reliability, with low RMSE (0.11–0.13) and better consistency despite being less precise. Both sensors lacked z-axis tracking and historical path data, limiting their utility in 3D inventory management. The study also identified critical gaps in system interconnectivity, especially regarding real-time responsiveness and integration with complementary technologies such as barcodes, blockchain, and visual recognition systems. Conclusions point to the need for tailored applications of RTLS based on technological constraints and context-specific logistics goals. For optimal impact, firms must define what assets to track, balance power consumption, cost, and data granularity, and complement RTLS with interoperable systems for holistic visibility. Despite limitations, RTLS remains a promising enabler of sustainable logistics when implemented with clarity, purpose, and technological alignment within Industry 4.0 frameworks:

**Keywords:** interconnectivity 1, sustainability 2, production logistics 3

## 1. Introduction

Logistics and supply chain network visibility and collaboration through information sharing, both internal and external to the organization, have been the drivers to give an organization and its network the following benefits and competitive advantages: risk management, decision making support, safety, quality, customer-service, agility, lead time management, demand management, access to information and inventory management, (Astakhov, V. P., 2012). This has been seen as the development of visibility enabling technologies from SKU (Stock Keeping Unit), Bar Code, and QR Codes which needs a line of sight without sensors, to Cyber Physical Systems (CPS) that collects data using sensor technologies, wireless technology communication systems and transmit data to Industrial Internet of Things (IIoT) with no line of sight such technologies include Radio Frequency Identification (RFID tags), Smart Label (Real Time Locating System/RLTS), Geographic Information System (GIS), Global Positioning System (GPS), (Ela Innovation, 2022). However, these technologies present the following challenges: budget constraints, risk of losing business, reluctant to provide data, conflict of interest, disparate sources of information, lack of standardization, lack of skills and knowledge, and supply chain complexity, (Astakhov, V. P., 2012).

## 2. Objectives

The purpose of this research is to focus on the RLTS technology and expose its behavior in automotive industrial setup. It is very important to understand how RTLS technologies work, their implication to the environment and society throughout their life cycle and the applicability of this technology in logistics. To that end the research has the following research questions:

1. Is RTLS technologies compatible with other technologies in production logistics and supply chain management?
2. What challenges, enablers and opportunities are presented by RTLS technologies in production logistics and supply chain management?
3. Is RTLS technologies sustainable in regard to production logistics and supply chain management?

The paper will start with an abstract followed by an introduction, followed by methodology, then a systematic literature review (RLTS technology, application of RTLS, interconnectivity and sustainability), then followed by the experimental setup, followed by results, discussion and analysis and lastly conclusion.

## 3. Materials and Methods

The research method is experimental research design, which is quantitative in nature, however, some qualitative research will be done through a systematic literature review on the topic, comparing with results of experiments conducted on two different RTLS technologies provided by Scania. The theoretical perspective will showcase the possibilities of RTLS in production logistics while the analysis of experiment will indicate whether the sensors are applicable in the industry. The comparison will result in discussion of relevant applicability and future direction new reports could take. The authors will collect continuous data about the performance on the sensors to investigate accuracy and precision on path, position and lagging, and make an investigation on the technologies, there applicability with respect to sustainability. The authors will collect the data from an automotive industrial site (controlled and uncontrolled – with less electro-magnetic waves). These technologies have a human-machine interface which gives their location in real-time, which the authors record.

The experiment covers the performance of the available RTLS technology provided by Scania. It was decided to limit the scope to a simple experimental layout to see the results more clearer. That means that variables were not moving over time with the help of AGVs and were only moved between places by us. What could be measured were coordinates given by the systems, that are better described in section A, as well as the lag of reaction from the system. Those coordinates could be used to analyze the performance in a quantitative way.

### *A. Specifications of technologies*

#### *1) Cargo beacon*

Ela technology can be used to locate number of operators and tools present on the site, knowing in which zone or on which floor they are, will reduce amounts of accidents in the event of incidents (fire, collapse) each operator will receive an audible and visual alert telling them to evacuate. Improving the safety of a section, through restricting people with certain badges, means improving its overall performance by avoiding potential delays caused by lost time injury. The infrastructure is made of both fixed (anchors) and mobile network beacon which create a network mesh. The mobile beacons (TIM) does not use GPS technology but Blue Tooth (IEEE1451,5) to transmit data to the nearest NCAP (fixed beacon) and then to the industrial gateway (IEEE802,X). Placed at a few strategic locations, these gateways will centralize the raw data and transmit it to the client's server (Hyper Text Transfer Protocol) over internet or local area network. The information will be transformed into GPS data by the Wirepas Positioning Engine. Once the data is transformed, the end user will be able to visualize it on the business application. Time to locate inventory is less when using this technology, (AstraZeneca, 2022).

#### 2) GEPS

H&D Wireless' proprietary solution GEPS for Industry (Griffin Enterprise Positioning Services) enables a higher degree of visualization and automation for the logistics flow of manufacturing companies. The system digitizes and visualizes physical processes and identifies, among other things, the handling of materials, bottlenecks in production, utilization rate of resources and unexpected machine interruptions through radio positioning and artificial intelligence (AI). The ambition is to reduce manufacturing costs, reduce lead times and tied-up capital. GEPS for Industry currently has five sub-services for Asset management, Safety, Fleet management, Production Logistics and External Logistics, (H&D Wireless., 2022). The Wi-Fi solutions from GEPS Wireless are supported on leading Microcontroller platforms including 8-bit, 32-bit AVR, ARM, Corte, (Kalaiarasan, R et al., n.d.). The architecture and communication protocol standards are the same as Cargo Beacon. However, the only difference is that GEPS sensors work with wireless. Table 2 shows the main difference between the two technologies.

**Table 1: Table 2: Comparison between Bluetooth and Wifi Technology**

| | | |
|---|---|---|
| **Standards** | IEEE 802.15.1 WPAN;Blue Tooth (Cargo Beacon) | IEEE802.11 WLAN Wifi (GEPS) |
| **Range** | 100m | 5km |
| **Data Rate** | 1-3kbps | 1-45Mbps |
| **Frequencies (Bandwidth)** | 2.4GHz | 2.4, 3.7 & 5GHz |
| **Network Topology** | Star | Star, Tree, P2P |
| **Applications** | Wireless sensors (Monitoring and Control) | PC-based Data Acquisition, Mobile Internet |

### B. Design of experiments and set-up

Using the steps described by V. Astakhov in 2012 the design of experiments (DOE) was established, (Mueller, D & Vogelsang, F, 2021). The problem faced was the lack of understanding how the sensors worked and what performance they could result in. This understanding was needed to decide if the technology could be recommended or not. Overall, the objective of the experiment was to find out if these two technologies were applicable in production logistics; both when it came to accuracy of the sensed location of the tags as well as in the responsiveness of the system used. The solution would give more clarity if RTLS could truly be used as was stated in the literature.

The variables that could be measured were the coordinates from the system as well as the time of lag in it. The controllable factors that could affect the outcome were the three different sensors available and where they were located in Scania's Smart Factory Lab, either as coordinates or if they were in a specific controlled environment or not. Uncontrollable variables were people walking around, AGVs moving near the experiment, electric cables which produced EM signals, Bluetooth because of other devices, and Wifi volatility in the lab. The coordinates the systems measured had an accuracy of 15 decimal points in the Cargo Beacon but GEPS used a different reference point, so the coordinates were all integers.

The experiment itself was conducted on the floor of Scania's Smart Factory Lab. It could be split into two general parts; all iterations would be done both in a more controlled area and on top of a magnetic strip to see if that affects the performance. The controlled area was still affected by other environmental disturbances in the room, just not the magnetic strip. Within each part, two separate factors were measured, position and path, and the response of lag was also measured.

The set-up in the lab was as follows; the magnetic strip was measured with the length of 4210mm, so a tape of same length was put on the floor on the other side of the room. One part of the strip and tape was marked A and the other B for documentation purposes. Description of each part of the experiment are as following:

1) The position was measured by moving each sensor ten times between A and B, each time collecting data about the coordinates. This would show if the sensors were giving out the same coordinates for the same positions or not.
2) In the path part, the strip and tape were split into ten intervals with eleven positions and sensors moved stepwise from A to B and coordinates documented. The path was repeated two times for each sensor, so 22 measurements in total per sensor. By documenting the path, it was possible to see deviations of coordinates from the actual location on the line.
3) The lag of the systems was measured by doing the same movement of sensors as in the position part, but here the time from when the sensor was moved until the movement was shown in the system, would be measured. Lag was measured ten times for each sensor. The amount of lagging will show how responsive the system was and assist with the realization of where the technology would be applicable.

## 4. Results

The experiment was conducted on three separate occasions, and the same set-up was used each time. The same sensors were used and had the following tag ID.

- Cargo Beacon, circle: 9168862 and 5357987
- Cargo Beacon, rectangle: 11830416
- GEPS: AGV1

After the introduction of the equipment, we realized that the two software programs gave different data, Cargo Beacon (CB) only gave the last known coordinates while GEPS could track the movement. Also, the coordination system for both was different so it was not possible to compare results directly. Lastly, the output given by the GEPS website was just the location itself in the environment but not the coordinates, so a Scania employee had to design an API that resulted in coordinates. That caused us to only being able to test the GEPS on the last two occasions. Examples of the data collected for the sensors can be seen on table 2.

**Table 2: Example of data collected**

| | Sensor | Sensor 1 - Controlled | | | | |
|---|---|---|---|---|---|---|
| | | Expected Value | | Actual Value | | |
| Trial no | Position | X | Y | X | Y | Delta Sensor 1 - Controlled |
| 1 | A | 59,16766624 | 17,6431078 | 59,16770935 | 17,64313126 | 0,00005 |
| 2 | A | 59,16766624 | 17,6431078 | 59,16765976 | 17,64304543 | 0,00006 |
| 3 | A | 59,16766624 | 17,6431078 | 59,16770935 | 17,64310265 | 0,00004 |
| 4 | A | 59,16766624 | 17,6431078 | 59,16761017 | 17,64312744 | 0,00006 |
| 5 | A | 59,16766624 | 17,6431078 | 59,16766357 | 17,64319229 | 0,00008 |
| 6 | A | 59,16766624 | 17,6431078 | 59,16764069 | 17,64305496 | 0,00006 |
| 7 | A | 59,16766624 | 17,6431078 | 59,16765976 | 17,64307785 | 0,00003 |

During the last session at the lab, the Cargo Beacon sensors did not work so the team was unable to take all measurements that were planned. It was also realized during the last session that different orientations of GEPS sensor on A/B positions gave different results. These findings will be disregarded in the analysis and discussion since this was not considered for most measurements.

*A. Analysis of data*

For preparing these reports, the assumptions taken are as below

- For experiments in **position**, the expected positions of points A and B are the median values of the 10 individual points respectively.
- For experiments in **Path**, the expected values are the interpolation between the median values of position A and B from the Position data.
- For calculating the mean errors and RMSE, the distance between the measured and the interpolated values are considered. As the distance in coordinate geometry is always positive, measures like RMSE make more sense compared to other calculations.

For the three Cargo Beacon sensors position experiment results, as shown in the figure 1 below, are normally distributed with kurtosis of 0.5 to 2.9 (moderately to peak skewness), skewness of 0.48 to 1.50 and are fairly symmetrical, meaning the data near the mean were more frequent in occurrence than data far from the mean, this clearly shows how precise these sensors are.

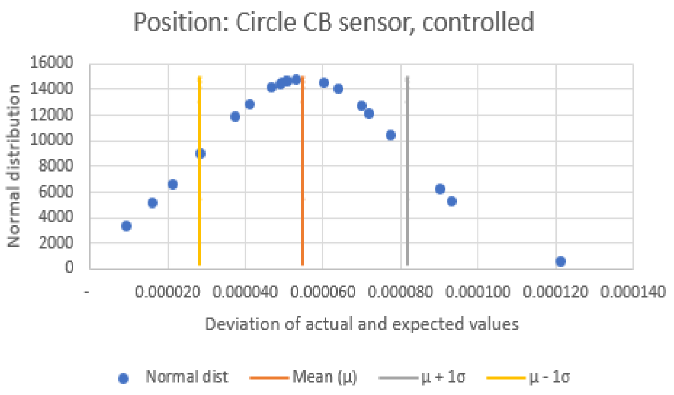


**Figure 1: Distance Precision of Cargo Beacon Sensor**

While as for GEPS sensors clearly show that there are homogenous types of groups because of positive skewness (0.6 to 1.25 and kurtosis of -0.82 to 2.28) distribution, most values on the graph are on the left side, and the curve is longer towards the right trail, meaning it has more outliers, meaning it is less precise in measurement. The magnetic strip (figure 2) shows more outliers evidenced by high skewness and kurtosis mainly because of magnetic noise in the strip.

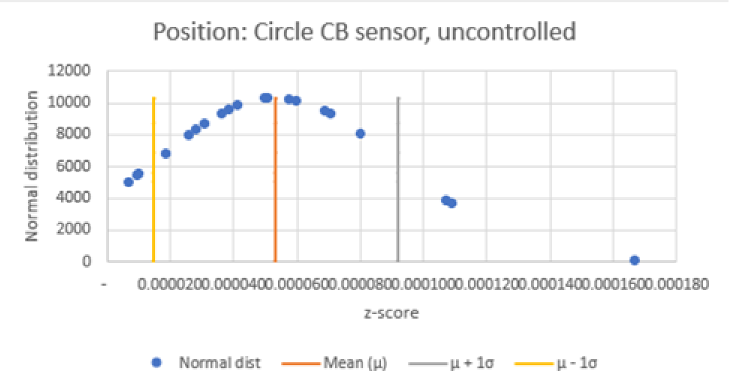


**Figure 2: CB Sensor with noise**

The graphs below show the levels of accuracy of the CB and the GEPS sensors. Although the CB is precise it is inaccurate as shown by figure 3. However, GEPS sensors (figure 4), although less precise are more accurate in terms of position and distancing.

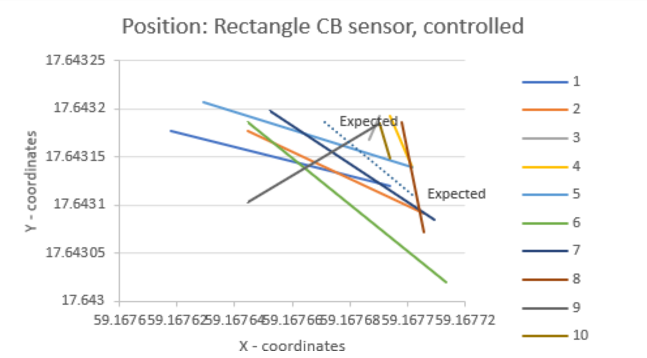


**Figure 3: CB rectangle sensor position measurement**

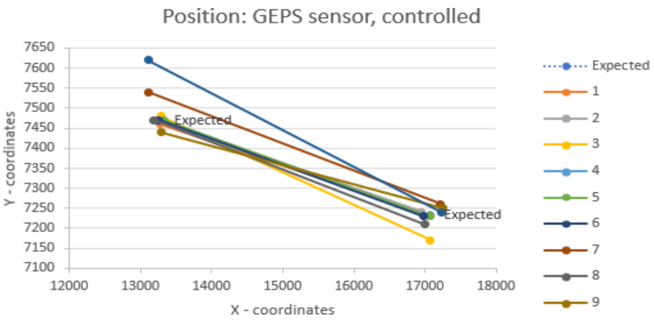


**Figure 4: GEP Sensor position measurement**

Figure 5 shows the high variations of path behavior of CB sensors with very high RMSE error for controlled path of 4.02 and that of uncontrolled path was 4.61. This could be mainly because of noise from the near-by AGV and the magnetic strip which provided signal interference. The CB sensors sometimes worked and sometimes they did not. The authors assume that it goes into sleep mode for battery saving mode and then submits the requested data when back online.

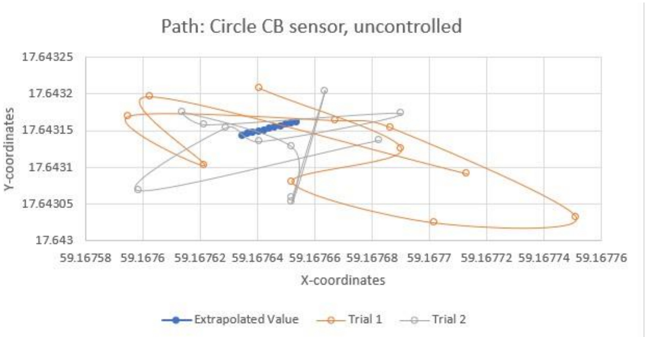


**Figure 5: CB Sensor behavior of path analysis**

The RMSE error for controlled experiment for GEPS sensor shown in figure 6 gave an error of 0.11 and that for uncontrolled gave an error of 0.13, it clearly shows that magnetic noise has a bearing on the accuracy of the path.

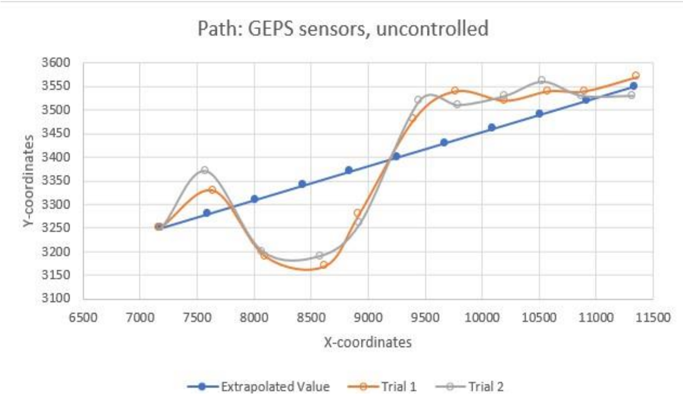


**Figure 6: GEPS Sensor behaviour on path analysis**

As shown in figure 7, the lag of CB sensors has a flat peakness, kurtosis of –1.59 which shows less outliers, the certain gap of data is experienced when the sensors fail to give real time data, when it activates sleep mode, the average lag is 43 seconds, the skewness of 0.11 shows fair symmetricity of the data.

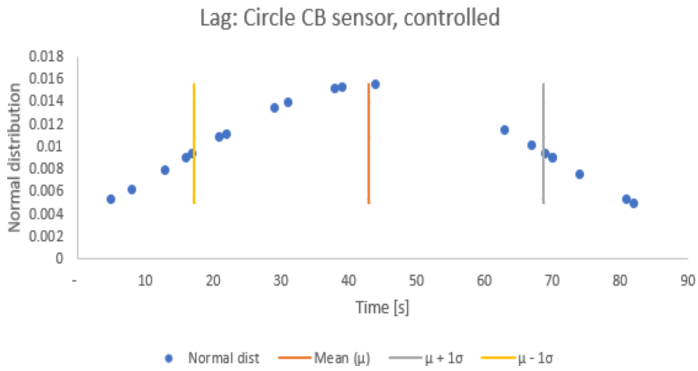


**Figure 7: CB Sensor lagging normal distribution**

The lag of GEPS sensors, figure 8, are flat peaked with kurtosis of 0.16 and skewness of 0.12 which is a clear indication of normal distribution. However, there is a tendency to be negatively skewed, with an average lag of 70 seconds. The level of accuracy of this sensor is so high that it causes the lag to be high because of high resolution.

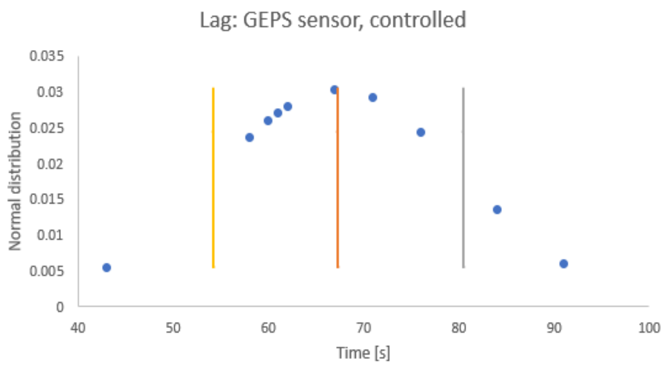


**Figure 8: GEPS sensors lagging normal distribution**

The major challenge throughout the experiment was the uncertainty of the sensors working since the Cargo Beacon ones had a habit of stopping suddenly. It was either fixed by picking the sensor up and vigorously moving it around to activate it or having a Scania employee contact the sensor supplier to fix it. This could have resulted in inaccuracies if the coordinates given by the system were collected when we were moving it around or when it was sitting in its position, it is impossible to know. The two circle Cargo Beacon sensors were used as one to shorten the experimental time by concurrently collecting measurements.

## 6. Discussion of Findings

The study's findings reveal that while RTLS technologies like Cargo Beacon (CB) and GEPS offer potential for enhancing production logistics, their practical application is limited by technical, sustainability, and integration challenges. Consistent with existing literature, RTLS effectiveness depends heavily on timely and accurate data—key to supply chain visibility and responsiveness (Kembro & Näslund, 2014). CB sensors, despite their battery-saving sleep modes, compromise visibility and responsiveness due to lag, undermining the goal of real-time disturbance handling. GEPS sensors, although more reliable, lack precision at high speeds and do not address vertical (z-axis) tracking or movement history—critical components for full asset visibility and inventory accuracy, as emphasized in contemporary logistics systems. In alignment with digital supply chain frameworks, RTLS alone is insufficient; it must be integrated with complementary technologies like barcodes, SKU systems, blockchain, and visual sensors for holistic performance and traceability. These integrations support complex functions such as kitting, line-side feeding, and supplier capability mapping, which are crucial for inbound, outbound, and internal logistics. However, integration brings high energy demands, system complexity, and costs, raising environmental and social concerns—highlighting the growing tension between technological advancement and human-system alignment. From an application perspective, CB is suited for low-precision contexts like hazardous zone personnel tracking, while GEPS fits better for broader asset tracking where perfect precision is not critical. Real-time precision remains a trade-off, as higher accuracy increases lag. Moreover, RTLS use must be selective to prevent data overload and inefficiencies. Blockchain emerges as a strategic enabler for enhancing decentralized operations, transparency, and transaction efficiency, addressing the limitations of isolated RTLS use. Interconnectivity remains a hurdle, especially with current reliance on low-frequency gateways like LoRaWAN, which offer energy savings but restrict data transmission and scalability. Finally, the study supports sustainability literature advocating for digital integration that reduces unnecessary inventory, optimizes material flow, and promotes responsible consumption. Environmental strategies such as digital invoicing, optimized fill rates, and eco-training must complement technical deployments. Thus, for RTLS to contribute meaningfully to supply chain sustainability, technological capability, human factors, and strategic integration must be balanced.

## 7. Conclusion

RTLS serves as a foundational element for logistics connectivity, offering benefits such as improved visibility, performance tracking, sustainability, data analytics, accountability, and worker safety. However, its full potential is hindered by integration challenges, particularly the absence of standardized protocols to align sensor outputs with legacy systems like Excel, leading to excessive data handling and potential errors. The GEPS sensor, although highly accurate, suffers from data volatility due to high-resolution processing, necessitating a balance between accuracy and response time for practical use in production logistics. Conversely, CB technology demonstrated faster output with lower accuracy, making it suitable for general asset tracking in low-precision environments, such as monitoring personnel near hazardous zones. Both sensors produced outliers, highlighting the need for integration with other technologies like visual sensors to ensure reliable real-time data. The current reliance on Wi-Fi and Bluetooth raises concerns about performance degradation under high traffic and the impracticality of installing multiple gateways in external logistics environments. As such, connectivity strategies must be re-evaluated for broader scalability and cost-effectiveness. A multi-lens approach is essential to assess the impact of digitalization on the economy, society, and environment. With unknown ecological effects of electromagnetic waves and high energy demands of IoT systems, responsible innovation is crucial. Our findings confirm that electromagnetic interference significantly affects RTLS accuracy. Therefore, comprehensive research and due diligence are vital before large-scale deployment, ensuring that technological adoption does not compromise environmental or social sustainability.

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