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# Vision-Based Assets Tracking And Maintenance Management on the Production Floor of Integrated Semiconductor Devices

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**ABSTRACT**

*The paper presents a cost-effective system for hardware assets (transportation carts and integrated circuit (IC) carriers) tracking and maintenance management on the production floor of a large-scale IC manufacturing plant. Currently, the preventive maintenance (PM) on these assets is implemented mostly by having the technicians to go around the factory floor to find the items that are due for maintenance. This is done by looking at the label information attached to each and every cart and magazine or IC carrier. Furthermore, after the PM procedure, the label on the cart/magazine has to be replaced by a new one with updated information. This a very time consuming and inefficient process. Inevitably, a new approach needs to be looked into in order to improve time efficiency as well as the accuracy of the assets tracking. One way is to replace the paper data entry to electronic data entry by using tagging and tracking technologies. The asset tracking identifier must be durable to withstand high-temperature conditions (up to 170$^{O}$C). Several technologies have been analyzed such as barcode-based identification, Radio Frequency Identification (RFID), Global Positioning System (GPS), iButton application, and Wi-Fi localization. Subsequently, the barcode technology was chosen due to its usage simplicity, cost-effectiveness, durability in the high-temperature environment (with appropriate lamination), and tag power independence. The proposed barcode technology solution uses handheld intelligent terminals with wireless communication capabilities and a host computer with a database linked not only to the preventive maintenance methodology but also to the integrated production information system of the production plant. In addition, the locations of the assets are tracked and can be shown on a visual factory map so that the staff can collect the carts and magazines easily. As a result, the system has dramatically improved preventive maintenance to make this process more convenient for the maintenance management task. Further expansion of the system by incorporating the visible-light positioning technique is proposed and elaborated as the direction for future development.*

**Keywords:** Identification Tags, Assets Tracking, Preventive Maintenance, Semiconductor Device Manufacturing.

## 1. INTRODUCTION

Carts and magazines are the assets for carrying unpackaged ICs (known in the industry as *dies*), partially assembled devices, and completely packaged ICs (also commonly known as *chips*) during the assembly, packaging and testing of semiconductor devices. There can be many hundreds of carts and thousands of magazines used at the modern large-scale semiconductor device production line. Normally, each cart contains five magazines and each magazine is used to carry up to 21 trays of chips and shown in Figure 1 [1].

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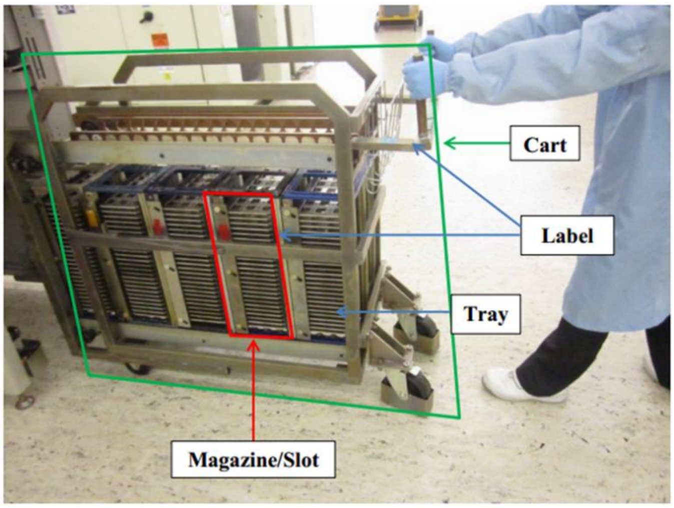


**Figure 1.** Cart, magazines and trays on the IC production flow (*courtesy of the Intel Products Vietnam*).

Depending on a stage of the production process the following types of carts and magazines are employed: *high-temperature carts* (HTC) and *high-temperature magazines* (HTM), as well as *low-temperature carts* (LTC) and *low-temperature magazines* (LTM). HTCs and HTMs are employed in up to 170$^0$C elevated temperature conditions (e.g., during the under-fill process step[2]), while LTCs and LTMs are used in the low-temperature conditions of 20$^0$C (e.g., during the chip attach or ball attach production steps [3]).

Preventive maintenance is employed in a planned and scheduled manner to ensure the carts and magazines are in good working order and they can be used in the production line. Each cart and magazine are assigned preventive maintenance period/date depending on the asset type and usage. For example, the period between scheduled maintenance rounds is 4 weeks for HTC, 8 weeks - for LTC, 4 weeks - for HTM, and 12 weeks - for LTM. To maintain these assets, technicians must go around the factory floor to collect the carts and magazines scheduled (or overdue) for the maintenance. This work is normally done manually and it often causes waste of time when trying to find an object in a large production area. Some carts and magazines may be currently in use, and thus their maintenance is to be postponed or rescheduled. From the industrial experience, up to 97% of carts and magazines can be tracked reliably while the positions of the remaining 3% of assets cannot be easily determined. Thus the development of a simple time- and labour-saving cart/magazine tracking system on the production floor of a semiconductor manufacturing plant is important for increasing the efficiency of the use and maintenance of the assets.

## 2. ASSET MAINTENANCE

Maintenance is an activity of repairing and extending the useful life of the assets. Traditionally the following four types of maintenance that are employed in the industry: *reactive (corrective), preventive, predictive* and *proactive* aiming to keep the assets in a well-working state [4]. In corrective maintenance, repairs are performed only after the occurrence of a breakdown or loss of functionality. Such an approach tends to impair the achievement of maximum profitability. Nevertheless, corrective maintenance continues to be a popular choice in many low-cost and non-critical systems due to its simplicity in application. *Preventive maintenance* (PM) does not consider the current health of the equipment, but only its estimated age and time since the last maintenance round. It utilizes time-dependent breakdown models to determine equipment health [5]. Predictive maintenance utilizes a database of historical maintenance records as a benchmark to determine current equipment health. However, its effectiveness is limited by the availability and quality of the database and the employed statistical models. The proactive approach addresses much more systemic elements of a maintenance program, rather than examining the machine itself. It is much more diligent and looks to *control the problems* that can lead to machine wear and tear as opposed to the deterioration itself state [4]. Proactive maintenance is more complex. It is more difficult to implement compared to preventive or predictive approaches due to a large volume of the required historic data-logs. Besides, it also requires significant expert analysis to comprehend and interpret the data.

In the current highly competitive industrial and economic environment, efficient maintenance approaches and strategies have been acknowledged as an essential strategic element in the manufacturing process planning. As a result, the *condition-based maintenance* (CBM) approach has gained increased popularity in recent decades in the production environment, in particular, in the high-volume semiconductor chip manufacturing [5]. It is important to mention that CBM may be applied to both predictive and proactive approaches. It incorporates reliability models, knowledge on equipment degradation (if available) as well as historical breakdown trends. This allows for identification of complex failure patterns leading to a more accurate assessment of the equipment's current health and reliability. As shown in the literature, there is a significant downside to CBM in the high-volume semiconductor production environment – its development process is typically quite time-consuming and costly [5]. Figure 2 shows some important factors contributing to the success of CBM implementation in the industry [6].

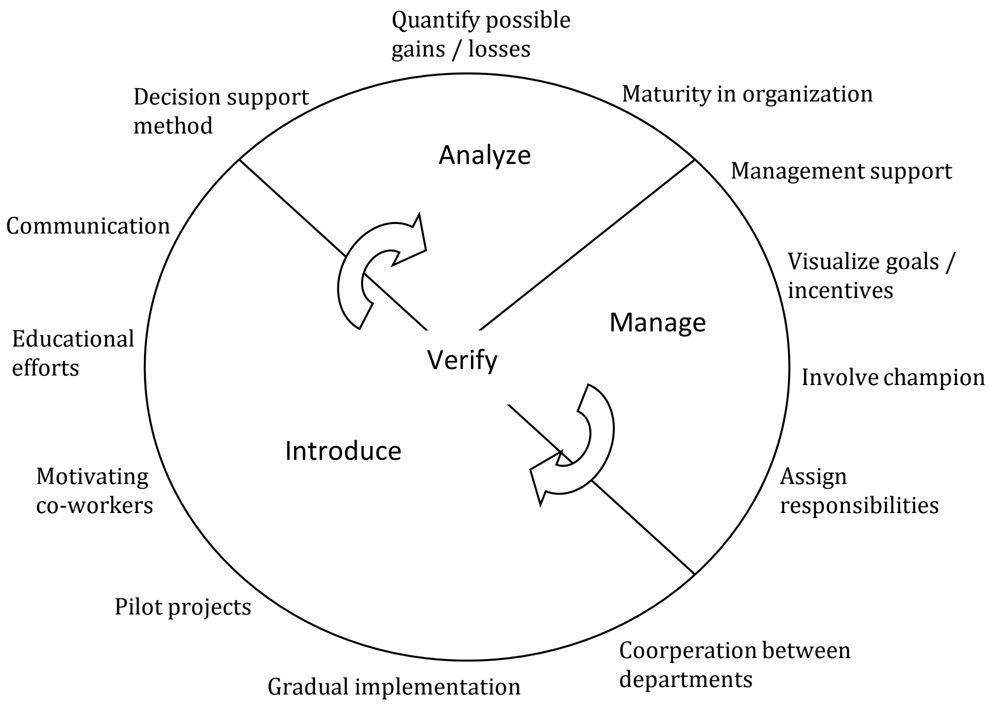


**Figure 2.** CBM implementation and the affecting factors.

In the mass production environment, minor breakdowns generally occur stochastically. Thus, performing some sort of "minor reactive (or even preventive) maintenance" to quickly get the equipment back in working order is common in the assembly, packaging and testing production floors. Such minor maintenance may not be tracked or recorded because it appears to be a trivial task. At the same time, the accuracy of the CBM system could be significantly compromised by the unaccounted minor maintenance rounds.

The system discussed in this paper aims to address this shortcoming by developing and employing a cost-effective visual-based asset tracking and comprehensive maintenance data collection system for carts and magazines for a large-scale semiconductor manufacturing plant while contributing to addressing the "Pilot Projects" factor of the CBM development and implementation cycle.

## 3. ASSETS TRACKING TECHNOLOGIES

Various technologies are available for assets location and tracking in the industry, such as *Radio Frequency Identification* (RFID), *Global Positioning System* (GPS), *Wi-Fi, iButton identification, barcodes*, etc. Each of them is associated with specific advantages and disadvantages. For instance, RFID tags are programmable so they can be used as parts of a portable database. A multitude of them can be read simultaneously with high speed. At the same time, they are expensive and generally not stable when operating at high-temperature conditions [7]. *GPS* technology is readily available nowadays and it is easy to use. However, it is not able to work sufficiently accurately and reliably in a range of industrial premises [8]. Besides, it requires the use of battery-powered trackers, which was not preferred by the target industrial company. *Wi-Fi* (and other wireless technologies, like *ZigBee, Bluetooth*, etc.) technologies can be sufficiently accurate. However, quite often their application is not cheap since it requires building a relevant communication and power supply infrastructure (which may be not desirable on the production floor). They also could lead to interference problems that are largely unacceptable in the manufacturing environment [9]. The one-wire *iButton* technology uses special computer memory (and some additional circuitry) chips encapsulated in protective stainless steel cans. iButtons are quite reliable data carriers that could contain an asset identifier and other relevant information. They are widely used in areas such as logistics, access control, sales, temperature conditions monitoring, and many others. A good example of the iButton technology application is the warehouse stock management and tracking automation system [10]. It is beneficial that iButtons can provide stable autonomous operation for quite a long time (each of the memories is backed by an in-built lithium-ion battery). Unfortunately, the operating temperature range of iButtons is relatively low [11].

The *barcode* technology is widely applied in various industries and business areas. It is fast, accurate, cheap, and durable. Besides, it doesn't require tag power sources and it can work in a high-temperature environment.

Because of these advantages, the barcode technology (combined with the use of handheld barcode readers with wireless communication capability) has been chosen as the most acceptable approach for the assets (carts and magazines) tracking in the semiconductor IC manufacturing environment.

## 4. SYSTEM IMPLEMENTATION

In the industry, the maintenance is traditionally organized in four steps: making up a maintenance plan, carrying out maintenance works, checking up after maintenance, and summing up maintenance works [12]. There are also some additional factors affecting the maintenance process, such as production schedule, scene management and quality management arrangements. Normally, the manufacturing plant applies these considerations in the process of planning and carrying out maintenance for assets like carts and magazines: a) the maintenance plan is developed for the entire asset set; b) technicians collect items scheduled for the maintenance; c) the maintenance is carried out so the assets become again ready and available for the use; d) the quality control is applied, and e) the maintenance data are collected and reports analyzed if and where required.

With respect to the maintenance, carts and magazines can be divided into five main types: *schedule, overdue, inventory, in production,* and *rejected* depending on their positions and maintenance dates. The *schedule* assets are identified for collection to undergo the maintenance. The *overdue* items were scheduled for maintenance earlier but were not sent to the maintenance for whatever reasons. The *inventory* items are put in the inventory areas after completing the maintenance, while the *in production* carts and magazines are being currently used in the manufacturing process, and thus their maintenance will be performed at a later date. Finally, the *rejected* assets are to be excluded from the production process due to seriously broken hardware.

The general architecture of the system is shown in Figure 3. It utilizes a handheld barcode scanner/mobile computer terminal (see Figure 4) linked to the host computer via a wireless link (e.g., *Datalogic Skorpio X3* [13]).

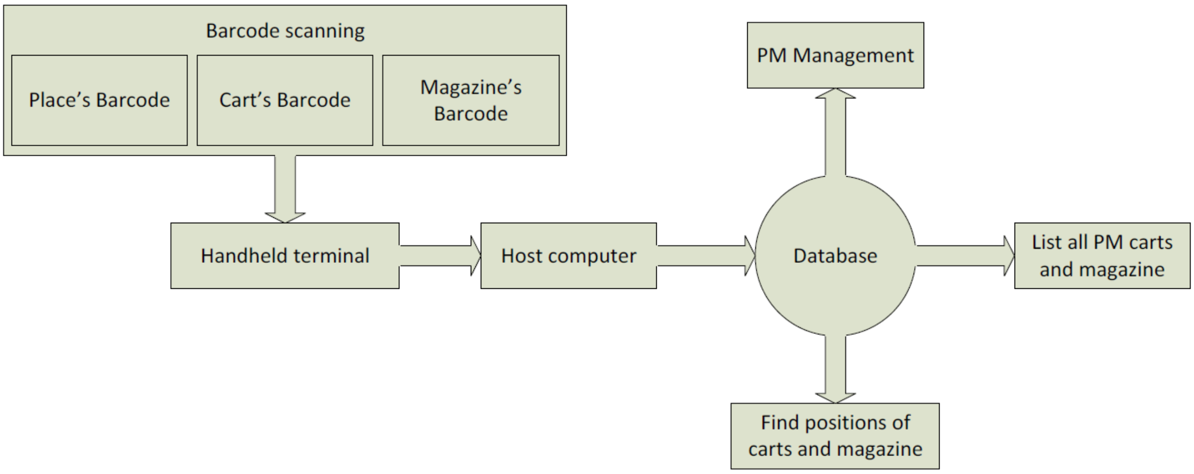


**Figure 3.** Asset management and maintenance automation system.

**Figure 4.** Handheld barcode reader and mobile computer terminal [13].

During the system operation, the barcodes attached to carts and magazines are read by the handheld reader thus capturing places and identifiers of the carts and magazines. The scanner/mobile computer terminal displays the received barcode and information associated with the identified asset. It also generates a warning signal if the received identifier does not match the corresponding item in the system database or maintenance schedule. The sizes of the barcode tags are different for different objects. The tags for floor areas are larger than those for the carts and magazines. To protect the floor tags and to extend their longevity, durable plastic films that can withstand mechanical scratching and effects of high temperature are employed to cover the surface. The scanning procedure includes three steps: scanning the barcode of a *place,* scanning the barcode of a *cart* located on that place, and, finally, scanning the barcode of a *magazine* on that cart. The captured data are organized in a folder-like structure in the database.

Locations of the carts (and thus the magazines) depend on the production process and the equipment they are associated with on the production floor. Figure 5 displays an example of the production floor layout where yellow rectangles show the places of placing the carts with the magazines.

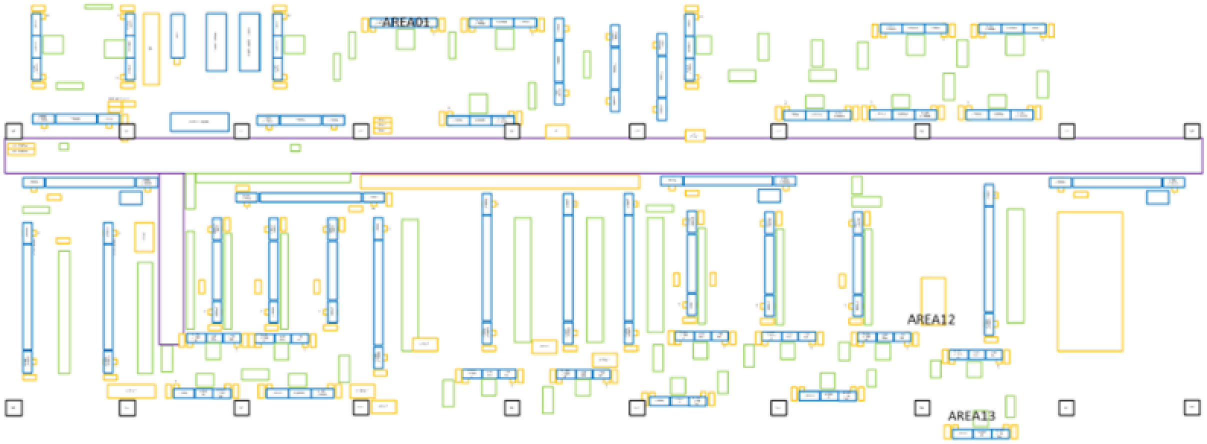


**Figure 5.** Example of the production floor layout and cart/magazine locations.

It can be seen from previous figures that there are just two large areas and many small areas where the carts can be present. The large areas (so-called *inventory areas*) are for the carts with magazines that are available for the utilization after passing through the scheduled maintenance. All the carts and magazines placed above the large horizontal path are the high-temperature assets, while those placed below the path - are used in the low-temperature process steps. Each small area, contains between two and five carts. It can be seen that there is a high multitude (several hundred) of places for cart parking spread around the floor.

In order to address the issue, the production floor is divided into 11 main areas (AREA00 - AREA10). Each area is largely associated with specific asset types. For example, high-temperature carts and magazines are usually located in AREA00, AREA01 and AREA02; low-temperature carriers are placed in ARE03 - AREA07; AREA08 and AREA09 are the inventory areas; while AREA10 is the location of rejected carts and magazines. A map of the production floor is created and shown in Figure 6. This map is used by the system to display the location of an asset.

The system database is designed to contain locations of all the carts and magazines and to support maintenance management in Figure 7. The scanning history (records of all barcode readings) contains the time and place of the carts and magazines scanning in association with the scanned identifiers of the carts and magazines used in the factory (*Hi-temp carts, Low-temp carts, Hi-temp magazines, and Low-temp magazines*).

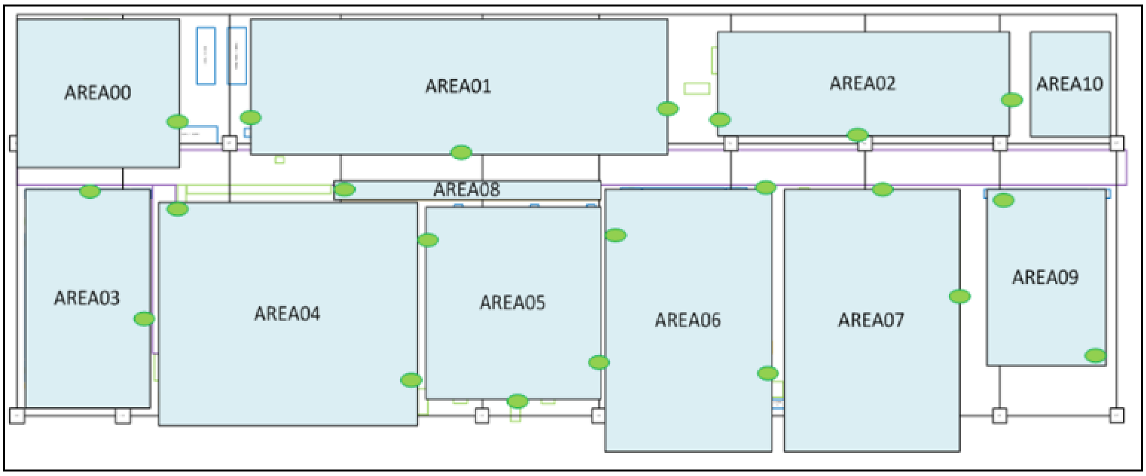


**Figure 6.** Grouped areas on the production floor.

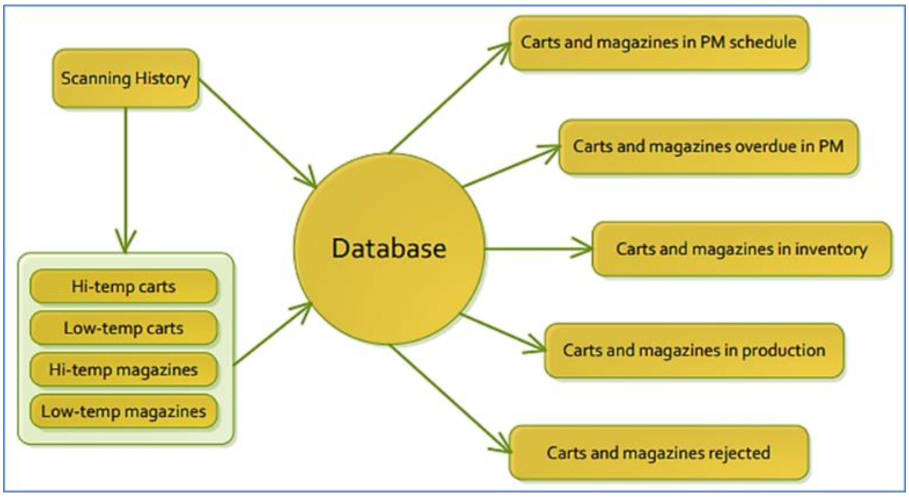


**Figure 7.** System database.

The section *Carts and magazines* in PM schedule contains the list of all carts and magazines scheduled for maintenance in the current day. The *Carts and magazines overdue in PM* section lists the overdue for the maintenance carts and magazines*. The Carts and magazines in the inventory* section contain data on all available carts and magazines that have undergone the maintenance and are put in the inventory areas (AREA08 and AREA09). The section *Carts and magazines in the production* section, lists all carts and magazines that are currently being used in the production process. Finally, *the Carts and magazines rejected* section itemizes all broken carts and magazines placed to the rejected area (AREA10). Since the four types of carts and magazines are employed on the production floor, the database is organized to have four parallel and independent links between the library (the first level database) and five database sections in the second level as shown in Figure 8.

In order to save time, the system supports a reduced number of scans, i.e., it is sufficient to scan just once a place barcode and then sequentially scan several cart identifiers, or scan the cart identifier once before scanning several magazines in it. The software also accepts the scanning of just a place and cart, or a place and magazine identifiers. The software also supports the maintenance management. Whenever a cart or magazine has undergone the maintenance and moved into the inventory areas (AREA08 - AREA09), the area identifier is scanned along with the identifier of the fixed cart or magazine.

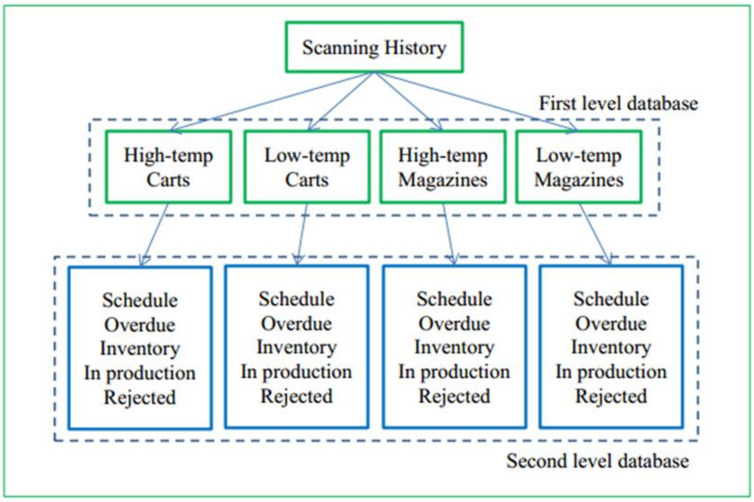


**Figure 8.** Database organization.

The software is built not only to track the location of the carts and magazines on the factory floor but also to manage the preventive maintenance process. Figure 9 shows the view of the asset library.

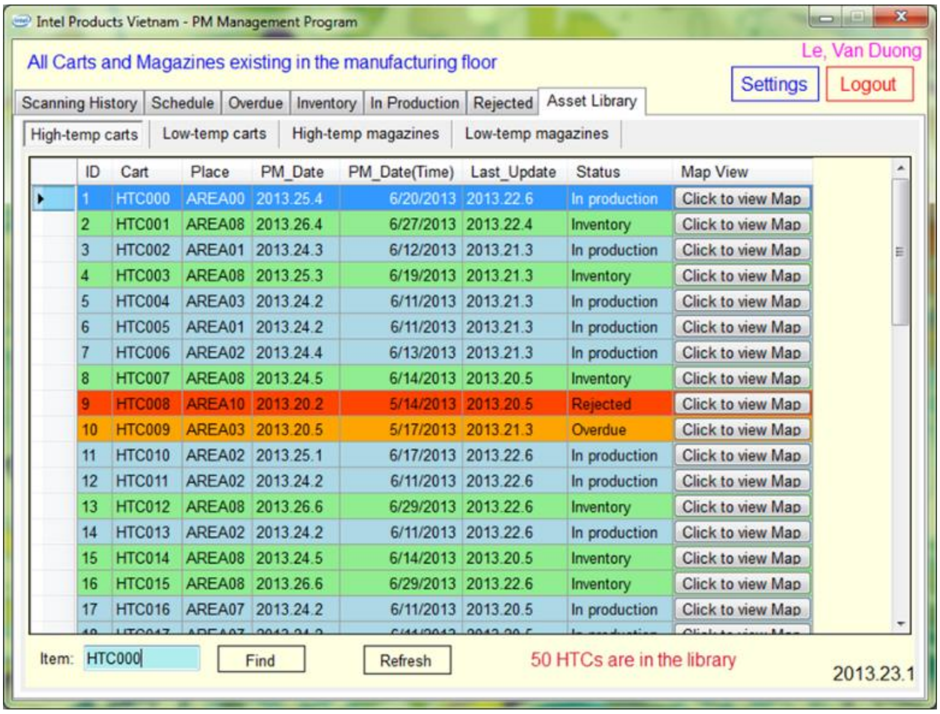


**Figure 9.** Asset library view.

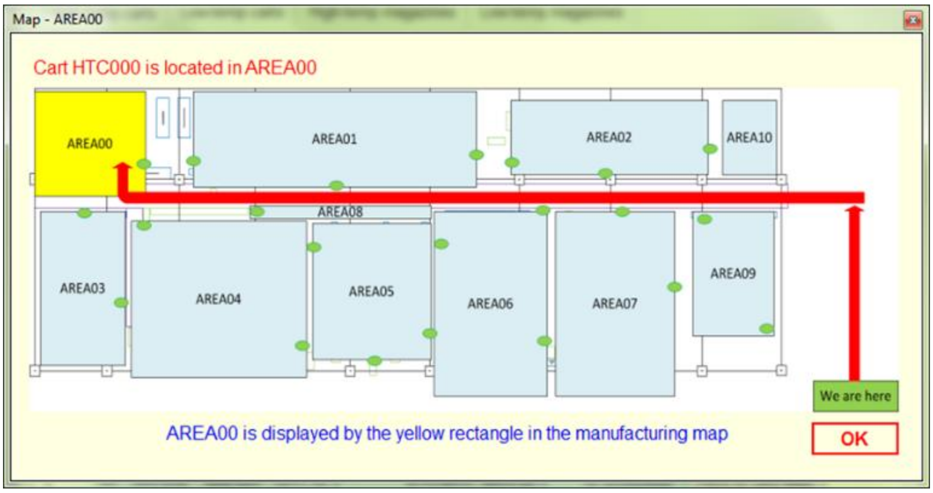


**Figure 10.** Asset tracking map.

The physical location of a cart or magazine can be easily found by just clicking a corresponding button "*Click to view Map*" in the asset record line as shown in Figure 10. Moreover, the program classifies types of carts and magazines by colours (e.g., red for "*rejected*" and blue for "*in production*"). It also helps in finding an item in the library. Besides, the software allows engineers to automatically move an item that has undergone the maintenance to the inventory database and to produce a new maintenance schedule for that item. There are two ways to record the completed maintenance: it can be done either by scanning (the asset plus identifier of the preventive maintenance area), or by selecting the asset in the table and click the button "*PM Done*" leading to moving the cart or magazine to the inventory list with a new date of maintenance.

## 5. CONCLUSIONS AND FUTURE DEVELOPMENT

This paper presents the asset tracking and maintenance management system that was developed and successfully implemented on the production floor of one of the worlds largest multinational electronic product manufacturers. It demonstrated the required high efficiency in tracking locations of the carts and magazines while supporting maintenance management. The system has been built around Microsoft SQL server as the tool to manage, store, organize and retrieve information from the asset database. The system allows multiple users to access the database from many computers across a network. Furthermore, the use of the SQL server made the software application package compact and easy to execute on any computer supporting a suitable environment.

Reliability of the system will be further improved by combining the barcode and image-processing/image-recognition technology. It will be able to read not just a barcode, but also the text identifiers of the carts/magazines as well as to locate the cart positions as illustrated in Figure 11. This will be combined with the enhancement of the database and software system/ environment.


**Figure 11.** Magazine labels.

Further improvement of the system is going to be based on the recent development of an efficient *visible light positioning* (VLP) approach employing received signal strength [14]. This approach will utilize the existing lighting infrastructure of the production site to identify positions of the carts on the production floor. Each of the cart is to be equipped with a small size receiver employing a photodiode sensor. The electronic/computational circuitry of the receiver will implement the fingerprinting-based visible light positioning using *received signal strengths* (RSS) as inputs. A square wave modulation will be employed to identify each luminaire by the receiver using *Fast Fourier Transform* (FFT). A position within the production floor will be characterized as a vector *identifier* (ID) made up of the detected RSS from each of the luminaires like in Figure 12 [14].

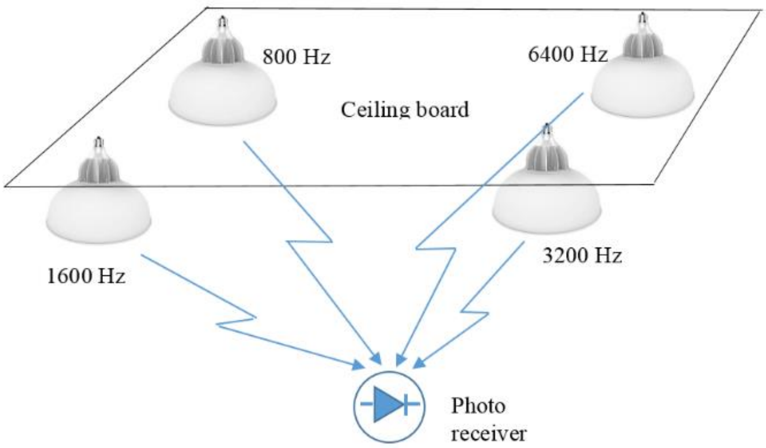


**Figure 12.** Visible light-based positioning [14].

An offline (done just once) database will be constructed by taking a set of RSS measurements that uniquely identify selected locations on the floor where the cart is localized in. The localization of the carts will be performed by capturing the light signals and then running a classifying algorithm to determine an estimate of the position based on the offline database. This approach will use the *Weighted K-Nearest Neighbor classifier* [15] characterized by its high accuracy.

Preliminary experimental results show that squared chord distance metric offers the best localization accuracy. An effective method for estimating the *Lambertian* optical propagation model from a small number of offline measurements allows them to generate fabricated RSS leading to the reconstruction of the fingerprint database without any significant site survey. In turn, it enables accurate localization and easy calibration of the system implementing the developed approach.

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