



COB-2021-1099

DIGITAL TRACEABILITY SYSTEMS FOR QUALITY CONTROL IN AN AUTOMOBILE MANUFACTURER

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Abstract. Traceability is a crucial factor for the implementation of Industry 4.0, monitoring not only the location but also the status of products and assets enables intelligent manufacturing management. This study aims to evaluate systems to implement remote car traceability in a quality testing process. Firstly, opportunities for improving the traceability of cars through the quality testing process were assessed. Four enabling technologies were analyzed: radio frequency identification (RFID), Bluetooth low energy (BLE), LoRa and Ultra-Wideband (UWB), and a comparison based on five performance indexes, namely: cost, reliability, flexibility, quality and speed were performed. The quality process under study, which requires a traceability solution, was analyzed by sizing and characterizing the monitoring areas, raising all possible status of the cars and, finally, defining the solution requirements. Then, a study on the impacts that the possible implementation could have on the process of two policies to reduce the workforce dedicated to the activities and the related cost reductions. Still, a last stage of the project would consist of carrying out a proof of concept (POC), although it has not yet been carried out, this stage had some initial developments that will be exposed. Furthermore, this work addresses a discussion about the competition between new and established technologies. The main discussion revolves around the comparison between RFID and real-time location system (RTLS) technologies. The eligibility of the technology was based on the greater scope and the smallest addition of activities to its respective operation, with the cost of implementation and operation being a decisive factor. Real-time monitoring presents itself as the best solution for monitoring process failures. BLE technology stands out in said competition. It is noteworthy that the lessons learned during the process contributed to modifying the project planning.

Keywords: industry 4.0, traceability, manufacturing, automobile industry, inventory management.

1. INTRODUCTION

Traceability is an essential factor for the implementation of Industry 4.0, monitoring not only the location but also the status of products and assets enables an intelligent management of manufacturing. Rodrigues *et al.* (2009) report that the successful implementation of a vehicle tracking system is related to the comparison of technological alternatives for monitoring, the integration of systems (positioning and corporate), exploration and analysis of the generated data for the operation, and finally, the reduction of implementation, maintenance and communication costs.

Radio frequency identification (RFID) technology is already widely used in inventory control applications. However, for a more assertive control of processes with complex flow, real-time location technologies (RTLS) have been presented as an attractive alternative, due to their high flexibility. Many confuse RTLS with RFID and, therefore, believe that this is the only solution available, and implementing inadequate technology can result in high costs and inefficiency of the solution (Novidá, 2020a).

In the context of the automobile industry, vehicles need large areas for allocation (usually open-air yards), therefore, a face-to-face inventory tends to demand a lot of dedicated labor time. Despite being fundamental, such activity does not add any value to the product, making this an adequate scenario to apply technology in place of human execution.

This study was carried out in an automobile manufacturer where quality testing and rework procedures make up a diversified flow. In this process, location is closely related to automobile status. The present consist in reporting the study of systems to track the location of each automobile that passes through the quality testing process of the company, in order to provide a better management of the quality control process.

1.1 Current situation

The project began with the need to quickly and accurately carry out the inventory of automobiles present in the qualitative assessment process of an automobile manufacturer. Currently, transfers between assembly, evaluation and

rework stations are reported, through the manual action of the operator. The transfer is carried out in order to inform the vehicle's destination station. During the production procedure, these “notes” follow a single possible flow, however, when the automobile completes its production cycle and enters to the qualitative assessment process, there is more than one option available for the automobile flow. The automobile’s flow complexity in the evaluation process is because it may fail at some stage and need to be directed to a rework station. Figure 1 illustrates the flow between the automobile evaluation stations, the arrows indicate their approval. Upon approval, the automobile is allowed to proceed to the next station, if the automobile fails, it is redirected to one of the rework stations.

In Figure 1, the flow between the evaluation stations is simple and orderly, however, Figure 2 details that when an automobile is redirected to a rework station, the flow becomes diversified. A single assessment station can redirect automobiles to different rework stations (depending on the breakdown classification). In addition, a rework station can route the automobile to another station in the same category (which solves other types of breakdowns). After the rework procedures, the automobile returns to the evaluation station.

To make the inventory or find any automobile that has a specific status, a face-to-face inventory of all vehicles allocated in the plant is carried out daily. This inventory is made manually with paper notes and, later, this information is transferred to a spreadsheet editor. The physical inventory at the end of daily production consists of noting the Vehicle Identification Number (VIN) of each automobile, the location where it is parked and the current status in the evaluation process. The on-site inventory data and the system data are compared to find possible transfer failures in the production management system. The specific location of the automobile is only possible through a search and physical location performed by an employee.

2. THEORETICAL FOUNDATION

2.1 Enabling technologies

The technologies for tracking products and assets in the industry are diverse, in this work the main technologies offered for tracking in the Brazilian automobile industry will be mentioned, they are RFID, LoRa, BLE and UWB.

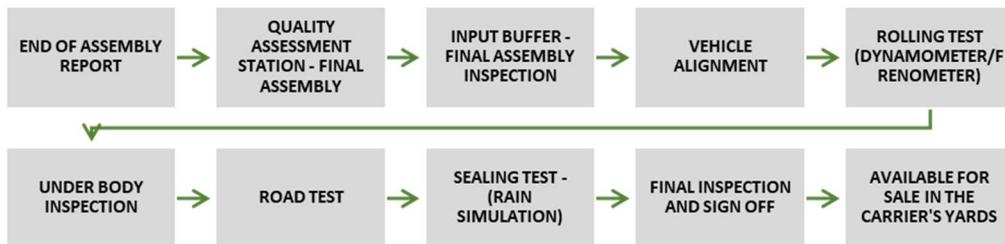


Figure 1. Evaluation process flow.

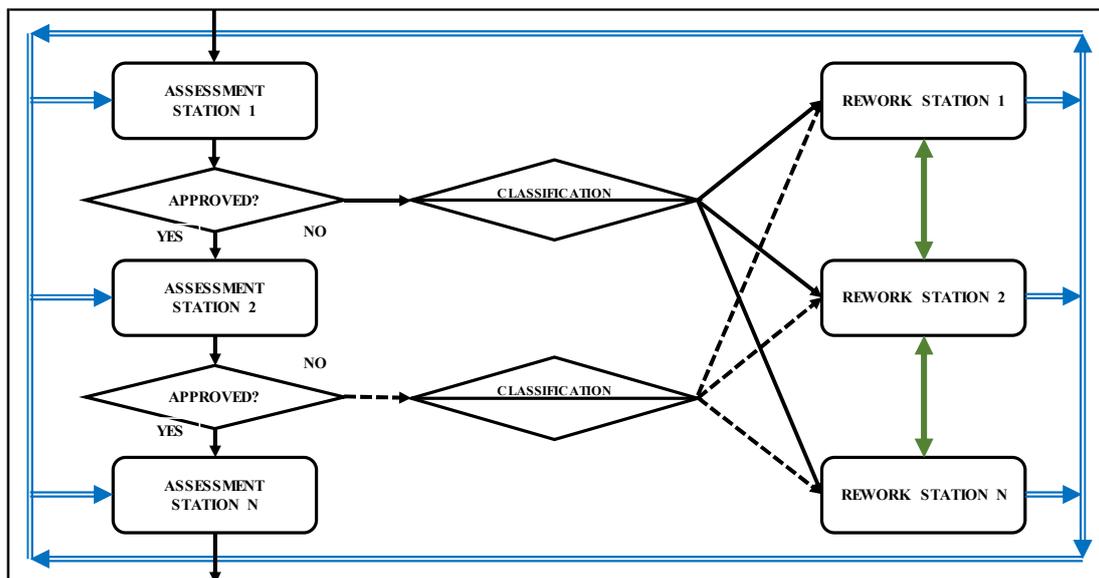


Figure 2. Flow between assessment and rework stations.

An RFID identification system basically uses three physical elements: an antenna, a reader and an RF tag. The tag plays the role of emitter and the antenna the role of receiver, so the antenna transmits the integrated signal to the reader which converts the RFID radio waves into digital signals. Such signals can be understood by a computer that will analyze the information linked with the tag (RFID Brasil, 2020).

Tags are classified into active, semi-active and passive. Passive tags use the energy produced by the antenna signal and do not have their own energy source. Active tags, on the other hand, have an energy source, however, they are only activated when they receive the antenna signal (Silva, 2017).

Fernández-Caramés *et al.* (2019) report that reading distance is commonly related to RF tag type: in passive tags the read distance generally does not exceed 20m, while in active tag communications, it can easily reach 100m in unobstructed environments.

Bluetooth low energy (BLE) technology was conceived as a communication technology and is ideal for situations in which it is necessary to send little information in a short period of time. BLE allows information to be sent sporadically, and when not sending information, devices go into sleep mode. Thus, energy consumption peaks occur (when the modules are communicating with the gateways), however, the average consumption is very low (Embarcados, 2020).

The BLE technology tracking module is called Beacon, the device has reasonably small dimensions and emits an intermittent signal of radio waves that can even be detected by a smartphone. With this, it is possible to create applications based on the user's proximity to objects, places and situations of interest. As it is a communication via radio waves, penetration into structures (such as concrete) does not usually be a hindrance (Taggen, 2020).

Seferagic *et al.* (2020) report that, unlike classic Bluetooth, which was designed as a point-to-point cable replacement, BLE offers greater range using mesh topology. For such topology, an experimental study observed a range of about 50 m indoors and up to 165 m for open environments without line of sight. For line-of-sight environments, the BLE featured a range of up to 790 m. BLE technology uses 40 channels of 2 MHz, 37 of them are used for bidirectional communication between connected devices, these channels vary in frequency (frequency hopping) to enable better communication. The other 3 remaining channels are called advertisement channels, these are used to discover other devices and establish a connection and diffuse transmission (Araujo and Vasconcellos, 2012). Seferagic *et al.* (2020) also mention that BLE has configurable parameters, such as the announcement interval and the connection interval, which influence its performance in the various applications of the technology.

LoRa is a long-range, low-power communication technology. It is based on a network with a star topology, like a cell phone network. The modules send and receive data from specific Gateways, which forward them via IP connection to local or remote servers (Instituto NCB, 2020). Its main features are: long range, interference immunity, low power consumption, multipurpose device (can be used in public and private networks) and radio operation (Instituto de Engenharia, 2020).

LoRa technology has several architectures. One of them is the LoRaWAN protocol which defines an architecture for operation, safety, power adjustment (aimed at maximizing the durability of the module's batteries), and the types of applications. The system is basically formed by modules, gateways, network server and application server.

Ultra-Wideband is a radio communication with a bandwidth greater than 500 MHz. It is a robust technology, thanks to its spectral spread, and its main characteristic is the high transmission speed (Rodrigues *et al.*, 2020).

Rodrigues *et al.* (2009) mention that both Bluetooth and UWB follow the same principle. However, UWB's transmission speed, one of its strengths, is 100 to 500Mbps, higher than any other type of wireless transmission. Other advantageous features of the UWB are interference immunity (signal multipathing), security against intrusion, and interference immunity with other wireless technologies.

To carry out the tracking, two elements are basically used: the sensor and the tag. The tag sends billions of pulses per second across an extensive frequency spectrum. The sensor captures this signal and calculates the location of the tag with an accuracy of up to 15 centimeters (Novidá, 2020b). UWB tags developed for industrial applications weigh around twenty grams and can reach a communication range, with UWB Sensors, of up to two hundred meters (Zebra, 2020).

2.2 Benchmarking of tracking solutions

Rodrigues *et al.* (2009) highlight that with current technologies, tracking techniques are no longer the main difficulty. To develop an automobile tracking system, attention must be focused on: comparing technological alternatives (hardware and software); integration with corporate systems; exploration and analysis of data; and, finally, reduced implementation, maintenance and communication costs.

Rodrigues *et al.* (2009) highlight that although positioning and communication technologies are created in different contexts and for different purposes, nowadays, both have multiple complementary functions. Automobile tracking solutions that integrate these technologies experience strong dynamics, arising from prices and the market.

Seferagic *et al.* (2020) use the following factors to benchmark technologies: cost, scalability, latency assessment, reliability, reach and energy consumption. They also report that adverse industrial environments pose a series of challenges for wireless communications: reliability, fault tolerance and low latency are the greatest.

The transmission range is influenced by transmission power, propagation properties, and the complexity of coding and modulation. For technologies that transmit with a constant power, reducing the complexity rate allows the decoding of a weaker or distorted signal by the receiver to occur, which allows an increase in the transmission range (Seferagic *et al.*, 2020).

Reliability is determined by the media access control (MAC) design and the modulation and encoding scheme (MCS). One of the biggest reliability drawbacks for wireless technologies compared to wired technologies is inter- and intra-technology interference in the air, where collisions and loss of data packets can occur (Seferagic *et al.*, 2020).

Power consumption is dependent on data baud rate, MAC topology, and hardware design. The low data rate results in long transmission times that end up increasing node power consumption and reducing battery life. Analyzing the topology, nodes in multi-hop networks consume more energy than in single-hop networks, considering that, in addition to the node's own transmissions and receptions, they also play the role of forwarding data packets to other nodes. The complexity of encoding and decoding also contributes to energy consumption (Seferagic *et al.*, 2020).

Latency is defined as a delay in data transmission that results from the time it takes a request to be completed, i.e., the time it takes for a data packet to be transmitted from a sending point to a receiving point (Trybe, 2020). Factors that contribute to latency are propagation, transmission, and processing. Propagation is simply the time that the data packet takes to travel between the two points, whereas transmission consists of the means by which this data will be transported (optical fiber, wireless, among others) and, in addition to these, the processing that occurs when a node examines and changes a data packet also influence latency (Brasil Cloud, 2020).

Data rate and bandwidth are additional factors that impact latency. The higher the data rate and the greater the bandwidth, the shorter the delay. Furthermore, multi-hop topologies increase latency, considering that the forwarding and routing of packets influence transmission time. Situations where a link fails and the system must compute a new route, introduce more delay, all this can make multi-hop networks unsuitable for applications that demand very low latency (Seferagic *et al.*, 2020). On the other hand, multi-hop networks have the advantage of a longer range and also contribute to better reliability. This is because the loss of a link will not result in communication failures, as is the case with single-hop networks.

When it comes to cycle time, it basically consists of the time it takes the system to identify the devices in a control loop. This factor is strongly influenced by the number of nodes that the network has (Seferagic *et al.*, 2020).

Rodrigues *et al.* (2009) mention that to define an automobile tracking solution, the first important decision is to define the desired type of spatial tracking: continuous, discontinuous or hybrid. Which basically consist of:

- a) the continuous system allows locating the automobile at any point along the route;
- b) the discontinuous (or punctual) system informs if the automobile has crossed reference points in its path;
- c) the hybrid system is a combination of both procedures; it enables the increase of traceability in specific areas.

Rodrigues *et al.* (2009) report that monitoring the movement of an automobile continuously requires a system for automatically processing data. The system configuration should allow issuing an alert when the observed behavior of the automobile is not suitable for that area. This same system should make it possible to visualize the position of the fleet on maps. Therefore, it is essential that the level of cartographic accuracy of the automobile coordinates is compatible with that of the cartographic base that the system will use to process the spatial data.

To manage a fleet of automobiles without the need to visualize it on a map, it is possible to use an option called electronic fence. This technique consists of comparing the coordinates obtained on the route with those obtained from tracking the automobile. If the automobile crosses a border that it shouldn't, an alert is issued (Rodrigues *et al.*, 2009).

3. DEVELOPMENT

3.1 Mapping of improvement opportunities

In the process, automobiles are subject to following diversified flows in different qualitative assessments. The Manufacturing Execution System (MES) is used to control the production flow and in the quality evaluation process (post-production). One of the main problems with automobile traceability is transfer failures. Transfer failures mainly occur when an employee at a workstation fails to transfer the automobile to the destination station. Some of the other problems that may occur are systemic malfunctions, problems with dispatching production orders and error in reading the product barcode.

To map the pointing failures, the daily verification between the actual location and the systemic location of the automobile was started. This verification was carried out daily from the inventory data carried out at the end of the production shift. In this way, it was possible to find out which stations are most critical for pointing failures. Transfer failure data shall be used as the basis for evaluating the performance of the implemented solving technology.

Another opportunity for improvement was the project's impact on the management of rework stations. When an automobile fails and needs to go through a rework station, its time spent in the process tends to increase. To manage the time an automobile spends in a certain station, the "aging" parameter is used. This parameter is generated from the MES and consists of the calculation of the time (in days) since the date of the last transfer of the automobile. As a result of the failures in pointing, the "aging" obtained from the MES does not always represent a reliable data.

3.2 Analysis of enabling technologies applied to the problem

During the project elaboration process, several technologies were researched, among them RFID, LoRa, UWB and BLE. These technologies were evaluated based on the five performance objectives proposed by Slack *et al.* (2002), namely: cost, reliability, flexibility, quality and speed. It is important to emphasize that the comparisons were carried out for the application of technology in the problem situation. Figure 3 consists of a polar diagram drawn up using the data obtained in the technology research and the quotes that were sent by potential suppliers. The current situation is the baseline for the parameters, minus the cost. It requires further analysis, since the operating cost is directly impacted with the implementation of a solving technology.

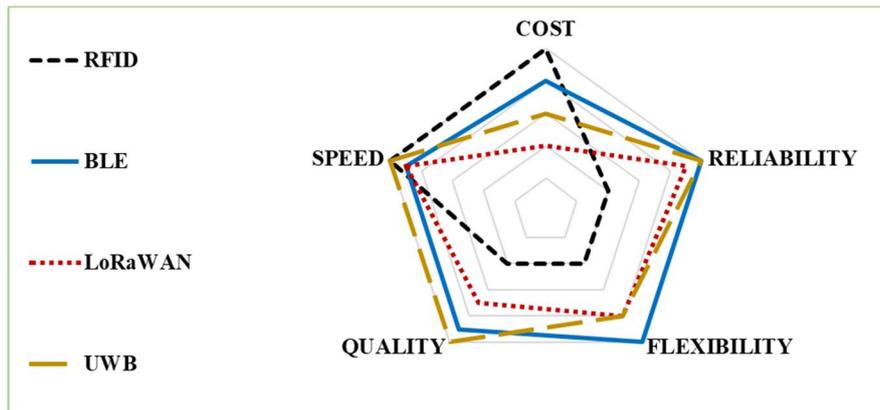


Figure 3. Comparative polar diagram of enabling technologies.

It is important to note that the cost assessment is qualitative, and the lower the cost (implementation and operation) the greater the technology advantage in this regard. The reliability analysis consisted of identifying whether the technology could pass on data that was not consistent with reality, and whether the data could be lost in the communication procedure between the readers and the tracking modules. In terms of flexibility, it was judged how much the implemented technology could integrate with other systems for an intelligent management of factory processes (such as: communication with smartphones, transmission of automobile sensor data, among others). Quality was judged on the accuracy of the automobile's location, and on how the information would be made available to the user. The last item, speed, was analyzed as the speed the technology would make available to carry out an inventory, and to locate a specific automobile (this factor is strongly influenced by the network topology used).

When analyzing the diagram in Figure 3, it is noted that the technology that presents the greatest cost advantage (in implementation and operation) was RFID technology, another possible finding is that data acquisition is done quickly. However, in other respects, this technology was estimated to have poor performance. This is mainly because RFID is a technology that was developed for purposes only focused on location, unlike the others, which were developed for purposes that also encompass communication.

In addition, the implementation of RFID in automobile tracking requires installing portals to read the attached tags. Thus, it will only be possible to identify specific automobile movements, and real-time monitoring is not possible. With RFID, traceability can only be done through the "electronic fence" technique. It is necessary to define entrance and exit portals of the areas. The logic of the system consists of analyzing which portal was the last that identified the automobile and, thus, the location of the automobile will be the area that has that portal defined as an entrance.

It is important to emphasize that the exit portal of an area should be considered as the entrance portal of another adjacent area. In the data management system, it would not be possible to identify whether a automobile, in fact, is contained in the indicated area. If a portal fails to read the label or an improper movement occurs, the data presented by the system will not be consistent with reality. Vendors report that reading RFID tags (active or passive) is a delicate process. In most cases, parallelism between the antenna and the tag is required, in addition, to requiring that, the automobile must not exceed a maximum speed to pass through the portals.

The other competing technologies (BLE, LoRaWAN and UWB) are kind of Real Time Location System (RTLs), i.e., they would allow the complete tracking of the coverage area, making it possible to identify the presence and estimated position of the automobile in real time.

From the research of technologies and meetings with suppliers, it was found that the technology that presents the best reliability in data transmission is the Ultra-Wideband (UWB). This is because the UWB has the highest communication and data transmission speed among the other competing technologies. In addition, its simplified network topology and its high penetration capacity result in a low noise rate, preventing data packets from getting lost in communications. Bluetooth Low Energy (BLE) technology works like UWB; however, its data transmission rate and penetration are

relatively low. As a result, BLE has a slightly lower reliability and location accuracy than UWB. However, the BLE solution has a greater cost advantage when compared to the UWB.

The analysis of the literature allows to infer that the LoRa technology, used as LoRaWAN protocol, is a very interesting solving technology because it uses a reduced number of antennas (when compared to the number of gateways that are used in BLE and UWB technologies) for coverage of an area, and because it has the greatest reach among competing technologies (up to 10 Km according to the suppliers). On the other hand, literature and vendors report that indoor traceability is not so well performed using only the LoRaWAN solution. Thus, the quality of automobile tracking accuracy tends to lag (when compared to BLE and UWB).

In terms of speed, RFID and UWB technologies stand out, however, RFID does not allow real-time monitoring of automobile. In this way, carrying out an inventory can be done quickly, as all data will be obtained through a history of automobile movements, i.e., the location of an automobile is based on the last time it was identified in a portal RFID reader. When the user requests a detailed inventory, the system will only compute the latest movement records for each automobile. However, the speed to locating a automobile would not be impacted by the latency effect (a characteristic effect of RTLS tracking systems). Other competing technologies experience data transmission delay (latency), UWB is identified as the RTLS technology that suffers the least from such communication effect.

3.3 Definition of project requirements

The study of improvement opportunities combined with the study of enabling technologies resulted in the definition of the scope of the automobile remote traceability project for the automobile industry's quality assessment process.

The data management system must be developed in such a way as to allow, at a minimum: the inventory of all the assembler's automobile, the location of a specific automobile and the location of automobiles that have a specific characteristic or status. These locations must be made from the search performed by the user in the data management system, which may have as input variables: VIN, model, version, color, status and length of stay. The system should allow the combination of different input variables to ensure a refined search. The general inventory of automobiles must be generated in the data management system itself; the user will need to inform the data they want to view in the report. The system should generate the reports so that they can be converted into Excel spreadsheets.

The data management system interface must be designed to show the automobile's location in the manufacturing plant. Ideally, the location of all monitored automobiles appears on the plant map in real time. With such a view, the employee who wishes to perform a procedure in an automobile will only need to perform a search for it in the system and go to the indicated location.

In addition, the data management system must inform the time an automobile remains at each station, as well as its respective movement history. Such data must be independent of the notes made in the MES. Thus, data must be acquired from the continuous monitoring of the automobile's location within the process. This information acquisition mode aims to enable the comparison between the data arising from the monitoring of the location with the data entered in the MES, enabling the mapping of possible transfer failures. Figure 4 shows a flowchart of the comparison logic between the data from the MES, and the data acquired by the tracking system, if the information of both is not equivalent, the system issues an alert. Such a situation can configure a failure of the pointing or an inappropriate move.

The residence time data can be used to analyze the crossing time of the test stations. In this way, allow the elaboration of actions to balance the time between the process stations. Furthermore, it enables the analysis of the average repair time at each station of this modality.

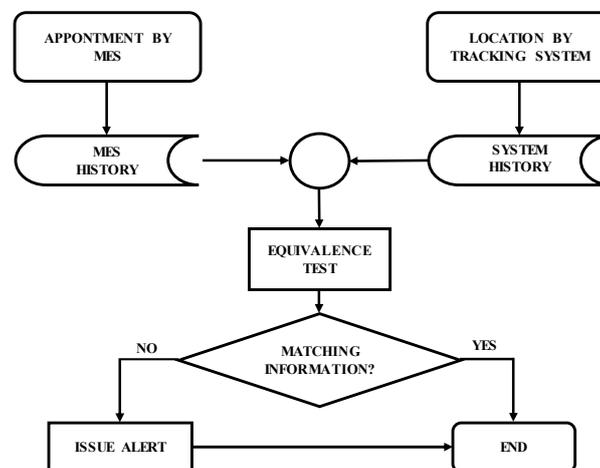


Figure 4. Logical flow of data comparison in the system.

3.4 Expected impact

The implementation of the project aims to eliminate the data collection activity that is currently done manually on a daily basis at the end of the production shift. The data acquired in the physical inventory is consolidated into spreadsheets for later exposure at the daily closing meeting. These are the main data for managing production at the manufacturing plant, so they must be as accurate as possible.

Another situation that demands the location of specific automobile occurs when a quality problem arising from defects in the manufacture of a component part is identified. In this way, a check is carried out on all automobiles that used parts from that lot. To carry out this activity, it is necessary to find all these automobiles for proper inspection. This activity is called “campaign” and is normally carried out in the automobile allocation yards. With the implementation of the remote traceability system, the aim is to eliminate the need for physical search of these automobiles, the system will indicate the location of each one, and then, a mover will search this automobile for the inspection procedure in a dedicated area for this activity.

Once implemented, the tracking system is expected to change the profile of activities related to the automobile control in the quality control process. Figure 5 is a graph that shows the comparison of hours dedicated by employees in the current situation and estimated in the project post-implementation.

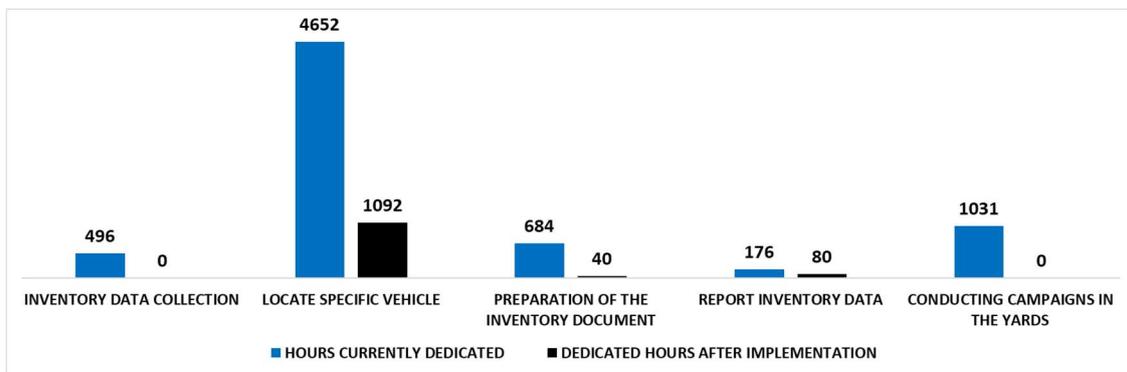


Figure 5. Comparison of hours/activity between current situation/post-implantation situation.

A reduction of **85.03%** in dedicated time is estimated, allowing redirection to activities that add value to the product. It is important to mention additional activities that should arise due to the project implementation, some examples are: attaching the tracking module to the automobile, linking the module code with the VIN, resetting the modules data, transporting the modules from the pick-up point to the placement point, among others. These activities have not yet had an estimated time. However, it is expected that such increased time is small compared to the total time saved.

3.5 Proof-of-Concept (POC)

Initially, traceability will be tested on automobiles as part of the assembler evaluation process. An initial version of the data management system, to be used at the proof-of-concept (POC), was developed in partnership with suppliers. They presented an existing platform (which is used in a company in another segment) and asked the project team to prepare an equivalence document, with data to enable the adaptation of the existing platform for use in the assembler's problems. This document contains the entire range of possible data for identifying the tracked automobiles, as well as all the addresses that the automobile may go through during the POC.

After the adaptations, the data management system for the pilot plan was developed. This platform makes it possible to register and monitor the location of automobiles that have the tracking module attached in it. Other tools found in this system are performing transfers between stations, monitoring the time an automobile remains in each location, monitoring the vehicle's movement history, creating alerts for specific situations, searching for the location of a specific automobile, location of the automobile by status and/or characteristic and, allow the realization of an instantaneous inventory.

The version developed for POC was designed to be, at first, independent of the MES. Because of this, the referred system has automobile transfer functions like those already used in the MES. The testing stage (POC) does not include the integration between the developed system and the system already used. Figure 6a consists of an image of the systemic link screen between the tracking module and the automobile, whereas in Figure 6b it is possible to note the location of the monitored automobiles over the assembler area. This development was done jointly between the assembler's project team and the suppliers (E-Trind and Taggen). In this application it will be possible to view the location (in real time) of each automobile that has a linked tracker.

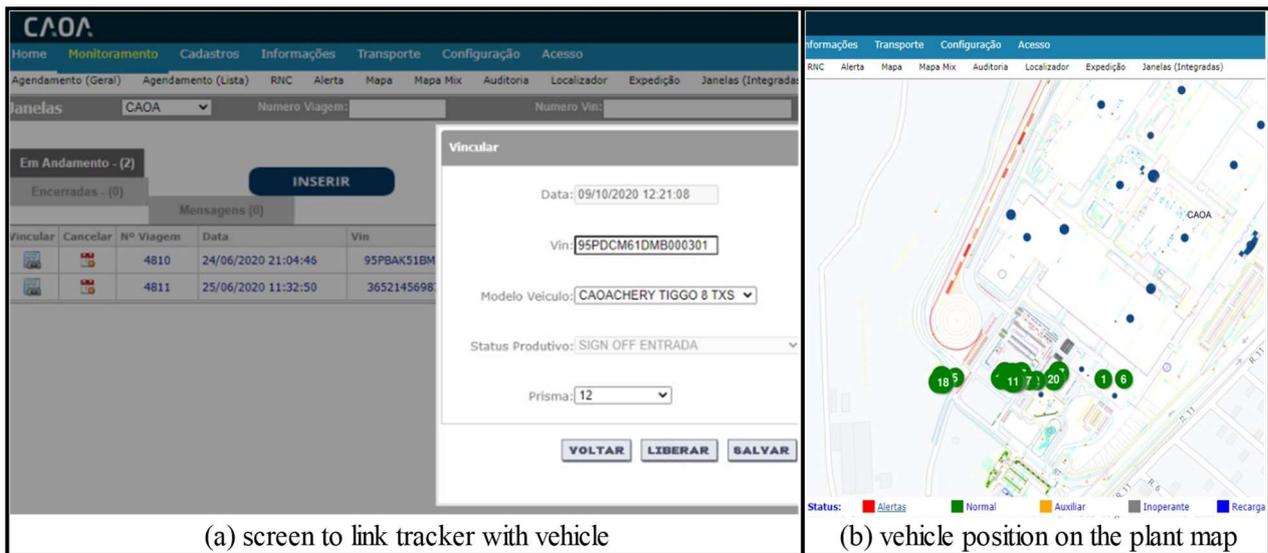


Figure 6. Digital platform screen developed by E-Trind and Taggen.

In the system to be developed for the implementation, it is ideal that the movement history is obtained from the continuous monitoring of the automobile's location. To enable such action, the system must identify duly distinguished monitoring areas, from the moment the automobile enters an area, a counter is activated to monitor the dwell time. It may happen that an automobile enters an area only for reasons of movement, that is, no procedure will be performed on that automobile. So that the movement history does not contain unnecessary information, each area will have a minimum time of stay so that the presence of the automobile is registered in its history. If the counter does not reach a specified minimum time, that movement will not appear in the automobile history. These times must be determined by the project team during the execution of the POC.

3.6 Discussion

The study of technologies applied to the automobile traceability in the quality control process resulted in some findings about the best technologies and methods to be applied as a solution to the problem.

Among the technologies studied, Bluetooth Low Energy (BLE) was the most interesting when applied as a solution technology. Because it has the best cost-benefit ratio, in addition to being a flexible technology that would enable integration with future projects.

The other RTLS technologies (LoRaWAN and UWB) also presented themselves as a good solution for automobile tracking, however, they present a high implementation cost when compared to BLE. Ultra-Wideband (UWB) has the benefit of offering the best accuracy and data transfer capacity, while LoRaWAN has the main benefit of long tracking range, which results in the need for a reduced number of antennas. However, as the problem presented does not require a level of accuracy as refined as the UWB can offer, since the automobiles occupy a considerable area, an accuracy of up to 10 meters would be reasonable. Analyzing the solution by LoRaWAN technology, its respective modules and antennas have a high added value (when compared to other technologies) and the use of a reduced number of antennas would make it difficult to zone small areas, resulting in a poorly detailed tracking.

The BLE solution would need a number of gateways close to the amount needed by the UWB solution, however, BLE gateways have a reduced value when compared to UWB gateways, as well as BLE technology modules (Beacon) are more cost-effective than the UWB modules.

When it comes to information storage and transfer capacity, UWB and LoRaWAN are superior when compared to BLE. However, the need for data storage and transfer between modules and readers is well served by BLE. Considering that the automobile information must be stored in the management system itself, the module's function will only be to link the location with the automobile data. Thus, the module will act as a trigger to make the system look for information related to a certain automobile. The idea is that the information is stored in the cloud, so the data storage and transfer capacity of the tracking module does not tend to be a critical point.

RFID technology presented itself as a more limited solution when compared to RTLS solutions. The solution using only RFID makes real-time tracking impossible. Although, at first glance, it appears to be a cheap solution, RFID requires the installation of reading portals, as well as the delimitation of borders to allow vehicles to only enter and leave a certain area by passing through the portals. All of this would result in building reformulating costs and probable changes in automobile handling procedures. Furthermore, one can believe that the automobile tracking system would only be reliable if there were no failures in the handling procedure, i.e., this solution is highly dependent on human operation.

The solution using RFID was considered a competitor due to its high popularity in traceability applications for the industry. However, for the proposed problem, where the product flow is diversified, a solution using only RFID does not result in great advantages. The cost-benefit ratio tends to be low, considering that operational failures would result in problems that would demand too much labor to solve.

Analyzing the data management system that must be developed, it can be deduced that its integration with MES is essential. Although this integration serves, at first, only to compare the data, it was found that the variety of data sources tends to provide greater reliability for the process management. The tracking technology management system must use a logic that associates the status of the automobile with its location, while the MES will continue to obtain the location through the transfers that are made by employees. This logic is intended to enable the data management system to find discrepancies between the automobile's location and its status reported in the MES. In this way, it will be possible to issue alerts when such information (status and actual location) is inconsistent with each other. The length of stay (or "aging") must be monitored from the automobile tracking information.

In view of the previous paragraph, it appears that it will be necessary to (systemically) zone the monitoring area of the manufacturing plant into smaller areas, that is, however much the system delivers the automobile's actual location point (with an accuracy of up to ten meters), it will still be necessary for the system to identify which area that point belongs to. Only in this way will it be possible to identify the length of stay and the failures in the appointment. As long as the automobile does not cross the boundaries of a certain area, the time spent on the automobile will continue to count. This prevents the maneuvers that an automobile experiences (within a station or yard) from being interpreted as processing movements.

Another observation made was that the accuracy of location may be different for different areas. When an automobile is at a workstation (roll test, for example) such accurate is not required, however, when the automobile is in a yard, an accuracy of up to ten meters is required. This is because finding an automobile at a process station is a simpler task than finding an automobile at an allocation yard. Automobiles of the same models and colors are allocated in the yards, some of them can store up to 800 vehicles, on average.

4. CONCLUSIONS

In this work it was presented the development of a study on systems to implement remote automobile traceability in a process with diversified flow, being this process, the quality tests. The initial problem consisted of proposing solutions that would enable an assertive inventory of the automobiles present in the process, however, with the study of technologies, opportunities for improvement in quality control management were perceived.

Regarding the evaluation of the studied systems, it was noted that the older and more popular technologies tend to be evaluated as highly eligible solutions, such as the case of RFID technology. Older technologies tend to have lower costs and greater availability in the market. One of the longest phases of the project was to verify, through the cost-benefit ratio, which newer technologies could result in solutions with greater scope and, even so, have a low technological risk. The suppliers contacted provided great assistance, enabling the visibility of new opportunities for improvement. Thus, it was concluded that knowing the possible solutions, without a doubt, contributed to a better definition of the project scope.

RFID technology was the first candidate for solving the problem, considering that the initial objective was only to guarantee a fast and accurate inventory, without too many details. The study of Real Time Location System (RTLS) type technologies made it possible to plan the expansion of the tracking solution to monitor, in real time, the tests and rework components of quality control.

Cost was one of the main factors in evaluating enabling technologies. Indeed, defining the optimal point that the solution should reach was a painstaking task. The inclusion of a technology tends to eliminate some activities and require new ones to be implemented. New activities would demand new costs. The definition of the most adequate solution consisted in analyzing the technology that had the best relationship between the reduction of the labor employed (for inventory control) and the lowest labor added for its operation. Among the four technologies analyzed, BLE, UWB and LoRa (used by the LoRaWAN protocol) presented similar performances in this regard. However, of these three, the technology that presented the lowest cost was Bluetooth Low Energy (BLE). With the disadvantage of having a lower accuracy than UWB and a lower range than LoRaWAN. Nevertheless, for the proposed application, the solution using BLE seems to perfectly meet the requirements imposed for accuracy and range. Furthermore, BLE had an adequate data transfer capability.

5. ACKNOWLEDGEMENTS

The authors would like to thank Prof. Dr. Ademyr Gonçalves de Oliveira, to Prof. Dr. Marcelo Stehling de Castro, CAO A Montadora, Taggen, E-Trind, EMC / UFG, LabMEC, FUNAPE, CAPES, CNPQ, and FAPEG.

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