ABSTRACT

The automotive components industry represents a strong sector on the Portuguese metalworking industry. There are many national companies in this area but there is also a strong presence of foreign capital, through numerous multinational companies that lodge in our country, some for interest to be closer to some final consumers (assembly lines in Portugal and Spain), others by diversification strategy and still others by interest in terms of competitiveness.

It is well known that most multinational companies installed in Portugal on metalwork field offers extremely appealing competitiveness ratios, which will not be unrelated to strong engineering component associated with them and the engineers’ creativity of a large part of these professionals.

Due to cost pressure, shortened development cycles as well as increasing variety and technical product complexity companies face more complex parallel development processes. Automating a manual process can greatly increase the productivity of a manufacturing facility. It can reduce overall system life cycle costs, reduce machine start-up time, and improve product quality and consistency.

Keywords: Process integration, automated lines, automation.

INTRODUCTION

The production of components for automotive industry presents a lot of requirements whose are based in high quality, very competitive price, delivery time in line the expectations and great flexibility. Analysing automotive industry in the last two decades, the manufacturing paradigm has changed significantly, drifting from a dedicated massive production system to another custom production [1]. Numerous management methods has been developed, departing from massive production optimization techniques to agile or flexible productive processes in order to accommodate the market change driven by customers’ needs and expectations [2]. Indeed, agile production systems will allow quick cost-effective reactions to unexpected and ever-changing market demand, supporting fast product launches for previously unforeseen products tailored to meet changing customer requirements [3]. At the same time, techniques based on the Toyota Production System (TPS) have been devoted to identify and cut wastes of time related to production tasks or logistic operations those do not create added-value [4, 5]. Lean methodologies have increasingly been developed leading to significant improvements on business [6] and environmental performance [7].
Automation has been a cost-effective way to overcome the most of the challenges that production systems have faced with. Thus, several research works have been carried out in order to improve manufacturing systems, cutting wastes and increasing the production rates [8, 13]. However, ergonomic concerns and the interaction between humans and automated or robotized systems have to be cared in order to make easier their integration [9, 14-15].

Products’ modularity has also been an issue intensively studied [16, 17] regarding some complex systems used in the automotive industry. Nevertheless, splitting tasks may be a wrong way because if the operations will be carried out in different equipments, this policy will lead to intermediate stocks or new management systems in order to keep the production flow coherent and in line. Though, the integration of different tasks can be an interesting way to keep the materials flow intelligible and improve the product competitiveness by diminishing of the logistics and intermediate stocks.

Regarding the production of metallic harnesses for mechanical actuation of several devices in cars, we can find a lot of manufacturing processes needed to produce conduits with very low commercial value. Furthermore, the new automotive manufacturing paradigms referred above require that setup tasks are recurrent despite the products integrate the same family and the changes between them allow the use easy changeable and compatible tools as well as the change of cutting length.

This work intends to integrate some of the processes used in the car metallic harness products in an unique equipment never designed before, allowing continuous production of these products and minimizing the logistic operations and the intermediate stocks, keeping the production agile by the introduction of automated systems those helps to keep the setup time in a competitive way.

METHODS

This work started from a company need related to the automotive components production. The problem arose from the need to increase production of two types of currently produced products due to the existing means reached the maximum capacity. Knowing this fact it was necessary to new production capacity to cope with the increasing demand in the present and near future, so the opportunity to upgrade the existing line appeared and it was proposed to those entitled.

The current process for the A harness family is composed of two preparation stations (Operation A and C), two injection machines (Operation B) and one assembly line as described in the image (figure 1) with the corresponding characteristics (table 1).

Harness A (figure 2) is composed of a metallic cable with cable end fittings in zamak alloy (1), a conduit (2), two injected conduits end fittings (3), a protection tube (4), label (5) and finally a fixation rubber (grommet) (6), this family contains all this components and the difference in them can be encounter in the sizes and position of the conduit, protection tube and fixation rubber (Table 2).
Fig. 1 - Harness A assembly process.

Table 1 - Characteristics and Workforce for A harness production.

<table>
<thead>
<tr>
<th>Assembly line characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>9 seconds</td>
</tr>
<tr>
<td>Output</td>
<td>400 pieces/hour</td>
</tr>
<tr>
<td>PHH</td>
<td>133 (3 workers)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Operation B</td>
</tr>
<tr>
<td>2nd Operation B</td>
</tr>
<tr>
<td>Operation C</td>
</tr>
<tr>
<td>1st Operation A</td>
</tr>
<tr>
<td>2nd Operation A</td>
</tr>
<tr>
<td>Assembly Line</td>
</tr>
</tbody>
</table>

TOTAL: 6.6 workers per shift

The assembly/production of this family is divided in 3 steps:

1. Preparation of a sub-assembly with the conduit (2), the protection tube (4) and finally the grommet (6) in the two preparation station (Operation A and C);
2. The sub-assembly from the preparations stations goes to the injection machines (Operation B) to inject both conduit end fittings, the first and second step is interconnected as represented in figure 1;

3. The sub-assembly with the injected conduit end fittings reaches the assembly line to receive the last components, the metallic cable with cable end fittings in zamak alloy (1) and the label (5) becoming as shown in figure 2.

Fig. 2 - Schematic diagram of A Harness.

Table 2 - Specifications of the different A harnesses.

<table>
<thead>
<tr>
<th>Reference</th>
<th>A+/+-3 mm</th>
<th>B+/+-0,5 mm</th>
<th>C+/+-7 mm</th>
<th>D+/+-5 mm</th>
<th>E+/+-5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>500</td>
<td>42,9</td>
<td>180</td>
<td>220</td>
<td>91</td>
</tr>
<tr>
<td>A2</td>
<td>645</td>
<td>43,2</td>
<td>165</td>
<td>380</td>
<td>58</td>
</tr>
<tr>
<td>A3</td>
<td>550</td>
<td>42,4</td>
<td>N/A</td>
<td>N/A</td>
<td>130</td>
</tr>
<tr>
<td>A4</td>
<td>530</td>
<td>42,4</td>
<td>221</td>
<td>210</td>
<td>120</td>
</tr>
<tr>
<td>A5</td>
<td>490</td>
<td>42,4</td>
<td>247</td>
<td>150</td>
<td>131</td>
</tr>
<tr>
<td>A6</td>
<td>510</td>
<td>42,4</td>
<td>211</td>
<td>200</td>
<td>119</td>
</tr>
<tr>
<td>A7</td>
<td>570</td>
<td>42,4</td>
<td>270</td>
<td>200</td>
<td>128</td>
</tr>
<tr>
<td>A8</td>
<td>560</td>
<td>44,1</td>
<td>304</td>
<td>160</td>
<td>57</td>
</tr>
<tr>
<td>A9</td>
<td>540</td>
<td>44</td>
<td>276</td>
<td>120</td>
<td>98</td>
</tr>
</tbody>
</table>

As for the cables B of the second family it is composed of one preparation station (Operation B), one injection machine (Operation A) and one assembly line as shown below with the corresponding characteristics (table 3).
Fig. 3 - Harness A assembly process.

Table 3 - Characteristics and Workforce for harness B production.

<table>
<thead>
<tr>
<th>Assembly line characteristics</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cycle time</td>
<td>8 seconds</td>
</tr>
<tr>
<td>Output</td>
<td>450 pieces/hour</td>
</tr>
<tr>
<td>PHH</td>
<td>112 (3 workers)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workforce</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation A</td>
<td>0.5 worker</td>
</tr>
<tr>
<td>Operation B</td>
<td>1 worker</td>
</tr>
<tr>
<td>Assembly Line</td>
<td>4 Workers</td>
</tr>
<tr>
<td><strong>TOTAL: 5.5 workers per shift</strong></td>
<td></td>
</tr>
</tbody>
</table>

B harness (figure 4) presents the following components: metallic cable with cable end fittings in zamak (1), a conduit (2), one injected conduit end fitting (3) and one punched conduit end fitting (4), a protection tube (5) and label (6). This family contains all these components and the difference in them can be found in sizes and position of the conduit and protection tube (Table 4).

The assembly/production of this family is also divided in two steps just like the harness A and these steps are:
1. Sub-assembly preparation of the conduit (2), one injected conduit end fitting (3) and the protection tube (4) in the preparation station (Operation B) and the injection machine (Operation A);
2. The sub-assembly reaches the assembly line to receive the last components, the metallic cable with cable end fittings in zamak alloy (1), one punched conduit end fitting (4) and the label (5), becoming as shown in the figure 4.

![Fig. 4 - Schematic diagram of B harness.](image)

<table>
<thead>
<tr>
<th>Reference</th>
<th>A+/-3 mm</th>
<th>B+/-0,5 mm</th>
<th>C+/-7 mm</th>
<th>D+/-5 mm</th>
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</thead>
<tbody>
<tr>
<td>B1</td>
<td>300</td>
<td>51,3</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>B2</td>
<td>352</td>
<td>52,3</td>
<td>50</td>
<td>250</td>
</tr>
<tr>
<td>B3</td>
<td>316</td>
<td>52,3</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>B4</td>
<td>366</td>
<td>52,3</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>B5</td>
<td>336</td>
<td>52,3</td>
<td>46</td>
<td>200</td>
</tr>
<tr>
<td>B6</td>
<td>326</td>
<td>52,8</td>
<td>57</td>
<td>218</td>
</tr>
</tbody>
</table>

Both these types of products are produced in one single assembly line, including two preparation stations and two injection machines.

**RESULTS**

The solution was to split the action plan in two different phases:

- First phase was composed of one new assembly line exclusively prepared for the production of A harness and the joining of the two preparation stations in one automatic sub-assembly line (a). The last one was designed to be capable of producing the necessary sub-assembly for both the A and B harnesses. At the beginning, just B harness was assembled in this line;

- The second phase will be composed of a new semi-automatic assembly line capable of producing only the B harness without the need for the preparation stations, the current assembly line would be free to produce both families as it was in the beginning.
Fig. 5 - A harnesses new assembly process.

Focusing on the first phase, it was needed a new preparation station that would integrate the two preparation stations in one single automatic sub-assembly line (a). This sub-assembly line would result in one worker reduction, increasing the PPH (Parts per Person per Hour), the quality guarantee, flexibility, easy operation and the decreasing of the stacking and movements of raw material through the plant floor. These preparation stations would be integrated next to the original assembly line, helping increasing the B harnesses production as stated before.

**THE PROPOSAL**

As mentioned before, due to the production increasing need of both families the R&D department decided to take the opportunity to upgrade, improve and use new technologies to: (a) increase or maintain the same production but with better relation on the PPH; (b) resolve or almost eliminate problems with quality in the process; (c) facilitate the assembly process for workers; (d) use new or upgrade the technologies applied in the process (d) keep up with all the technical specifications regarding the safety and ergonomics. This, off course, will result in a higher investment that will be compensated with the workforce reduction, resulting in a payback of 5 months regarding the investment needed.

In Table 5 we can see the difference in terms of work force for this year (2016) between the current process and the proposal process.

**Design of the new Preparation Station**

For the new preparation station, as mentioned before, there was a need to create an automatic sub-assembly that would integrate the two previous preparation stations and keep the same outputs but cutting on the workforce.
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<tbody>
<tr>
<td><strong>Current</strong></td>
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<td></td>
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<tr>
<td>Workforce per shift</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0,6</td>
<td>1</td>
</tr>
<tr>
<td>Shifts (2016)</td>
<td>2,7</td>
<td>3</td>
<td>2,6</td>
<td>3</td>
<td>1,7</td>
<td>3</td>
</tr>
<tr>
<td>Partial Workforce</td>
<td>10,8</td>
<td>9</td>
<td>2,6</td>
<td>3</td>
<td>1,02</td>
<td>3</td>
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<tr>
<td><strong>Total Workforce</strong></td>
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<td><strong>Cost per worker</strong></td>
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<tr>
<td><strong>Total Cost per worker (2016)</strong></td>
<td>29,42</td>
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<td><strong>Proposal</strong></td>
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</tr>
<tr>
<td>Workforce per shift</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Shifts (2016)</td>
<td>2,7</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Partial Workforce</td>
<td>5,4</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Workforce</strong></td>
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<tr>
<td><strong>Cost per worker</strong></td>
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<tr>
<td><strong>Total Cost per worker (2016)</strong></td>
<td>14,4</td>
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<tr>
<td><strong>Difference on Workforce</strong></td>
<td>180,240 €</td>
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</tr>
</tbody>
</table>

The objective and the tasks that this station need to execute are:

- Harness A – Welding of the protection tube (Operation C as in the old process), carry out the deformation on both conduit extremities (Operation A as in the old process), automatic extraction and segregation.

- Harness B – Welding of the protection tube (Operation C as in the old process), automatic extraction and segregation.

The schematic diagram of the station can be seen in the next example:
Fig. 6 - Schematic for the new preparation station.

Thus, for that, the process should follow the following specifications:

- Maximum cycle time – 9 seconds for the A harness and 8 seconds for the B harness. Minimum output of respectively: 400 pieces/hour and 450 pieces/hour;
- Setup time if necessary and in order to be carried out by a single worker – Maximum 10 minutes;
- Workforce – 1 worker;
- Scrap – Maximum 0,2%;
- The design of the machine should take into consideration all the lessons learned from the previous (and current) processes.

Lessons Learned

- The positions of the welds must be guaranteed according to the product specification. Examine the possibility of using simple welding tools even for smaller tubes. Positioning the machine sideways on the machine due to the mounting and allowing extraction to the next station;
- The welds must be carried out with fixed positioning jigs, through the use of two welding machines;
- The configuration of the welding tools nozzles have to be according to the company definition;
- The equipment must contain Poke-Yokes to guarantee the grommet presence, protection tube and carrying out the conduit correct deformation of the extremities;
- The equipment must be protected from any access and the welding machine properly insulated, due to the working characteristics needed.
DISCUSSION

The automatic sub-assembly line

Having all the data necessary for equipment design, the project was initiated starting with the integration of the preparation existent means, upgrading them to the equipment need and improving it on the known issues.

For example in the manual deformation of the conduit extremities machines, the worker had to exert a considerable force in order to the machine perform correctly the deformation of the extremities which, in a succession of times was a problem; the initial welding machine was not capable of performing the weld in the protection tube inferior to 150 mm needing a special tool for accomplish that (higher cost); also in the welding machine the protection of the worker against the effect of the type of welding used was very minimal (almost nonexistent), there are studies that show the harm on the health induced by this type of machines; the workflow of raw material and stock material needed are immense occupying a significant space in the plant floor, space that could be used to put new assembly lines or rearrange the existing ones in an easier way.

Regarding the issues stated before, the machine was designed as presented below:

The equipment will be divided in 4 stations:

1. Feeding Zone and Welding – Station where the worker will feed the equipment with the sub-assembly A and B harnesses components. After the worker positioning the sub-assembly, the protection tube will be welded to the conduit;
2. 1st Deformation Machine – Station where the conduit will be deformed in one end;
3. 2nd Deformation Machine – Same as the previous one but where the deformation will occur in the opposite end;
4. Extraction and Segregation – As the title implies, is the place where equipment will extract or segregate the sub-assemblies.

Description of the equipment functions

The equipment will execute the necessary sub-assemblies to feed the injections machines and the assembly lines, for that the equipment have a manual station where the worker has to:

1. Pick up the protection tube that lies in the support structures containing the box in which they arrive at the equipment, the grommet and the conduit to create the sub-assembly;
2. Place sub-assembly on the respective jig situated in the feed station and press the start command; while the protection tube is welded to the conduit the worker execute the step 1 again;
3. The deformation making processes in the extremities of the conduit, the product handling and extraction are carried out automatically;
4. When the box is full, it will appear the information on the control panel, so the worker must remove the box full, store in the defined position and put a new empty box.
Proceedings of the 5th International Conference on Integrity-Reliability-Failure

Fig. 7 - Automatic Sub-Assembly Line.

Old preparation station that executed operation A
Deformation of both extremities of a metallic cable
Welding Machine

Old preparation station that executed operation C
Harness A
Extraction Zone
Harness B
Extraction Zone

Current
New
Control Panel Operation

In order to operate the equipment exists a control panel that allows the worker (or technician) to perform different tasks necessary for the setup operations, adjustments operations, maintenance operation, automatic detected errors to help visualize what kind and what to do, among others. Some of them are:

1. Home Windows – Home window is where the worker (or technician) can select the reference to produce (a), select the work mode (b), see the number of cables produced in each shift (c), see and adjust each parameter for the welding machines (d) and the manual commands (e) (only accessible by the technician as it is protected by a password).
2. Manual commands for each machine – When the worker selects the work mode for each machine, there will appear a window with instructions and buttons to operate the machine. For example, in the welding machines, the worker has access to the command to descend each machine as well as see each parameter in order to confirm with the machine manual if it is the correct one in case of any error.

Fig. 10 - Manual command for the ultrasonic welding machines.

3. In case of any necessary adjustments to the axis that controls the positions of the machines, there is a window only accessible by technicians in order to adjust them, however, they are limited in order to control the process.

4.

Fig. 11 - Controlling the axis to adjust position of 2nd deformation machine and manipulators.

5. The most common errors have a distinctive window message in order to allow the worker to perform the correct actions, such as: The box in which the OK product falls are full (a), there were 3 sub-assemblies that were NOK (b) (in which the worker has to go to the scrap box and validate them), among others.
Safety and ergonomics

The equipment design, including mechanical and electrical designs, was performed to ensure maximum safety from the operation and maintenance point of view.

Before commissioning equipment service, users must be knowledgeable in this point to be knowledgeable of the dangers to which they are exposed. Regarding Maintenance and Tuners technicians must have specific training on the equipment operation.

Hazardous movements associated to the equipment constituents are fully protected by the following security systems:

- Automatic mode
  1. The feeding zone is protected with a sliding front door containing micro-switch sensors to guarantee the door sealing;
  2. Photoelectric barriers (resolution 14 mm, 11 ms response time and protection 760 mm height) to protect the lock movements of the sliding front door;
  3. Hazardous movements of the deformation machines and product manipulators are protected by an aluminum protection in all the surroundings up to 2 meters high. The material used is phenolic 4 mm, polycarbonate 5 mm and sound-insulating plates with 20 mm thickness;
  4. In order to reduce the noise emission of the machine, constituents were considered sound-insulating plates with 20 mm thickness;
  5. Existing access doors on the machine (maintenance, adjustments) have safety sensors that allow full machines stop when they are open;
  6. The machine has an emergency command in the feeding zone (manual station). The emergency command when activated removes the power to the equipment and has priority over other control systems. The machine only starts up again after removing the fixation clip command and activation of the reset and start;
  7. In order to limit any leakage of the harmful issues resulting from the welding zone, frontal withdrawal of final product is isolated by boxes with doors (exterior cables);
  8. Lower bench area is steel, not allowing access to dangerous movements.

- Manual mode – The equipment has a manual mode, used for interventions to the machine. This mode enables verification of the machines operation status with open security doors. Who intervene on the equipment must turn on the two-hand control to the corresponding plug for carrying out the security task.
In figure 13 is represented most of the protections and safety devices of the machine.

In respect to the ergonomics, the work cycle in this position is less than 30 seconds so it is considered repetitive work. In order to reduce possible MSDs (musculoskeletal injuries) it is advisable to carry out rotation with frequency less than or equal to 2 hours in order to not be utilized the same muscular groups and therefore their fatigue and soft tissue deterioration.

The ergonomics dimensions are in accordance to the company regulations and are as follows:

- Reach to the work center: 220 mm;
- Height to the ultrasonic welding machines to perform the setup: 1300 mm;
- Height to collect box with final product (front side for the exterior cables): 637 mm;
- Height to collect box with final product (rear region for the interior cables): 600 mm;

![Fig. 13 - Protection and safety devices.](image-url)
Setup Operation

This operation is carried out by the worker and what he/she need to do is:

1. Change the jig of the corresponding reference that the equipment will start to produce, in this one the worker will have to insert in the correct position the jig with the Poka-Yoke (fiber optics) correctly positioned to guarantee the presence of the grommet and protection tube. The position of the jig is marked on the base for a quick and correct positioning of the same (figure 14). The jigs are designed to change the minimal parts possible, less tool need to fix them and the weight (less than 12 kg) are below the minimal permitted by the company’s safety regulations.

![Figure 14 – Mounting jig on the feeding zone and two pieces jig.](image)

2. Completing the step 1, the worker will go to the control panel and select the correct reference in order for the equipment automatically adapt to the positions necessary for the 2nd deformation machine and manipulator.

![Fig. 15 - Markings to help the positioning of the different jigs.](image)
3. When the equipment finish the step two the worker will have to adjust both welding machines to the correct position in relation to the jig (figure 16).

Fig. 16 - Positioning of welding machines.

Finalizing these steps the equipment is ready to start producing, although the worker as to perform some sub-assembly samples to guarantee that equipment is performing the correct welding and deformation of the conduit extremities.

SWOT Analysis

**Strengths**
- Material flow is in an continuum line;
- Intermediate stock is reduced drastically;
- Helps the internal logistic department;
- It is all protected which helps minimize future problems with the workforce;
- It segregates the NOK sub-assemblies;
- Fully automatic.

**Weaknesses**
- In case of a malfunction the sub-assembly process stops altogether;
- Lack of one type of raw material could cause a stoppage time;
- The quality of the sub-assembly lines are depended on the correct maintenance and operation.

**Opportunities**
- Can be used in other type of products by redesign some of the support jigs;
- Is an reproducible equipment for different products.

**Threats**
- Maintenance procedures;
- Sensor faling can cause a stop in a long period of time.
CONCLUSIONS
The equipment at the moment is implemented and working, although it is still in an initial stage and the capabilities are well accepted by all the teams involved. There is still some final adjustments on the programming level to extract the equipment maximum potentialities. There are already perspectives to build a second preparation station and some are already implemented in the process of possible projects that the company could win.

The equipment has taught and provide the following:

- It is possible to integrate processes even when they present high complexity;
- This reduce drastically material storage between operations;
- With this it reduces the operations of the Internal Logistics Department;
- The material flow is transformed in an continuum line (Lean);
- In case of malfunctions there is a complete cut of production not leading to unevenness of stock in the different stations.

This work allows us to realize that through proper mechanical design and automation it is possible to promote the integration of sub-assembly operations, keeping high or even increasing both productivity and flexibility, eliminating all the concerns of quality and ongoing manufacturing products related to different tasks carried out in different workstations.

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REFERENCES


