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Proposal of a methodology to improve the level of automation of an assembly line

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Abstract. This paper's aim is to propose a new methodology for organizing and identifying the assembly operations that ought to be automated in an automotive assembly line. A state of the art in the matters of automation methods is presented to situate the research work and to analyze the different methods presented in the literature. As a result, there are some lacks in terms of methods that sought to help improve the level of automation. In the last part, the different requirements of the methodology are defined, which led to a proposal for a method that respects all the requirements and that allows not only the grouping of operations, but also the analysis of the automation and the line balancing. Finally, and to verify the proposal, three activities of the automation methodology have been applied on a Stellantis assembly line. The result of the study showed that it is possible to group several screwing operations.

Keywords: Automation, Assembly line, Methodology.

1 Introduction

After the first Industrial Revolution, factories underwent changes in the way they were organized and worked [1]. With the development of electronics and information technology, a great technological evolution took place; notably the automation of production lines.

Being in constant evolution, the automotive industry was the first to adopt this path [2]. Thus, and in order to remain competitive on the market, manufacturers have turned to automation to increase their production capacity and respond to product variability. Nevertheless, the automation of assembly lines remains a major challenge [3]. Although new technologies are highly developed, the use of highly automated processes is not necessarily the best solution [4]. Several criteria, such as profitability, cost, quality and ergonomics, are also involved.

The diversity of models and parts as well as the integration of new vehicles (hybrids, electric) are constraints to be taken into consideration to achieve an automation that meets these criteria. Thus, the objective of the research work undertaken is to define the principles and criteria, to identify and select the operations to be automated in order to develop a decision support method.

Today, since assembly operations are short in time, it is preferable to group them to optimize the profitability of automation. This leads to these following questions: What

is the most appropriate approach to identify groupings of operations and automate them? What are the criteria for grouping operations in order to balance the operator and machines loads?

2 State of the art on the different decision support methods

The literature in automation is technical and aims at developing new technologies rather than improving the level of automation of a production line. This section presents the different decision support methods found in the literature. It consists in seven methods that have been analyzed, while presenting their advantages and drawbacks. The aim is to study them in order to propose a method to improve the level of automation of an automotive assembly system. Thus, the methodology must be analytical (R1); it must allow a detailed study of all the operations, as well as the resources attached to them. The objective is to collect all the information related to the assembly process before proposing a solution. The methodology must also allow the study of several automation scenarios (R2), and through several criteria with different weighting, it must propose an automation scenario (R3). The method must give calculation rules (R4) for each of the criteria and must allow an analysis of grouping of operations (R5) and balancing of the assembly line (R6).

In the 2000s, Parasuraman, Sheridan and Wickens [5] proposed their method in the form of a flowchart containing several iterative steps. The first one is to identify the type of automation, then identify the different possible levels of automation. For each of them, one must examine its consequences on human performance: this is the first evaluation criterion. However, human performance is not the only important factor. Secondary evaluation criteria include the reliability of the automation and the costs of the proposed solutions. This method takes human performance as the evaluation criterion, and therefore does not give an opportunity to choose other preponderant criteria. On the other hand, for all criteria (primary and secondary), the method does not present calculation rules to quantify them, nor conditions to deduce the optimal automation scenario. And finally, the list of criteria is not complete, several parameters other than Man and costs must be taken into account.

In 2013, Konold and Reger [6] developed a method to identify the level of automation that should be adopted. It consists of 4 levels of assembly systems. The decision is made by analyzing several parameters such as production volume, cycle time, product life cycle etc. This method, as simple as it is, presents a single result that can be in the form of several levels of automation. However, it analyzes the entire process, and therefore does not study each workstation (or even operation by operation). As far as the input parameters are concerned, Konold and Reger do not give details on how they established the conditions for acceptance or rejection. It is also necessary to point out that these parameters are insufficient, and that the cost dimension is non-existent.

In 2005, Boothroyd [7] studied the assembly of an electrical outlet in order to identify the most suitable and cost-effective assembly process. The author calculated the cost of each component for six different assembly processes. For each possible

assembly scenario, he calculated the unit cost of the product. He estimated the cycle time for each station, the cost of each machine/robot, the labor cost, the efficiency rate, the quality control cost. Combining all of this data, Boothroyd performed a comparison of the overall cost of production for each of the six possible assembly scenarios. This method has several advantages, including the fact that it allows to analyze the components of the product, but also to start from several hypotheses and evaluate them in a quantitative way. Nevertheless, Boothroyd has used standard costs for machines and robots, but these costs differ according to their technical characteristics (more precision, more reliability...) which could distort the results. In addition, the only criterion used is the direct cost. It goes without saying, this criterion is preponderant for the majority of companies, but it is not the only one: the choice can be made on the basis of other criteria (quality, ergonomics ...).

In 2008, Almannai, Greenough and Kay [8] developed a decision support tool combining the Quality Function Deployment (QFD) method and the Failure Mode and Effect Analysis (FMEA) method. The methodology consists of 3 steps: the first one consists in identifying the criteria relating to the company's objectives using the QFD method. The second in, identifying the automation alternatives through a second multi-criteria analysis. Finally, the resulting solution is submitted to the FMEA which identifies the risks and potential failures associated with it. This method has several advantages such as relying on the company's objectives and decisions, as well as using evaluation criteria to confirm the best automation choice. However, the authors did not provide a list of criteria or a method for performing multi-criteria analysis. Nor did they provide any clarification on the definition of automation alternatives.

Kapp [9] has developed a method to evolve manufacturing systems to produce new products. This method is called USA (Understand, Simplify, Automate) [10] and consists of understanding the existing process, optimizing it (Simplify) then automating it. This method has several advantages, especially in terms of understanding and optimizing the process. Nevertheless, on the automation part, this method does not give a clear vision of the approach to follow in order to choose a profitable automation.

Lindström and Winroth [11] proposed methods called Dynamo and Dynamo ++, which was taken up and developed by Fasth and Stahre [12]. These methods consist of understanding the manufacturing process by studying the production flow, the functioning and constraints of each station and by identifying the operations and sub-operations carried out on the line. The analysis of all these data allows to assign the minimum and maximum possible level of automation to each operation. Once these degrees of automation have been identified, the authors proposed a list of criteria to evaluate each possibility; these criteria are chosen based on the company's strategy. These methods have several advantages, including the use of the definition of the level of automation that differentiates between physical and cognitive operations. The authors suggest that a good understanding of the functioning and constraints of a production process is beneficial before embarking on an automation approach. However, these approaches do not provide a decision aid for assigning possible levels of automation and choosing an optimal level. In addition, the evaluation criteria have not been addressed.

In 2008, Gorlach and Wessel [13] carried out a study of Volkswagen assembly lines at three different sites. By combining several criteria such as cost, productivity, quality and flexibility, the authors were able to determine whether or not automating these lines is cost-effective. This method proposes to study automation based on four criteria: cost, quality, productivity and flexibility. For each criterion, the authors proposed a series of parameters to be evaluated. These criteria are quantitative except the last one (flexibility); the authors did not explain how to quantify it. The authors did not propose a decision-support method neither on the choice of a technical solution, nor on the multi-criteria analysis to be carried out to choose the level that meets the criteria chosen beforehand.

In the Table 1, the methods found in the literature have been evaluated based on the requirements presented in section 2. As a result, none of the methods analyzed in the literature fully address the problem. Especially since none of the methods deal with the grouping of operations (R5) and the balancing of the line (R6). Certainly, there are methods in the literature that deal with these two topics, but they don't focus on automation. In this paper, we have cited the best-known methodologies that deal with the subject of automation. It is therefore essential to present a methodology that meets the industrial requirements cited above. This section introduces the proposed method and explains its different steps.

Table 1. Evaluation of methods found in the literature based on the requirements presented in section 2

| Methods | Requirements | | | | | |
|-------------------------------------|--------------|----|----|----|----|----|
| | R1 | R2 | R3 | R4 | R5 | R6 |
| Parasuraman & Sheridan's method [5] | | X | | | | |
| Konold's method [6] | X | X | X | | | |
| Boothroyd's method [7] | X | X | | X | | |
| Almannai's method [8] | | X | X | | | |
| Kapp's method [9] | X | | | | | |
| Dynamo & Dynamo ++ [11] [12] | X | X | | | | |
| Gorlach's method [13] | X | X | X | | | |

With R2: the methodology allows the study of several automation scenarios, R3: the methodology proposes an automation scenario, R4: The methodology gives calculation rules, R5: the methodology allows an analysis of grouping of operations, and R6: the methodology allows an analysis of assembly line balancing.

3 Proposal of a new decision support methodology

The proposed decision-support methodology is illustrated by a SADT in Fig. 1. This method consists of applying six main steps that aim at grouping operations, proposing and evaluating several automation scenarios while analyzing the line balancing. This method is mainly based on the experiences of the trade. This work will try to translate them into several constraints and rules to provide assistance to industrials.

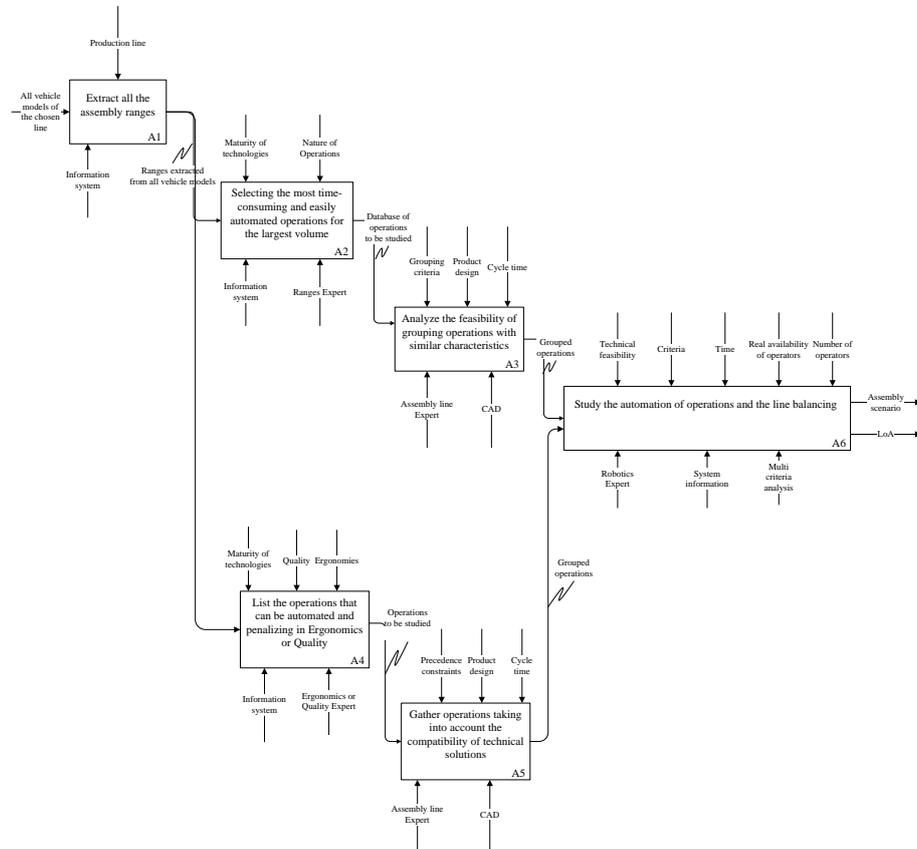


Fig. 1. Presentation of the proposed methodology to improve the level of automation

A1: This step consists of extracting all the assembly ranges from all the vehicle models on a production line. These ranges are extracted from the Stellantis information system.

A2: This step consists of creating a database presenting all the assembly operations with their duration and nature. The nature of the operations is the first selection criteria. For each type of operation, the level of maturity of the automation must be determined. The goal is to identify the longest and most easily automated nature of operations.

A3: This step consists of analyzing the possibility of grouping operations with the same nature and similar characteristics. To do so, six sub-steps illustrated in Fig. 2 are applied.

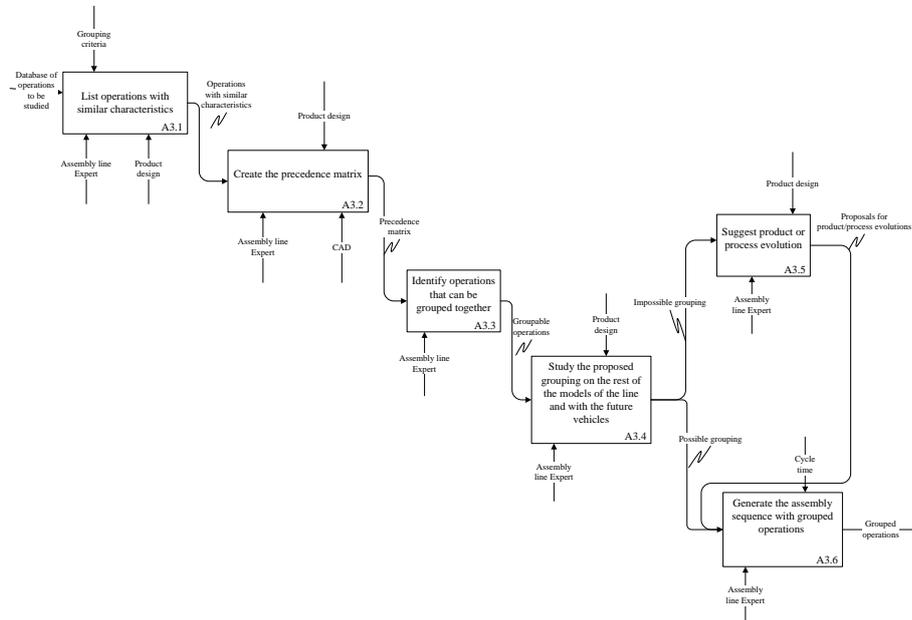


Fig. 2. Details of A3 - Analysis of grouping of operations

A3.1: The aim is to list all operations that have similar characteristics. This step requires analyzing the product and indicating, for each operation, the grouping criteria (qualitative and quantitative) established through discussions and meetings with Stellantis industrials. An example of these grouping criteria and codes is shown in Table 2. The available resources are the 3D model of the parts, experience and the knowledge rules.

Table 2. Sample Codes and Grouping Criteria

| Code title | Grouping criteria |
|---------------------|--|
| Grease / Lubricate | Nature, quantity, characteristics of the lubricant, surface accessibility, area on the vehicle |
| Checking compliance | Nature of control, accessibility, area on the vehicle |
| Screw, Tighten | Screw head, torque, socket, accessibility, area on the vehicle |

A3.2: The aim of this step is to study the planning of operations by drawing a precedence matrix.

A3.3: The aim of this step is to identify operations that can be performed in the same workstation and with similar characteristics.

A3.4: This step consists of analyzing the different products assembled in the line, but also the future ones, and identifying whether the grouping of operations is technically feasible for each of these products.

A3.5: If the grouping of operations proves to be impossible, evolutions of the product and/or production process can be proposed.

A3.6: The last step is to generate the assembly sequence with the grouped operations. The control point here is the cycle time.

A4-A5: These steps are an alternative of the previous process. The aim is to study and group together critical operations in ergonomics and/or quality (Same approach as A3).

A6: The sixth and final step of the methodology is to study the line balancing and evaluate the different automation scenarios through a multi-criteria analysis. The criteria chosen are cost, quality, ergonomics, flexibility and reliability of the means of production.

4 Example

The methodology to improve the level of automation of an assembly line was applied on a Stellantis vehicle assembly line. The application of the A1, A2 and A3 activity is detailed in the following sections.

4.1 A1-A2: Routing Extraction and Database Creation

The first step was to extract all the ranges. Then, we had to determine the scope and the nature of the operations to be studied.

The nature of the operations was classified according to the time and the level of maturity of the automation. Thus, it was decided to study the screwing operations. Then, a database was created by filling in, for each operation, the workstation number, the time and the grouping criteria. In the case of screwing, to be able to group the operations, it is necessary to have the same screw head, the same torque and the same socket. The screwing operations must be accessible, and must be done on the same vehicle area to make automation possible and profitable.

For confidentiality reasons, the extraction of the ranges, as well as the construction of the database will not be presented.

On the chosen production line, 272 screwing operations have been studied. The sockets are between 10 and 13 mm, the torques are between 2 and 70 Nm and the screw heads are Hexagonal or Torx.

4.2 A2-A3: Creation of the database and study of grouping criteria

Based on the grouping criteria for screwing operations (torque, screw head, socket, area on the vehicle, and accessibility), those to be studied first are the screwing operations that are accessible at the front and rear of the vehicle, have hexagonal head, 10 mm socket, subjected to a torque of 4 Nm.

Once the operations were identified, a matrix was drawn to study the different precedence constraints. The groupings of operations identified by applying the different stages of the A3 activity are the screw connections that concern: the lower bumper

absorber and the headlamps at the front of the vehicle, as well as the central support for the rear bumper. In order to carry out the grouping of screw connections, it is essential to validate the pre-holding of the parts. This last criterion has not been previously taken into account in the methodology to simplify it and avoid setting up several constraints that will make the search for groupings difficult.

5 Discussion

One of the objectives of this research work is to propose a decision support method to increase the level of automation for an automotive assembly system with the aim of improving quality, ergonomics and cost.

To ensure good profitability, the solution is to group together operations that have the same characteristics while analyzing precedence constraints.

At this stage, a grouping of screwing operations has been identified manually. A model based on constraint programming is being developed to help the industrials process all the input data, and depending on the constraints imposed, the model will propose an optimal grouping of operations. The next step is to propose several automation scenarios by specifying the appropriate technology to perform the grouped operations automatically. The decision will be made through a multi-criteria analysis that will take into account the cost, ergonomics, quality, flexibility and reliability of the means of production.

The methodology allows to explain the exact steps to follow in order to process the different input data (factory architecture, product design, production lines, assembly operations characteristics...), and thus to propose groupings of operations to have a profitable automation. With the tools being developed (precedence matrix, constraint programming model, etc.), the industrials will save time in processing all this information. Indeed, the program will display proposals for grouping operations, and based on the current technologies, the profitability of the project and the various criteria mentioned above, the industrials will choose the grouping of operations that will respect all these criteria. In perspective, and to validate the methodology and illustrate the gains after its use, we will apply it on a grouping of operations already performed by Stellantis.

6 Conclusion

A review of the literature shows that there are few methods to help people make decisions about the level of automation. These approaches are based on few criteria and do not clarify the methods for calculating or estimating these criteria. Thus, an analysis of these different methods has been carried out while explaining the requirements that the method must meet to answer our problem. The methodology must study all the information related to the architecture of the plant, the sequence of operations or the resources used. The methodology must allow us to group operations together, but also to propose several automation scenarios. Based on several criteria, this method must

study the line balancing and present the automation scenario that best satisfies all of these criteria.

To verify this methodology, it was manually applied on the Stellantis assembly line. The result is a grouping of 3 screwing operations. This paper presents the details of the application of A1, A2 and A3 activities. The next step will be to analyze the balancing of the line and to evaluate the choice of technologies and the automation scenario.

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