A Literature Review on the Level of Automation and New Approach Proposal

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Abstract. This paper sheds light on various definitions of the term automation. On the basis of a bibliographical study it hands out a state of the art in terms of the level of automation. The aim of the said paper is to study, analyze and discuss several definitions of the LoA proposed in the literature. On the grounds of this analysis, a set of requirements that ought to be respected by an accurate indicator were given out in order to propound a new definition of the LoA aimed at application in the manufacturing domain and its interest in order to optimize workstations. At the end of this bibliographical study, a table summarizing the list of different definitions, and the requirements that each of them meet is drawn. A proposal for a new definition of LoA as a time ratio is also presented. Furthermore, the application on an academic case study on an assembly line with 13 operations helped us demonstrate its interest.

Keywords: Automation, Requirements, Indicator, Level of Automation, Time.

1 Introduction

The word "automation" appeared in April 1947 in the department of Ford's vice-president, Del Harder, who wanted to use technology to change production rates and increase the productivity of automotive assembly lines [1]. In 1997, Parasuraman and Riley [2] defined automation as the performance by a machine (usually a computer) of a function previously performed by a human. Thus, according to Claverie [3], the automation of processes has changed working conditions and the role of human in industry. The latter has become, instead of an actor, a designer, maintenance agent or supervisor. In 2016, Vagia, Transeth and Fjerdingen [4] presented another definition of automation. For them, this term refers to a system that will perform the tasks for which it is programmed without having the choice or possibility to act differently. Its actions are predefined from the beginning and it has no possibility to change them in the future.

Today, the technological challenge for manufacturers is to have a versatile production line, flexible to the product and volume [5]. Therefore, choosing a good level of automation will avoid unnecessary investments in inadequate technological solutions. Establishing a good level of automation from the design phase of the line will avoid the enormous costs of changing the production line in case we realize the unsuitability after its implementation. So the objective of our work is to group together the operations that

can be automated in order to make the investments profitable and optimize the workstations. Which leads to this scientific question: **"How to qualify the level of automation of a work station? "**

The purpose of this paper is to present and analyze the different approaches proposed in recent years on the level of automation in order to finally propose a new quantitative approach.

2 The Level of Automation

Currently, there is no consensus on the definition of the level of Automation. In fact, the decision about automation should be driven based on several parameters and decision criteria. Therefore, this section introduces this concept by addressing the different approaches found in the literature. The objective is to come up with a new scale proposal for evaluating this indicator.

There are many definitions of the LoA concept. The method of evaluation is not the same, some studies propose a quantitative evaluation while others are moving towards a qualitative approach.

2.1 LoA defined as a degree of evolution of the expert system in decision-making

One of the oldest definitions that can be found in the literature is proposed by Sheridan and Verplank [6] and repeated in various works [7] [8]. The authors [6] identified six functions that a human operator or computer could perform during an operation: Requests, Gets, Selects, Approves, Starts and Tells. The authors explain how the human operator and the computer are supposed to cooperate under different LoAs for each of these commands. In this sense, the authors define automation as a total or partial replacement of a function previously performed by the human operator. This implies that automation is not total or non-existent, but that it can vary according to different levels. The Table 1 presents the 10 levels of LoA, defined by Sheridan and Verplank [6].

For example, at low level 2 (Table 1), several options are offered to humans, but the system has no say in the decision. At level 4, the computer suggests an alternative decision, but the human being retains the power to execute this alternative or choose another one. At a higher level 6, the system gives human only a limited amount of time to exercise his right of veto before making a decision.

Table 1. Definition of LoA proposed by Sheridan and Verplank **[6]**

LoA	Description
Level 1	Fully manual control, the computer offers no assistance
Level 2	The computer offers a complete set of alternatives. Several options are offered to human who decides
Level 3	The computer reduces the number of alternatives, and it is always the human who decides
Level 4	The computer suggests only one option, human can decide whether or not to follow it

Level 5	The computer executes the option if the human approves it. The approval of human is necessary
Level 6	The computer leaves a limited time to the human to decide before executing the action
Level 7	The computer executes the action automatically and informs the human
Level 8	The computer informs the human if he requests the information
Level 9	The computer informs if it considers it necessary
Level 10	Full control of the computer. It decides everything and acts independently

In this definition, the authors proposed a very broad and detailed explanation on computer and human operator cooperation under different LoA degrees from fully manual to fully automated. However, this definition is more oriented towards the control of systems than the operational part.

2.2 LoA defined as a degree of automation of physical and cognitive operations

In 2008, Frohm, Lindström and Winroth [9] defined the level of automation as the allocation of physical and cognitive operations between humans and technology. Indeed, for them, LoA is presented in two degrees: one for physical operations, and the other for cognitive operations. The Table 2 presents the seven LoA levels proposed by the authors.

Table 2. Definition of LoA proposed by Frohm, Lindström et Winroth **[9]**

LoA	Physical operations	Cognitive operations
Level 1	**Totally Manual**	**Totally manual**
Level 2	**Static hand tool** : Manual work with support of static tool	**Decision giving** : The user gets information on what to do, or proposal on how the task can be achieved
Level 3	**Flexible hand tool** : Manual work with support of flexible tool	**Teaching** : The user gets instruction on how the task can be achieved
Level 4	**Automated hand tool** : Manual work with support of automated tool	**Questioning** : The technology question the execution, if the execution deviate from what the technology consider being suitable
Level 5	**Static machine/workstation** : Automatic work by machine that is designed for a specific task	**Supervision** : The technology calls for the users' attention
Level 6	**Flexible machine/workstation** : Automatic work by machine that can be reconfigured for different tasks	**Intervene** : The technology takes over and corrects the action
Level 7	**Totally Automated**	**Totally automated**

The degree of description is fairly accurate and complete. However, the scale can lead to confusion. We don't understand the value of establishing two levels; a static hand tool (LoA = 2) and a totally manual (LoA = 1). Using a manual tool (such as a screwdriver or hammer) doesn't change the decision about automation. The level for

us should always be manual. Another problem concerns levels 3 (Flexible hand tool) and 4 (Automated hand tool). In fact, a flexible hand tool can be automated, such as an automatic screwdriver for which the drills calibers can be changed to deal with different screwsizes or types. The last point concerns level 7 (fully automatic). It can be flexible, such as robotic or reconfigurable stations. We believe that this scale describes the levels excluding new advanced robotic solutions that cannot be exclusively classified in a single category of the proposed scale. In addition, level 5 of static machine can in some cases be confused with level 7 of fully automatic. In fact, a dedicated static machine can operate autonomously and can be fully automatic.

2.3 LoA defined as a degree of intelligence and autonomy

In 1989, Riley defined a general model of human-machine interaction. His model presents factors that define 7 levels of intelligence (Table 3) and 12 levels of autonomy (Table 4) [10]. Each combination of an intelligence level and an autonomy level is called an automation state and each state corresponds to a predefined and unique form [11].

Table 3. Riley's proposed intelligence levels **[4]**

Intelligence Level	Description
Level 1	Manual operations
Level 2	Processing of available information
Level 3	The system cannot perform any action by itself, unless it advises the operator
Level 4	Recommendations: The machine has no power to act and is limited to communication with the operator
Level 5	Recommendations with interaction: The machine does not have the power to act and is limited to communication with the operator
Level 6	Adaptive recommendations: The machine has no power to act and is limited to communication with the operator
Level 7	The machine is a servant and has the possibility to perform actions

Table 4. Riley's proposed autonomy levels **[4]**

Autonomy Level	Description
Level 1	Manual operations
Level 2	Processing of available information
Level 3	The system cannot perform any action by itself, unless it advises the operator
Level 4	Recommendations: The machine has no power to act and is limited to communication with the operator
Level 5	Recommendations with interaction: The machine does not have the power to act and is limited to communication with the operator
Level 6	Adaptive recommendations: The machine has no power to act and is limited to communication with the operator
Level 7	The machine is a **servant** and has the possibility to perform actions
Level 8	The machine is an **assistant** and can perform actions but requires operator approval

Level 9	The machine is **associated** and can perform actions autonomously without explicit authorization from the operator, but the operator can always replace it
Level 10	The machine is a **partner** and has the same rights as the operator
Level 11	The machine is a **supervisor** and can replace the operator who has no authority
Level 12	Fully autonomous operation

In the first six levels of autonomy (Table 4), the machine has no authority to act; it is limited to communication with the operator. The last six levels give the machine the possibility to act. The distinctions between these levels of autonomy are based on the sophistication of the machine's information processing functions and the authority to manipulate the operator's screens. For example, an Associated machine is autonomous and able to perform actions without the explicit authorization of the operator, but the operator can always cancel it. A Partner machine has the same derogation power as the operator, and a Supervisor machine can replace the operator, but the operator cannot ignore it [11].

2.4 LoA defined as a cost ratio

The level of automation L_{auto} can be calculated based on the operating costs of equipment C_{eqh} (€/h) and Labor costs C_{Lab} (€/h) [12], as shown in equation (1)

$$L_{auto} = \frac{C_{eqh}}{C_{eqh} + C_{Lab}} \quad (1)$$

When the ratio L_{auto} is zero, it is assumed that production is entirely manual; the operating cost of the equipment is negligible compared to the cost of Labor. When this ratio is equal to 1, it is the Labor cost that is negligible compared to the operating cost of the equipment, so production is fully automated.

This approach has the advantage of describing the LoA in a quantitative way. However, it does not provide a true picture of the rate of automation in a workshop. The definition of cost is not sufficiently representative. For example, if we consider a workshop of 8 workstations, with 2 automated workstations at a high cost. The ratio L_{auto} will be close to 1, without a high automation rate. This limit more significant in countries where investment and operating costs are significantly higher than Labor costs. Thus, this approach does not reflect the actual level of automation of a production line.

An analysis of the various works in the literature shows that most of the proposed approaches address the entire process and lack precision in describing the Level of automation of each workstation or operation.

3 Requirements and Suggested LoA definition

The purpose of the bibliographic study that was carried-out is to analyze the different definitions of levels of automation presented in the literature. An appropriate definition

and scale must first be established to be able to describe all possible automation scenarios before making a decision.

3.1 Requirements

Our scale must be **applicable** for existing production systems **(R1)** and **applicable** for future production systems **(R2)**. A good indicator should be **quantitative (R3)**, measurable data that can be easily monitored to maximize or minimize our LoA as needed. The scale must concern the **operating mode (R4)**, i.e. the physical operations that the machine or human can perform. A good definition of LoA must be **objective (R5)** and can allow decision making according to a methodology rather than intuition. The indicator must allow **partial automation (R6),** and therefore have levels between fully manual and fully automatic. And finally, the scale must give a **clear vision to decision-makers on the operator and machines load (R7)**, which allows to study the line balancing and take into account the profitability aspect. The **Table 5** summarizes the different approaches identified with the requirements they meet.

Table 5. Table summarizing the different approaches identified in the literature with and the requirements they meet

Authors	Requirements						
	R1	R2	R3	R4	R5	R6	R7
Sheridan and Verplank	X					X	
Frohm, Lindström and Winroth	X			X		X	
Riley	X			X		X	
Windmark, Gabrielson, Andersson and StŒhl	X	X	X	X	X	X	

It can be noted that none of the proposed definitions in the literature respect all the requirements. Nevertheless, all definitions are applicable. Most of them are qualitative and allow partial automation. There is only one definition that is quantitative, but unfortunately, it takes cost as a criterion, which really does not give a clear vision of the level of automation. However, none of the definitions found in the literature take into account the operator and machines load aspect.

3.2 Suggested LoA definition

We appreciate defining a good level of automation as the best allocation of resources and their associated levels of automation. The indicator chosen to quantify the LoA is Time, which makes it possible to study the load of operators and the load of automated tools, in order to get a clear vision of line balancing.

To improve decision support methods for assembly line automation, it is necessary to develop a new definition of the LoA. Therefore, the definition proposed will be at the workstation level and not at the level of the entire process. This allows us to analyze all operations and suggest several automation scenarios to choose the optimal one. The

level of automation must be quantitative and must vary from fully manual to fully automated with intermediate levels to represent human-machine collaboration. The indicator chosen to quantify the LoA is Time. Hence, the proposed LoA is defined as a time relationship between the time of automated operations T_{auto} (min) and the cycle time T_c (min) as shown in equation (2).

$$LoA = \frac{T_{auto}}{T_c} \quad (2)$$

If the LoA ≈ 0%, the workstation is completely manual; the only resource is human. If the LoA ≈ 100%, the workstation is fully automated; the only resource is the machine. Between the two levels, the station is semi-automated; the two resources present are human and machine.

4 Case study

For reasons of confidentiality, we have presented in this paper an academic case study. The Fig. 1 shows a production line with several workstations. The analysis is done on the first workstation with a cycle time equal to 1.86 min.

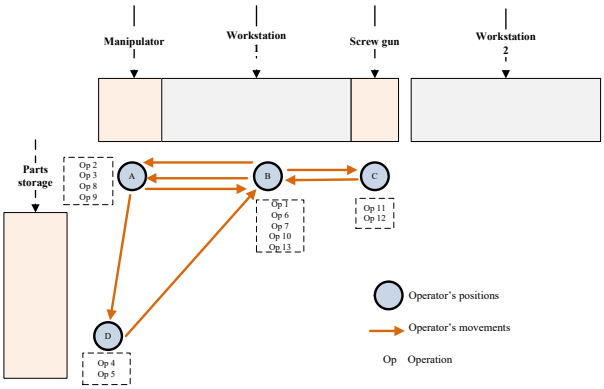

Fig. 1. Fictive production line and presentation of the operations and the different operator's positions

The tasks done by the operator are presented in Table 6 which also shows the time (in min) for each of the operations.

Table 6. Description of the operations done by the operator, his position and the duration of each one of them

Operation	Description	Position	Time (min)
Op 1	Move to the manipulator's zone	B	0.1
Op 2	Take the manipulator	A	0.02

Op 3	Move to parts storage	A	0.2
Op 4	Pick up the part with the manipulator	D	0.08
Op 5	Move to the workstation 1	D	0.2
Op 6	Drop the part	B	0.02
Op 7	Move to the manipulator's zone	B	0.1
Op 8	Put down the manipulator	A	0.02
Op 9	Move to the workstation 1	A	0.1
Op 10	Move to the screw gun	B	0.1
Op 11	Take the screw gun	C	0.02
Op 12	Move to the workstation 1	C	0.1
Op 13	Screw	D	0.8

According to this configuration, $LoA = 0\%$; the station is totally manual. If we decide to automate the picking and dropping of parts, Op1, Op2, Op7, Op8 and Op9 will be suppressed. Op3, Op4, Op5 and Op6 will be fully automated so $T_{auto} = 0.5\ min$. In this case, $LoA = 27\%$. The indicator shows that 27% of the operations on the first workstation are automated. Therefore, we know the availibility of the operator which allows us, not only, to optimize and improve the workstation, but also to balance the line to make it more efficient.

The reasons for automating can be seen from different viewpoints either to reduce labor costs, to increase the quality level or to solve ergonomic problems. Our approach is limited since it takes into account only the physical operations therefore a second approach should be considered so as to integrate other aspects related to work conditions such as mental workload, ergonomics etc.

5 Conclusion

In this paper, we have presented a review of different definitions of the Level of automation. We also discussed and analyzed each one of them in order to allow the reader to understand the difference between these definitions. We went through three main points: the LoA definition in the literature, the difference between each of these definitions and the chosen criteria for an appropriate definition. Finally, we have listed a set of requirements that a good definition of LoA must respect, and based on these requirements, we proposed a quantitative definition of the LoA that was applied on an academic case study.

6 Acknowledgments

This work took place in the framework of the OpenLab Materials and Processes combining Arts et Métiers network, GeorgiaTech Lorraine and Groupe PSA.

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