



HAL
open science

Intelligent Poka-Yokes: Error-Proofing and Continuous Improvement in the Digital Lean Manufacturing World

David Romero, Paolo Gaiardelli, Daryl J. Powell, Matteo Zanchi

► **To cite this version:**

David Romero, Paolo Gaiardelli, Daryl J. Powell, Matteo Zanchi. Intelligent Poka-Yokes: Error-Proofing and Continuous Improvement in the Digital Lean Manufacturing World. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2022, Gyeongju, South Korea. pp.595-603, 10.1007/978-3-031-16411-8_68 . hal-04768925

HAL Id: hal-04768925

<https://inria.hal.science/hal-04768925v1>

Submitted on 6 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Intelligent Poka-Yokes: Error-Proofing and Continuous Improvement in the Digital Lean Manufacturing World

David Romero¹[0000-0003-3610-0751], Paolo Gaiardelli²[0000-0002-2207-3628],
Daryl J. Powell³[0000-0001-7224-2306] and Matteo Zanchi²[0000-0002-9834-0489]

¹ Tecnológico de Monterrey, Mexico
david.romero.diaz@gmail.com

² University of Bergamo, Italy
paolo.gaiardelli@unibg.it, matteo.zanchi@unibg.it

³ Norwegian University of Science and Technology, Norway
daryl.j.powell@ntnu.no

Abstract. Poka-Yoke devices have always been regarded by lean manufacturing companies as essential quality control and assurance tools to support efficient and effective manufacturing processes and procedures. Thanks to their ease of use and low cost, these devices help maintain high-quality standards and also encourage organisations to undertake Kaizen continuous improvement activities. With the advent of new digital and analytical technologies, these devices have undergone significant transformations. Based on a study of the scientific literature and the results of brainstorming sessions conducted with factory managers and lean experts, this paper analyzes how and to what extent digitalization changes the definitions, functions, approaches, and perspectives of traditional Poka-Yokes. Furthermore, it examines how the change in data collection, sharing, analysis, processing, and feedback (interpretation) approaches brought by the digitalization and smartification of Poka-Yoke devices affects the operational performance of modern Digital Lean Cyber-Physical Production Systems.

Keywords: Digital Manufacturing, Smart Manufacturing, Lean Manufacturing, Digital Lean Manufacturing, Poka-Yoke, Error-Proofing, Error Prevention.

1 Introduction

Digital Lean Manufacturing (DLM) leverages the potential of *cyber-physical quality management systems* (i.e. tools, techniques, and practices), particularly *quality control systems*, to increase the stability and performance of production processes towards (near-)zero-defect manufacturing [1]. One of those practices is the use of traditional and digitally-enhanced *Poka-Yokes* as one of the means to detect and predict errors and defects in *Digital Lean Cyber-Physical Production Systems (CPPSs)* [2]. These modern production systems can be composed of advanced automation, collaborative, and/or manual subsystems, where humans are involved in activities such as monitoring and/or operating production equipment and individually and/or collaboratively performing manual operations to ensure the right functioning of these three types of subsystems. In such activities, human inadvertent mistakes can influence the *operational reliability* of production equipment and manual operations, and therefore their quality output. Hence, *Poka-Yokes* play a fundamental role in achieving (near-) zero defects or errors in such complex production systems. This paper explores the digitally-enhanced evolution of

Poka-Yokes from a twofold perspective, first from an *error-proofing perspective* as these progress towards “error prevention” rather than “error correction” devices, and second from a *Kaizen perspective* as these gain additional “intelligence” to digitally understand human and machine errors and provide insights on how to mistake-proof production processes and procedures by (re-)design.

2 Methodology

This research work was developed based on a scientific literature review focused on *Poka-Yoke devices*. The main outcomes of the literature analysis were then grouped according to five distinctive dimensions, namely: definitions, functions, approaches, perspectives, and examples. Several brainstorming sessions were then conducted with factory managers and lean experts on the evolution of these error-proofing devices in light of their new potential digital and analytical capabilities in the emerging Digital Lean Manufacturing world [2]. After introducing the main characteristics of *traditional Poka-yoke devices* concerning definitions, functions, approaches, perspectives, and examples, factory managers and lean experts were asked to give their points of view on their “digitization” impact. Common views were then incorporated and transcribed. On the other hand, in case of different or apparently conflicting interpretations, a subsequent meeting with the parties concerned was held to find a common point of view, avoiding any bias.

3 Poka-Yokes: Definitions, Functions, Approaches & Perspectives

3.1 Definitions

Traditional *Poka-Yokes* (*Poka* – inadvertent error, and *Yoke* – avoidance) are defined as devices that perform 100% inspection of automated and manual operations for the prevention, detection, elimination, and correction of process and procedure errors and defects at their source to avoid affecting product quality and operators’ health and safety [3,4]. Being made of physical, functional, or symbolic barriers [5], *Poka-Yokes* contribute to facilitating the making of the correct action far easier than the mistake and mitigate the effects of the mistake if the error cannot be eliminated. Moreover, as *technology* has evolved, *Poka-Yokes* have also too from simple and economic jigs, pins, locks, fixtures, sensors, visual signals, warning devices, and go/no-go gauges [6,7] to advanced quality controls used to predict and prevent errors rather than detect and correct such, and to collect error data for real-time and post-analysis to provide immediate feedback for corrective measures and later insights for the continuous improvement of a process or procedure (re-)design. Hence, *Poka-Yokes*’ evolution has progressed towards an “error prevention” tool and a “continuous improvement” mechanism.

An *Intelligent Poka-Yoke* is a device that works with smart sensors, real-time data, and instant feedback mechanisms to predict if a human or machine error will occur based on task-tracking and intent prediction methods or in-process controls to prevent a mistake in a process or procedure. *Intelligent Poka-Yokes* are characterized by their new “assisting” nature towards zero defects and errors rather than their traditional error detection approach as well as by their new role as a *Kaizen mechanism* collecting and providing error data for processes or procedures continuous improvement.

An *Intelligent Poka-Yoke device* is different from other *smart IoT devices* from the viewpoint that its *primary function* is oriented to reducing human and machine errors and improving processes and procedures in a production line. Furthermore, *Intelligent Poka-Yokes* should be particularly developed following an integrated “process-centric” and “human-centric” design approach, and incorporating different digital and analytical technologies that must provide real-time feedback to the operators for error-proofing processes and procedures towards (near-)zero-defect manufacturing.

3.2 Functions and Approaches

Traditional *Poka-Yoke devices* have three main features, being (i) inspection methods, (ii) function setters, and (iii) function regulators [8,9]. As *inspection methods*, these offer three types of inspection [8]: (a) *judgment inspection*, which aims to sort out defective products so they do not reach the customer; this type of inspection does not prevent defects nor does it provide instant feedback so the next defects in the process can be avoided right away, (b) *informative inspection*, which purpose is to provide “after the fact” feedback to improve a process or procedure and prevent future product defects (e.g. control charts), and (c) *source inspection*, which focuses on determining “before the fact” the process conditions that will create an error-free production. As *function setters*, these provide four “setting methods” to support inspection [8,9]: (a) *physical methods* that determine whether an error exists in a process or procedure based on contact mechanisms such as switches, limits, proximity sensors, position sensors, displacement sensors, and pass sensors or a defect in a product by testing its size, shape, colour or any other similar physical attribute, (b) *grouping and counting methods* (also known as fixed value methods) that use counting or measuring approaches to ensure no errors have occurred when a specific number of movements are not made (e.g. fulfilling a picking or delivery order, which must be correct and complete), (c) *sequencing methods* (also referred as motion-step methods) that verify that a standard sequence (i.e. standard operating procedure) has occurred, and (d) *information enhancement methods* that ensure required information for a process or procedure is available at the correct time and place. And as *function regulators*, these deliver two “regulatory mechanisms” for processes and procedures [8]: (a) *controls*, which stop a process or procedure once an error has been detected – using jigs, pins, and locks – restricting its continuation till the problem has been eliminated, and (b) *warnings*, which purpose is to only alert the operator – using bells, buzzers, or warning lights – without stopping the process or procedure that an error has occurred or is about to occur so the corrective action can be made when considered appropriate.

Furthermore, traditional *Poka-Yoke devices* work using two main strategies [10,11]: (a) a *prevention-based strategy* (or proactive strategy) aiming to avoid the occurrence of an error or defect, or (b) a *detection-based strategy* (or reactive strategy) focusing on detecting that the error or defect has happened, and two main approaches [12]: (a) a *passive-approach* by suggesting the need of corrective action, or (b) an *active-approach* by forcing correcting action.

On the other hand, *Intelligent Poka-Yokes* still have their three main features, but these have been focused, renewed, and digitally enhanced, and one more new feature, a fourth one, has been added as *Kaizen tools*. As *inspection methods*, these now mainly focus on (a) *informative inspection* with an extended purpose to support data-driven

processes and procedures continuous improvement by recording in real-time, using smart sensors and computer vision systems, all errors and defects (i.e. big data) for their post-analysis and use for discovering improvement possibilities [13], and on (b) *source inspection* by using task-tracking and intent prediction methods in human constrained procedural tasks (e.g. maintenance and assembly tasks) to track these and provide in real-time guidance and prompt feedback if necessary to a technician or an operator, using AR-based or light-based guide systems, on the correct course of action according to the standard operating procedure so errors can be prevented from occurring in the first place or allow the human to fix the error as soon as it occurs [14], or in-process controls by using smart sensors and actuators to monitor and if necessary to adjust a process (parameter) to prevent an error in a machine and as a result a product out of specifications [15]. As *function setters*, these use new and advanced versions of the original four “setting methods” to support inspection: (a) *virtual methods*, in the past physical methods, such as non-contact mechanisms like electromagnetic induction, laser imaging, optical method, electrical method, ultrasonic method, etc. that measure the work-piece without producing any deformation in it – due to contact with it [15], (b) *grouping and counting methods* such as computer vision grouping [16,17] combined with projection mapping technology to overlay light on the identified parts or products to be easily grouped, smart bins equipped with weight sensors for real-time recognition of their filling levels and the automatic triggering of their withdrawal e-Kanban cards for inventory replenishment (control) and with smart labels based on e-paper tech for offering updated product information as well as real-time order status and delivery date [18], and pick-to-light and put-to-light systems driving operators in their picking and placement activities in the assembly line and warehouse so they can easily and quickly pick the right part or product and the placed it in the right place [19], (c) *sequencing methods* such as pick-to-sequence and put-to-sequence, including picking and placing verifications, based on AR-based or light-based guide systems and smart sensors (e.g. break beams to detect whether the operator has reached into the correct bin) so operators can diligently assemble and distribute parts in the right order [20], and (d) *information enhancement methods* such as e-Kanban systems [18], digital Andons [20], and other digital “push” information systems based on mobile computing and smart wearable technologies that allow notifying and delivering the right information to the right person at the right time for problem-solving or troubleshooting. And as *function regulators*, these deliver improved “regulatory mechanisms” with more sophisticated (a) *controls* that early-detect, diagnose a problem, and in some cases correct it before it actually occurs to avoid procedures or processes stoppage based on intent prediction methods [14] and in-process controls [15] to prevent error, and (b) *(early-)warnings* that based on “predictive” approaches and digital Andons (i.e. tablets, smartphones, smartwatches, smart-glasses, etc.) can provide at any time and at any place “early” alerts and other “proactive” e-notifications to the right person to call it for countermeasure actions [20].

In summary, *Intelligent Poka-Yoke devices* work using a *prevention-based strategy* and an *active approach* to error-proofing.

3.3 Perspectives

From an *error-proofing (tool) perspective*, “Intelligent Poka-Yokes” aim to become preventive, proactive, and active devices creating the right conditions before executing

a process or procedure step and assisting humans and machines during the execution of a sequence of steps to avoid errors and defects. A clear manifestation of this evolution is the emergence of new digital operator assistance systems providing AR-based visual aids to the workers so they can make the right judgements and if needed steer their actions or intended actions to drive the next “right” step [21,22], and new or renewed smart manufacturing technologies for in-process controls based on closed-loop and real-time feedback systems compensating for a process instability to avoid a rejected work-piece (e.g. in-process gauging systems) [23].

From a *Kaizen (mechanism) perspective*, “Intelligent Poka-Yokes” will collect error data for real-time and post-analysis to provide first immediate feedback to operators and machines to solve problems right away (i.e. short-term countermeasures), and second address their root cause by providing later insights coming out from real-data based simulations (e.g. digital twinning) for the continuous improvement of processes and procedures by redesign (i.e. long-term countermeasures) to prevent errors or defects happen again. Furthermore, *Intelligent Poka-Yokes* will enhance the *Kaizen continuous improvement cycle* by (i) documenting reality with the help of automatic data collection systems (e.g. smart sensors and computer vision systems), which can provide more reliable (big) data in comparison to manual systems, (ii) identifying waste with the support of advanced analytical and prediction tools capable of anticipating problems, (iii) eliminating non-value-added steps with the assistance of real-time optimization techniques, (iv) developing and (v) implementing short and long-term countermeasures with the help of advanced modelling and simulation techniques, (vi) verifying change with the support of task-tracking systems, (vii) measuring (improvement) results with the assistance of IoT-based performance measurement systems, and (viii) making (new) standard operating procedures digitally available to aid workers with AR-based guide systems in their jobs. One further emergent enhancer is foreseen in the near future, (viii) short-run machine learning algorithms for AI-based support of small-batch and one-of-a-kind production systems management, where large repetitive datasets are difficult to realize.

4 Discussion and Examples of Intelligent Poka-Yokes

Generally speaking, the development of an *Intelligent Poka-Yoke device* consists of four steps: (i) selecting the sensing technology (e.g. smart sensor(s) and/or computer vision system) to “detect” an error or defect, (ii) analysing the error or defect with data analytics tools, (iii) determining the error or defect root cause with the help of real-data based simulations (e.g. a digital twin), and (iv) (re-)designing and implementing tools to avoid the error or defect recurrency with the support of advanced modelling and simulation tools.

The most promising technologies supporting the development of *Intelligent Poka-Yokes* are smart sensors (or IoT-based sensors), computer vision systems (and AI-based cameras), augmented reality, (big) data analytics, and machine learning. Examples of their usage to add “intelligence” to *Poka-Yoke devices* are: Auto-ID technologies such as barcoding and RFID systems for parts and products always right identification, intelligent in-process controls at machine tools auto-correcting process deviations automatically, torque drivers and callipers to perform manual operations to exact specifications, computer vision systems and AI-based cameras for parts and products

detail inspection, AR-based guide systems for always correct assembly sequences, machine learning-based measurement systems analysis for efficient low volume, high mix production management, etc.

Consistent with Table 1 where the main features of a *traditional Poka-Yoke* vs. an *Intelligent Poka-Yoke* are shown, the following statements can be made:

- If compared to traditional Poka-Yokes, *Intelligent Poka-Yokes* perform better in terms of both reliability, quality, and response time, therefore, to operational performance. Indeed, thanks to their ability to collect, analyze, and interpret a large amount of data and their mutual relationships in real-time, these devices facilitate the recognition of problems that are hidden or have not yet emerged in products and processes but will arise in the near future.
- On the other hand, *Intelligent Poka-Yokes* may lead to incorrect interpretations, considering risky situations that are not, with a consequent increase in quality management costs, or rather unrisky critical situations, if the data interpretation system has not been properly set up, or the amount of data is so large that it overloads the decision-maker, leading him/her to error.
- Since *Poka-Yoke devices* can also be used for supporting setup activities, the improvement in quality and response times allowed by their digitalization means less time for production changes, with a consequent improvement in the flexibility of the manufacturing system. Moreover, adopting digital tools such as *Intelligent Poka-Yokes* increases the flexibility of the decision-making system as “intelligent” systems can reprocess the decision-making logic in relation to the experience gained over time.
- Despite the continuous hardware and software cost-cutting, *Intelligent Poka-Yokes* can result very costly in economic terms, or at least too expensive when compared to traditional ones which, in line with lean principles, must be easy to use and cheap.

Table 1. Traditional Poka-Yoke vs. Intelligent Poka-Yoke

Function	Traditional Poka-Yoke	Intelligent Poka-Yoke
Collection	<ul style="list-style-type: none"> • Manual Data Collection • Limited Data Collection • Historical Data Collection 	<ul style="list-style-type: none"> • Automatic Data Collection (with Smart Sensors) • Big Data Collection • Real-Time Data Collection
Sharing	<ul style="list-style-type: none"> • Delayed Data Sharing 	<ul style="list-style-type: none"> • Instant Data Sharing (IoT-enabled)
Analysis	<ul style="list-style-type: none"> • Basic Data Analytics Tools <ul style="list-style-type: none"> ◦ Statistical Process Control ◦ Root-Cause Analysis ◦ Correlation Analysis 	<ul style="list-style-type: none"> • Big Data Analytics Tools <ul style="list-style-type: none"> ◦ Machine Learning ◦ Data Mining ◦ Predictive Analysis
Optimization	<ul style="list-style-type: none"> • Post-Optimization 	<ul style="list-style-type: none"> • Real-Time Optimization
Feedback	<ul style="list-style-type: none"> • Real-Time Feedback 	<ul style="list-style-type: none"> • Real-Time Feedback (IoT-enabled) • Enriched Feedback (AR-enabled)

Although *Intelligent Poka-Yokes* can offer great benefits to perfect error-proofing, these smart devices can also come with some drawbacks, which are referred to here as the “Poka-Yoke Paradox”. On the one hand, *Intelligent Poka-Yokes* promise to enhance “error prevention” in *Digital Lean Cyber-Physical Production Systems*, while on the

other hand may uncover an inherent risk in which operators may become “too dependent” on such smart devices to detect potential errors and defects, rather than rely on their human senses to care about quality and think deeply about potential *Kaizen* opportunities. Thus, the *Poka-Yoke Paradox* can be formulated in such a way that the reliance on *Intelligent Poka-Yokes* may incur a detrimental effect on the “Thinking People System” of lean manufacturing, something that *traditional Poka-Yokes* and *Jidoka systems* were actually designed to improve.

5 Conclusions and Further Research

Recent developments in digital and analytical technologies have opened up a variety of data-driven possibilities for error-proofing processes and procedures towards (near-) zero-defect manufacturing. Implementing *Intelligent Poka-Yokes* can be the starting point for evolving from an “error detection” to an “error prevention” paradigm and to enhance the *Kaizen* continuous improvement cycle for years to come. However, the need to safely access and manage reliable (big) data in real-time on the shop floor, calls for the necessity to adopt also new data management technologies like 5G, blockchain, and metadata analysis.

Though this paper presents several useful reflections around the digitalization and smartification of *Poka-Yoke devices*, it is suggested that further research could benefit from practical insights from applied research, for example, case studies and/or action research projects. Furthermore, it is particularly suggested the development of research works addressing the definition of criteria to decide between the use of traditional Poka-Yokes vs. Intelligent Poka-Yokes on the shop floor, the identification of manufacturing environments and processes/procedures that are most suitable for the deployment of Intelligent Poka-Yokes, and the explanation of more concrete examples for the use of Intelligent Poka-Yokes in *Kaizen* mechanisms.

Acknowledgements

The authors would like to acknowledge the support of the Research Council of Norway for the research project: *Lean Digital*.

References

1. Romero, D., Gaiardelli, P., Powell, D., Wuest, T., Thürer, M.: Total Quality Management and Quality Circles in the Digital Lean Manufacturing World. IFIP, AICT, 566:3-11 (2019)
2. Romero, D., Gaiardelli, P., Powell, D., Wuest, T., Thürer, M.: Digital Lean Cyber-Physical Production Systems: The Emergence of Digital Lean Manufacturing and the Significance of Digital Waste. IFIP, AICT, 535:11-20 (2018)
3. Robinson, H.: Using Poka-Yoke Techniques for Early Defect Detection. 6th International Conference on Software Testing Analysis and Review, pp. 1-12 (1997)
4. Fisher, M.: Process Improvement by Poka-Yoke. *Work-Study*, 48(7):264-266 (1999)
5. Saurin, T.A., Ribeiro, J.L.D., Vidor, G.: A Framework for Assessing Poka-Yoke Devices. *Journal of Manufacturing Systems*, 31(3):358-366 (2012)
6. Grout, J.R., Downs, B.T.: Mistake-Proofing and Measurement Control Charts. *Quality Management Journal*, 5(2):67-75 (1998)

7. Kattman, B., Corbin, T.P., Moore, L.E., Walsh, L.: Visual Workplace Practices Positively Impact Business Processes. *Benchmarking: An International Journal*, 19(3):412-4 (2012)
8. Shingo, S.: *Zero Quality Control: Source Inspection and the Poka-Yoke System*. Productivity Press, Cambridge (1986)
9. Chase, R.B., Stewart, D.M.: *Mistake-Proofing: Designing Errors Out*. Productivity Press, Portland, Oregon (1995)
10. Bayers, P.C.: Using Poka-Yoke (Mistake-Proofing Devices) to Ensure Quality. *Proceedings of IEEE Applied Power Electronics Conference and Exposition*, 1:201-204 (1994)
11. Chao, L.P., Ishii, K.: Design Process Error-Proofing: Strategies for Reducing Quality Loss in Product Development. *ASME International Mechanical Engineering Congress and Exposition*, 118: 255-264 (2005)
12. Gamberini, R., Gebennini, E., Rimini, B., Spadaccini, E., Zilocchi, D.: Low-cost Automation and Poka-Yoke Devices: Tools for Optimising Production Processes. *International Journal of Productivity and Quality Management*, 4(5-6):590-612 (2009)
13. Buer, S-V., Fragapane, G.I., Strandhagen, J.O.: The Data-Driven Process Improvement Cycle: Using Digitalization for Continuous Improvement. *IFAC-PapersOnLine*, 51(11): 1035-1040 (2018)
14. Bovo, R., Binetti, N., Brumby, D.P., Julier, S.: Detecting Errors in Pick and Place Procedures: Detecting Errors in Multi-Stage and Sequence Constrained Manual Retrieve-Assembly Procedures. *25th International Conference on Intelligent User Interfaces*, ACM, New York, NY, USA, pp. 1-10 (2020)
15. Junaid, A., Siddiqi, M.U.R., Mohammad, R., Abbasi, M.U.: In-Process Measurement in Manufacturing Processes. *Functional Reverse Engineering of Machine Tools*, CRC Press, pp. 105-134 (2019)
16. Buhmann, J. M., Malik, J., Perona, P.: Image Recognition: Visual Grouping, Recognition, and Learning. *Proceedings of the National Academy of Sciences of the United States of America*, 96(25):14203-14204 (1999)
17. Belu, N., Ionescu, L.M., Misztal, A., Mazăre, A.: Poka-Yoke System based on Image Analysis and Object Recognition. *IOP Conference Series: Materials Science & Engineering*, 95:012138 (2015)
18. Peron, M., Alfnes, E., Sgarbossa, F.: Kanban System in Industry 4.0 Era: A Systematic Literature Review. *Advanced Manufacturing and Automation XI, Lecture Notes in Electrical Engineering*, Springer, 880:12-19 (2022)
19. Battini, D., Calzavara, M., Persona, A., Sgarbossa, F.: A Comparative Analysis of Different Paperless Picking Systems. *Industrial Management & Data Systems*, 115(3):483-503 (2015)
20. Mohamad, E., et al.: Framework of Andon Support System in Lean Cyber-Physical System Production Environment. *Manufacturing Systems Division Conference*, pp. 404-405 (2019)
21. Moencks, M., Roth, E., Bohné, T.: Cyber-Physical Operator Assistance Systems in Industry: Cross-Hierarchical Perspectives on Augmenting Human Abilities. *IEEE International Conference on Industrial Engineering and Engineering Management*, pp. 419-423 (2020)
22. Mark, B.G., Rauch, E., Matt, D.T.: Worker Assistance Systems in Manufacturing: A Review of the State of the Art and Future Directions. *Journal of Manufacturing Systems*, 59:228-250 (2021)
23. Shi, J.: *In-Process Quality Improvement: Concepts, Methodologies, and Applications*. *IISE Transactions* (2022)