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A Systematic Literature Review of Poka-Yoke and Novel Approach to Theoretical Aspects

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For many years, Poka-Yoke (PY) has been used as one of the means to overcome challenges that can affect errors and defects in process. It is a widely accepted concept-a way of thinking, which undoubtedly contributed to significant results in a struggle against the occurrence of errors in various work processes. However, although PY seems to be well understood in theory, there are a large number of scientific papers and books that still seek to clarify and redefine PY, in order to finally implement its application at full capacity. Many authors, as it seems, want to emphasize inconsistencies in current theoretical and practical experiences. This claim is supported by the fact that over 50 similar and different PY definitions have been found in literature. It seems that most researchers do not sufficiently perceive generally accepted attitudes in the field of PY, as well as differences and inconsistencies in some of them. Due to a sense of confusion during the process design stage, an effort to predict locations of possible sources of error is a direct consequence of the diffuse knowledge in the field, which imposes the need to change that state. This paper summarizes the latest studies and definitions in the field of PY applications, in order to propose a comprehensive and generally acceptable definition of PY. In order to find what is common to the most important attitudes in the field of PY, a systematic literature review has been undertaken, with the goal to identify the areas of disagreement, to recognize any gaps that exist and outline personal experiences and attitudes in the field. The novel approach to the types of PY presented in this paper should provide a solid foundation for the creation and development of PY model and a systematic approach to the application of PY in production and service systems. Finally, some conclusions and prospective future research directions are presented.
Keywords: lean, Poka-Yoke, literature review, process, error, inspection

Highlights

- *Detailed systematic literature review on Poka-Yoke (PY) is presented.*
- *More than 50 examples and case studies on PY are reviewed.*
- *A novel approach to types of PY is proposed.*
- *Examples of PY devices are created and discussed.*

0 INTRODUCTION

In today's fast-growing industrial world, mistakes are inevitable. Thus, in order to reach competitive edge, quality as a major concern has to be improved and mistakes have to be reduced to a minimum level [1]. As described by Prester et al. [2], advanced manufacturing technologies can affect and minimize cost of mistakes. Finding a tool that can prevent and detect sources of abnormalities will be the most challenging task for all [3]. Poka-Yoke (PY) provides solution to that.

As has been argued by some authors, PY has been largely ignored in academic research and evidences of its use and implementation have been mostly attributed to practitioners. Moreover, there are some who are not even familiar with the term [4]. A gap in theoretical background, definition and application guidelines of PY still exists [5]. To date, only one paper has been found regarding the history and characteristics of PY [6], while formal definition is still something to be wished for.

In the course of different projects, authors of this study have, on several occasions, been in a situation to perform certain tasks so that all the related activities remain error-free. Having previous experience with implementation of lean tools and concepts on a large number of projects [7], the authors came upon an idea to apply PY in error elimination. However, the process of solution design for the observed problems relied mostly on the designer's intuition [8]. To avoid this situation, one should find prerequisites for the efficient design of PY through analysis of a large number of practical experiences from various journals and books in this field, and adopt the idea of PY as a lean tool which allows "eliminating the cause of error."

At the time when the authors first addressed this problem, the general conclusion was that there were numerous definitions of PY. Although all of them were good in their own way, there were some inconsistencies which needed further elaboration. There was an evident lack of a review article which would address the problem in an adequate manner. Therefore, it was decided that the team should engage in a fundamental PY research in order to determine

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the common grounds which connect the various approaches to this field. In this light, the primary research objective of this study is to emphasize those ideas and attitudes that are coherent, widely accepted, and as such could be used to define PY. In addition, this study aims to formulate conclusions which should be helpful in creating a design model for PY, allowing faster development of solutions in different work processes.

The importance of suppressing errors, both from a scientific and practical point of view, was increasingly realized after WW2. At the beginning of this period, statistical process control was a major tool in error suppression.

The occurrence of an error leads to an outcome where final product or service does not meet requirements of the previously defined standard [9]. No matter what kind of product is in question, each system is looking for a solution to conduct its processes in an error-free way. Regardless of the nature of products and processes, the necessary machines combine more or less complex equipment and tools which influence human-performed actions in terms of work tasks, further affecting the occurrence of (material) processing errors.

1 METHODOLOGY

Within academic environment, literature review has been used as one of the most common methods for analysing and studying topics of interest. This paper draws from the work of Tranfield et al. [10] who provided a systematic literature review by introducing three different stages: planning, conducting and reporting.

1.1 Planning Process

Following methodology of [11], journal articles and conference papers were analysed using digital databases: Scopus, IEEE Xplore, Emerald, Springer, Taylor and Francis. Moreover, most cited books were also thoroughly analysed. As a specific and unique term, PY was selected for a major search criterion, in order to cover all relevant sources. Considering the lack of research studies in the field of PY, year of publication or citation counts were not used as additional filters.

1.2 Conducting the Review

The first step in conducting literature review included the search of digital databases for the PY keyword. The results revealed 1202 journal and conference manuscripts.

After eliminating redundancy, the search results were filtered for terms such as errors, mistake prevention and detection, and lean thinking, resulting in the remaining 323 manuscripts. Many of the results used word PY when quoting tools and methods for removing defects, errors or wastes, without providing any specific definition, case study or characteristics of PY. All manuscripts where PY was mentioned once or twice in that manner were removed, leaving us with 172 manuscripts. References from each of the remaining set of papers were analysed to establish whether they included most cited books and other relevant papers and articles which referenced PY in terms of mistake proofing, error proofing or fool proofing, resulting in the final set of 73 papers.

1.3 Reporting and Analysing Results

The final set of papers was analysed with the focus on following aspects:

- inspection system,
- functions of PY,
- history and definition of PY,
- steps in PY implementation,
- PY enablers and barriers,
- examples and case studies on PY.

2 SYSTEMATIC LITERATURE REVIEW RESULTS

Distribution of the final set per year of publishing is shown in Fig. 1. The research was conducted during March 2018, and some articles published online were also included in this review. The chart reveals an increasing interest in PY research since the appearance of Shingo's book on Zero Quality Control, in 1986 [12].

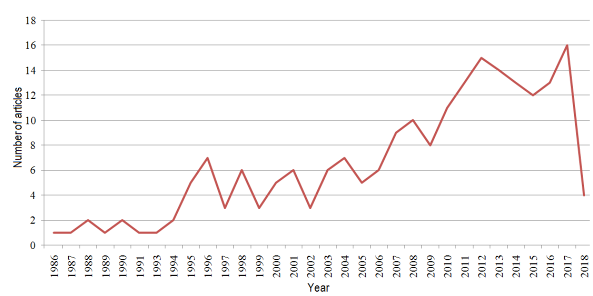


Fig. 1. *Yearly distribution of journal articles, books and conference papers on PY*

2.1 Inspection System

Production consists of the network of processes and operations [12]. Processes include changing the shape or quality of the product, inspection, transportation of elements and delay in time. To improve manufacturing process, many quality control methods were developed relying on the inspection process. Inspection system classification according to Shingo [12] includes: judgment, informative, and source inspection.

Judgment inspection examines product at the final stage instead of a prior stage, before it reaches the customer. It only affects inspection errors, without decreasing the defect rate [13]. In order to accomplish zero defect rates, detection is not an option. Inspection needs to prevent defects from occurring, while the one that affects processing stage delivering feedback on quality problems is called the informative inspection. Once defects occur, the information is transferred to production, the defects are treated faster, and data reports are used for future control of the process [14].

Statistical process control (SPC), successive and self-inspections are most widely used and described as part of informative inspection. Using control charts, variation in quality control can be traced statistically. SPC are based on sampling, but it is not 100 % inspection, and cannot prevent defects from occurring. Shingo also became unsatisfied with SPC after he realized it cannot achieve zero defects [15].

Another type of inspection is self-inspection. Operator inspects the process and products as he or she works on them. Compared to SPC it allows faster feedback, helping operator who performs inspection to detect any unusual behaviour, to identify and remove possible causes of defects [16].

Inspecting the work done by previous operator is part of successive checks. If the check procedure is performed by an independent operator, the inspection will be more reliable and cost efficient [17]. If the line is stopped, the operator who performed previous process will feel responsible for that. This atmosphere will affect the operators to become more focused. Fisher [16] explains that it brings 100 % inspection several times and because it is being done while the operation process is in progress, it minimizes the costs. He argues that both self and successive checks are used after defect, which means rework has to be done. Shingo [12] explains the difference between self and successive checks saying that it depends on who performs the inspection. Authors emphasize the use of self-check comparing to successive one, explaining faster information feedback and process improvement [14]. In service sector Chase and Stewart [18] brought new type of inspection calling it *joint inspection* in order to overcome errors and misunderstandings between customers and service providers.

Source inspection happens at the source [19], before any action is taken, inspecting elements necessary for quality production [14]. Authors Hinckley and Barkan [3] argue that source inspection checks inputs such as man, machine, method, material and information in order to eliminate defects while processing. Defect-free status is secured by controlling each of these input elements [13]. Shingo [15] explains that vertical source inspection checks inputs and conditions before the event, while the horizontal inspects on operation. According to Hinckley [20], inspection must be upstream of the process in order to eliminate wastes. Since errors cause defects, the goal of inspection has to be focused on eliminating those errors [21].

SPC and self-checks are competing methods, because they both provide informative inspection, while SPC and source inspection are compatible, since source inspection can be used to eliminate human errors or special causes found by SPC [22]. According to Fisher [16], self-, successive- and source-inspection are used together for reaching maximum results.

In order to reduce process mistakes, Tsuda [23] identifies similar classification: mistake prevention as source inspection; mistake detection as informative inspection; preventing mistake influence and mistake-proofing in the work environment that can be accomplished by 5S, also described by de Saint Maurice et al. [24]. Shimbun [13] explains the importance of source inspection and 100 % inspection using PY in sustaining zero quality control, where source inspection is more important.

2.2 Functions of PY

It is in human nature to make mistakes [12]. Mistakes made by humans are often the cause of most defects in production environment [25] and in some service industries can create significant negative outcome [24]. Another cause of failures could be poor management support, training and process design [26]. However, blaming humans will not eliminate defects and problems in an environment [19].

The inspection systems described earlier can be used to eliminate most of these failures improved by device that automatically detects mistakes. Shingo [15] named this device PY or mistake proofing, where human intelligence need to be respected. He further explained two different functions of PY. Regulating function includes control and warning type. Control type shuts down the process while the warning type only alerts operator by light or sound without stopping the process [27]. Which one to choose depends on defect frequency and their impact [28]. Some authors [29] confirm that stopping the process is preferred in order to solve the problem, by applying judoka or PY to eliminate the source of defect that relies on machine, since humans can make inadvertent mistakes [30]. Even some intentional errors can be eliminated by control PY device [31]. Saurin et al. [5] identifies control type features: turn off machine, obligate operator to perform the work by standard procedure and automatically remove defects from the production line. PY control type is used in a form of jigs, pins, locks and sensor devices while the warning type PY is used in a form of light or buzzer [5]. Both control and warning devices have to be cost effective and easy to implement [20].

The setting function of PY is based on contact, fixed value and motion step method [15]. Using the contact method, abnormalities in shape, size or colour will be detected whether or not the contact between product and device is made. Fixed value method detects errors if a specific number of motions fail to be repeated. Motion step method relies on standard procedure and if any step is forgotten, it will detect abnormalities. Fixed method is mostly used in places where the same activity is repeated while motion step method is used at one place where the operator has to process several different operations. Chase and Stewart [32] classify setting functions into: physical, sequencing, grouping and information enhancement functions. According to Chao and Ishii [33] there are two PY approaches: Prevention based (regulating function) and detection based (setting function) or proactive and reactive [30]. Prevention devices can be further classified as: passive, such as visual signs [33] active devices that check for errors in size or shape and control- oriented that shut down the process in case of any abnormalities [34]. De Saint Maurice et al. [24] introduce forcing function, as a physical constraint or barrier designed in a way that no mistake can be made.

In order to eliminate defects, their source has to be identified [1]. According to Hinckley and Barkan [3], three sources of defects exist: variations as out-of tolerance conditions; mistakes made by human or machine and complexity of product and process. Defects can be classified as isolated, which happen once, and those that happen frequently in a series [19]. If there is a complexity, the system has to be simplified. For variation, traditional quality control such as SPC has to be applied, while mistakes require source inspection and PY as the best solution [20]. Because of complexity and variability of work, mistakes in the construction industry are accepted as inevitable [35]. Stewart and Grout [14] explained that complexity is a root cause of mistakes and variability. Based on Shingo [15] regulating function, the quality control tree has been developed to overcome barriers of other quality methodologies by integrating sources of defects and quality factors in one single model. Misiurek [36] developed PY generator sheet as a preventive tool for errors detection based on job breakdown structure with key points and 5W1H approach.

As has been quoted by Shingo [12]: “PY is not an inspection system, it’s a method of detecting defects or mistakes that can be used to fulfil inspection function.” In choosing the best quality control method, the first step is to choose the right inspection system, then the appropriate function, and finally, to choose the appropriate contact, fixed value or motion step method of PY. In some cases the right inspection system can be controlled by third-party inspection institutions [37].

2.3 History and Definition of PY

The history of the term dates back to 1961 [38] when Shingo visited Yamada electric plant in Japan. The company had a problem with a missing spring attached to a switch. The problem occurred when the operator tried to pick up the springs from the big box and needed to assemble it to the switch. Failure to put all the springs resulted in defects. The problem was solved by a small tray placed in front of the operator where he needed to put only two springs from the big box. Thus, after the assembling process if nothing was left, it meant that all the springs were in place. Analysing each book, paper and article, around 50 similar and different definitions were identified. Many of them substitute the term PY with alternative terms, such as term mistake proofing, error proofing or fool proofing or describe PY in terms of devices, such as sensors, jigs, fixtures or visual signals.

Following the work of Shingo [12], PY has been defined as a physical device that performs 100 % inspection and prevents defects from occurring. It is a Japanese term meaning (poka) inadvertent error (yoke) avoid [13]. First term was baka-yoke [30], which means idiot proofing or fool proofing. While Shingo was explaining baka-yoke at a production floor, some women broke into tears, being offended by the term. Considering that even best workers are prone to mistakes, the term has been changed

Table 1. *Summarized definitions of PY*

Author	Definition of term
Shimbun [13]	PY is a technique for avoiding simple human error at work.
Erlandson and Sant [29]; Hinckley and Barkan [3]; Vinod et al. [6]	PY is a system that uses simple devices or work methods for error prevention in manufacturing, service or other industries. The main purpose of PY is to detect defect, stop the process and to define and eliminate the cause. It is a technique developed to reduce physical and cognitive demands of tasks in manufacturing and assembly process that creates connection between worker and process in a form of feedback so errors can be prevented in future. A tool used in achieving the goals of zero defect and Six Sigma.
Fisher [16]; Robinson [40]	PY is a concept, application of simple mechanisms, methodology, warning or control device that involves prevention, detection, elimination, and correction of errors at their source, assuring that no defect will reach the final customer.
Downs and Grout [41]	PY devices are used to ensure that conditions for high quality production exist (source inspection) or to provide rapid feedback to operator on defects so cause can be eliminated (self-checks).
Stewart and Grout [14] Stewart and Melnyk [42]; Swamidass [21]	PY is a quality improvement approach, simple device or systematic practice that prevents permanently the recurrence of the defect it is designed to eliminate. PY is used for process where desired outcomes, defined by customer are inevitable. By following process procedures and steps, operators will be able to reach desired outcome without defects.
Tsou and Chen [38]	PY uses devices on process equipment to provide 100 % inspection and to prevent causes that result in defects.
Al-Araidah et al. [28]	PY is the use of process, design features or automatic devices to prevent or detect errors in process.
Pakdil et al. [43]	PY is a simple and economical device used at service and manufacturing process for mistakes prevention, which does not allow employees to fail.
Saurin et al. [5]; Vidor and Saurin [30]	PY is a system or device for prevention and detection of abnormalities that affect product quality and operators' health and safety. Being made of physical, functional or symbolic barriers it contributes to the reduction of maintenance of stability and variability processes.
Misiurek [36]	The solutions protecting employees from making mistakes are called PY. It's a preventive lean tool or simple mechanism that focuses on identifying and eliminating causes of variations in process, which can lead to defects.

to *mistake proofing* [12]. PY has been used under different names such as *error proofing* [29], *mistake proofing* [39], *idiot proofing, a*nd *fool proofing* [19]. Some definitions by authors are summarized and described in Table 1.

Other authors define PY as a philosophy [44], simple and economic jigs, fixtures, sensors, visual [45] or warning devices, go/no-go gauges, [22] and [31] used to redesign a process with stopping and warning functions in order to prevent abnormalities to became defect [46]. Authors [14] quote that PY has to be cost effective placed close to sources of errors [18]. Shimbun [13] explains that five best PY are guide pins, error detection and alarms, limit switches, counters and checklists.

2.4 Steps in PY Implementation

In order to sustain quality and implement mistake proofing process, summarizing the work of Hinckley [47] the steps for implementation with the use of Toyota production wheel are: understand the product or process so that simplifications can be made, identify mistakes and analyse them by criteria: how frequent they are and what impact they have on final customers and processes, apply source inspection and use specific control methods. If a method is approved it needs to be evaluated and standardized.

Estrada et al. [48] developed an approach to PY design, which is applied at an early product design stage to decrease assembly quality problems that could be identified latter in process. The approach is based on PY design requirements, product design characteristics and potential quality issues, which could occur later in the process. They used a 5-step approach in order to avoid assembly quality issues: identify the product expectation and potential issues, make priorities regarding their effect in future, identify the root cause and use PY design requirements to avoid potential problems. Further Estrada [49] proposed MOKA methodology that could be applied to capture and store gained knowledge from previous PY solution so it can be used for future designs. Customer, process, qualitative or quantitative metrics, focus, urgency, and time compression (FUT) are the four building blocks integrated into an eleven step approach, while developing PY process, as proposed by Stewart and Melnyk [42].

Different methodologies and steps while implementing PY according to authors [19] and [50] could be summarized as follows: problem identification, workstation observation, identification of most frequent errors, identification of error sources, propose PY solution, evaluate solution, choose the best solution, design PY, implementation, testing, monitoring, maintenance and continuous improvement. Brainstorming, FMEA and Ishikawa diagram have been used in order to discover sources of defects or while choosing the appropriate PY solution for the problem. In choosing the right PY solution, selection criteria were based on cost, time and simplicity.

2.5 PY Enablers and Barriers

From the literature review, a few studies have shown enablers and barriers while implementing PY. Rathee et al. [51] has identified 30 enablers of PY in Indian manufacturing industries and classified them into *very relevant enablers*, where some of them are training, quality of raw materials, warning devices, cost evaluation, software tools; *relevant enabler*s, such as colour coding, feedback mechanism, automation, and *less relevant enablers*, such as complexity of work, and synchronization. According to Vidor and Saurin [30], PY can fail, so a new PY for PY needs to be in place in order to sustain zero defects. Other PY barriers identified in literature are: lack of awareness and training on PY, high cost of investment, frequent product design modification, change in the way of thinking [4], fear from losing the job, complexity, lack of knowledge and management support [46]. One of the barriers that have been addressed by several researchers is the cost. Tsou and Chen [38] analysed effects of PY on economics of a defective production system. They have shown that the cost of a defective system gets lower with the use of PY, but it depends on the inspection costs and PY investments [41].

2.6 PY Examples and Case Studies

Wiech et al. [52] presented a PY solution for placing an object correctly during setup process of a milling machine, by introducing optical object detection device. Badiger et al. [53] showed some PY solutions using limit switches, clamps and sensors. Zhang [27] explained how wireless technology together with PY can eliminate human errors during logistic process, by using wireless scanning devices that can stop the process in case wrong shipment is picked. Jadhav et al. [54] introduced PY for shaft assembly of a two wheeler. System uses logic controllers and sensors in order to eliminate mistakes made by operator and once it is set, process can be done automatically with alarm indicator if a problem occurs. Hedelind and Jackson [55] compared levels of automation in Japanese and Swedish industry and reported many PY devices used to support operators in assembly process controlled by a programmable logic controller (PLC). Another study of nut welding missing part was introduced by Wan Saidin et al. [56] using PY jig as the detection mechanism. Kattman et al. [45] have described the use of PY fixtures as visual devices ergonomically designed for quality checks. PY in a form of artificial sensors, fuzzy controllers and two fan sets have been used to detect, warn and control the quality of air, by detecting levels of CO and CO_2 [28]. Cooper [57] gives examples of how PY can be used for patient safety. Pre-loaded syringes, pill boxes with a single dose only, and a unique patient number as a preventive mechanism for errors in drug administration and patient safety. Patient administration process is stressful and takes a lot of waiting time. One of the main causes of defects in administration process is missing forms as inadvertent errors [58]. Using a colour coded booklet can improve the process of patient journey. Tommelein [59] explained that PY can be applied to architecture-engineering-construction industry or during image processing. Errors made by operators at cable assembly line were traced and eliminated using personal RFID, which enabled the implementation of the zero-defect principle [60]. Potters et al. [61] used four different quality methods: 5S, Kanban, PY and standard work sheet in their business simulation process for truck assembly, where PY has shown highest rate of effectiveness, influencing key performance indicators: rework, fastest lead time and adherence to delivery date. Selective assembly method can also be used in order to improve quality in product assembly process [62]. Other examples and case studies of PY implementation are presented in the Tables 2 to 7.

Table 2. *Implementation of PY in manufacturing*

Author	Area of implementation - Manufacturing
Saurin et al. [5]	Authors introduced a framework for assessing PY devices, designed for quality control and control of hazards to health and safety at work. In this framework, the sensor on a press machine was used to stop the press if a worker puts any part of the body within the working area. In addition, green and red lights on the press machine were activated by PY devices.
Gamberini et al. [34]	Italian producer of heat exchangers for sanitary warm water used PY to improve redesigned manufactory lines. Errors of mis-positioning were solved by customized pallets with pins for blocking the pallets on the manufacturing line. Quality improvements have been improved by placing labelling rod near the press. Anti-rotation devices for press were introduced in order to sustain press position in place.
Tak and Wagh [63]	A Missing metal clip problem on the punching machine was taken care of by a simple and cost-effective PY device. Sensors, solenoid valve and electronic control panel were used as a PY system to stop the air flow from the compressor.
Kumar et al. [64]	To control the variation of slide cylinder grinding, PY was applied. It solved the problem of wheel dash mark by using a digital device for measuring gap between the wheel and workpiece surface, while a dial indicator was used to display position of the wheel slide. The results showed improvement in rework time and product quality.

Table 3. *Implementation of PY in construction industry*

Author	Area of implementation - Construction
Saurin et al. [5]; Sadri et al. [35]; Dos Santos and Powel [25]	The authors [5] have shown an example how PY safety device can be used for controlling elevator on a construction site preventing defects while workers are around. Other authors [35] argued that 4 % to 5 % of construction costs relate to rework and waiting times. Wastes, they explained, could be improved by using remote controller device for trolley hoist process. On six case studies in Brazil and England, Dos Santos and Powel [25] confirmed that PY devices at construction sites are of little use when it comes to affecting variability, but can be used for safety reasons.

Table 4. *Implementation of PY in automotive industry*

Author	Area of implementation - Automotive industry
Connolly [65]	Hand held instruments during car paint inspection process are improved by car flash system, which consists of two robots from each side of a car. Robots for optical inspection are improved by sensor detectors, smart cameras connected with a PC network for part tracing, multi-angle spectrophotometer for colour inspection.
Rajendra et al. [66]	At a starter motor assembly line, a problem was identified with the assembling process between a retainer and a stop ring. The team used fixtures to eliminate the missing step of final pressing, sensors between the retainer and the stop ring in order to follow appropriate assembly steps. Laser sensors were used for detecting presence of parts and movement of pressing head. Results showed that, during assembly, process PY can eliminate problems caused by human errors.
Yi and Yusof [67]	A case study from an automotive part assembly company identified defects, misallocation and missing parts during assembly process of wires. Human errors were reported as the main cause of such errors. Automated sensor mechanism can be used to control operator's assembly steps by opening and closing the lids containing the parts from the first step, to the last one. If any step is omitted by worker, sound will be a signal for error detection and won't allow the next step.
Che-Ani et al. [68]	One of the main problems of an automotive assembly process was a broken plastic part connected to the sun visor of a vehicle. Colour coding and designing different parts and dimensions have improved self-inspection done by workers to remove further assembly defects.

Dano et al. [69]; Deshmukh and Mandale [44]	This case study describes implementation of PY in a workplace for putting rubber seals on car seat movement regulation mechanisms, in the case of a Polish automotive manufacturer [69]. PY was used as a laser and pressure sensor for the detection of parts and their position, slots and pneumatic actuators, while intelligent printers were used for printing barcodes, double buttons for safety, and warning signs for visual detection of finished product. PY resulted in improving quality, reducing costs and process time. Another example introduced by Deshmukh and Mandale [44] shows another car seat assembly problem, solved by a fencing device mounted on a conveyor for stopping defective parts, which were made out of standard.
Ab Rashid et al. [70]; Tsou and Chen [1]	Study shows wrong orientation of motorcycle bracket as being main cause of defect in a Malaysia company [70]. In order to resolve those problems caused by wrong positioning, a pin and a stopper were used to prevent workers from making a mistake during the process of moulding. Tsou and Chen [1] have reported the deformation of the welding fixture in a Yazaki automotive company in Taiwan. They also used a stopper to resolve this defect and have shown that PY activities do affect the cost of the production system.

Table 5. *Implementation of PY in software and service sector*

Author	Area of implementation - Software and service sector
Robinson [40]	The author reports that applying specific PY solutions could improve software development processes. Using a specific computer language and a unit test as a source method, can prevent wrong coding or detect errors before they become defects. Mistake proofing can be applied to prevent application menu defects by writing a program or scripts with alarm option for generating and resolving errors.
Shahin and Ghasemaghaei [71]	The authors have proposed a framework for classification of elements in service PY and recovery solutions. The framework can help service managers to perform error detection, in stages before or during service process. They also showed some examples of service PY: slot parts for paying a service on a vending machine, which are designed to prevent insertion of coins; bus station benches designed to prevent sleeping; using paper strips in hotels as a visual and detection mechanism for housekeeping personnel.
Chase and Stewart [18]	Classification of errors and steps for fail-safe implementation in service process were introduced in this study. A case study from a car dealer showed some of the most frequent process errors: forgetting appointment time, unnoticed customer presence by an operator, prolonged waiting time, high work load, misunderstanding, wrong diagnosis made by an operator, inventory problems. The solutions for these problems can be solved by bell signals, colour coding, car tags, joint inspection methods, checklists, computer diagnosis systems, limit switches, and motion step PY for alarming vehicle retriever specialist.

Table 6. *Implementation of PY for individuals with disabilities*

Author	Area of implementation - Individuals with disabilities
Erlandson and Sant [29]	PY controller was designed to improve weighting and counting process for persons with cognitive impairments. PY controller consists of software with scale weight, count and sensor mode. The authors have shown how PYC was applied in case studies, one in Michigan packaging process providing voice control to the operator who was unable to perform the task. The process was improved, from 5 pound boxes, to 152 boxes per hour. PYC was used for counting crashed cans controlled by sensor and light beams.
Treurnicht et al. [39]	The described the use of PY workstation in order to eliminate errors made by individuals with cognitive disabilities working on a ribbon cable assembly process in South Africa. Some of the possible errors were wrong socket alignment, wrong angle, length error, crimping and cutting errors. A specially designed box header pins and jigs colour coding and checklists, lights and test device were used, resulting in high level of productivity.

Table 7. *Implementation of PY in healthcare*

Author	Area of implementation - Healthcare
Grout and Toussaint [72]	A blood-lock, a single-use plastic lock allowing usage only by the code placed on patient's wristband, and automatic wheelchair brakes, are examples of mistake proofing devices in the healthcare process.
Kovach et al. [73]	Providing knowledge on error proofing strategies to healthcare managers can improve and prevent occurrence of errors in hospitals. Most of the strategies are used to prevent medication, pre-surgery and child errors by box labelling for special medications, different colour coding, pillbox, sponge counter bags, and protective electric plugs.

3 DISCUSSION

Analysis of the presented review of PY-related studies, lead to conclusion that there exist different approaches to creating a PY solution. Some approaches to the problem have influenced the way of thinking shown below. There are neither generally accepted types of PY, nor there exist models for solving problems related to eliminating the error. The context of their use and application is different, which will be further clarified by the following discussion. Special emphasis is placed on the nature of the means for the prevention or elimination of errors, as well as the point in time and manner of their application.

This discussion on PY shall begin from the general description of the work process, shown in Fig. 2, which illustrates a simplified work process. As can be seen, the work process, in essence, consists of a number of operations, i.e., activities, which must be realized in order to create a finished product or service. The process begins with the first operation, and ends with *m* operation. In order to fulfil quality requirements, each operation must be executed according to the predefined design solution. All operations represent a potential source of product failure. In each of the operations, possible aberrations from design solution can occur, which introduces errors. Error occurrence leads to a product (service) which is not compliant with the original requirements.

The next important question is when the error is likely to occur. Based on Fig. 2, it can be noted that errors are likely to occur at various time points. Area marked with letter A represents set of points inside operation, where errors can occur. The first potential error source is the beginning of operation execution, which is marked by point A_1 in the graph (Fig. 2). Another error source may be anywhere in between or at the end of the operation execution, marked with A_1 to A_n.

According to Fig. 2, error occurrence and appropriate reaction through PY, can take place at following time points:

- It is possible to prevent errors from occurring during entire operation - i.e., preventive reaction.
- Establish that the error occurred at point A_n, i.e., at the end of the operation, and take action to eradicate its consequences. This form of reaction to error occurrence is termed detection.
- The error can be detected by inspection at any other time point along the operation execution, which again represents detection. Some damage has already transpired, but the benefit is that it will not reach the buyer.

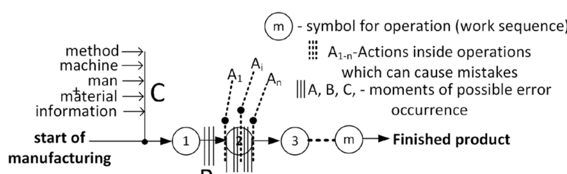


Fig. 2. *Process with operations*

It should be noted that the possible source of error can occur outside points area A, i.e., at points B, (between work operations), and C (at the very beginning of process). It can also transpire during inadequate transport or product handling, between work operations. This implies that PY solutions are also applicable to quality management outside work operations, as well as at the very beginning of the process.

The discussion presented so far, can be structured through establishment of adequate types of PY devices:

- passive devices PY - PPY,
- active preventive PY - APPY,
- active, for detection PY - ADPY,
- hybrid active, preventive - HAPPY, and
- hybrid active, detection - HADPY.

3.1 Passive PY - PPY

Passive PY means that devices are used to warn about possible error during the process. The devices used for that purpose can be light signals, sound signals or various modes of visual management (application of different types and colours). The deficiency of this type of PY is that it cannot prevent error (Fig. 3). However, actions are taken to signal its occurrence (Fig. 4).

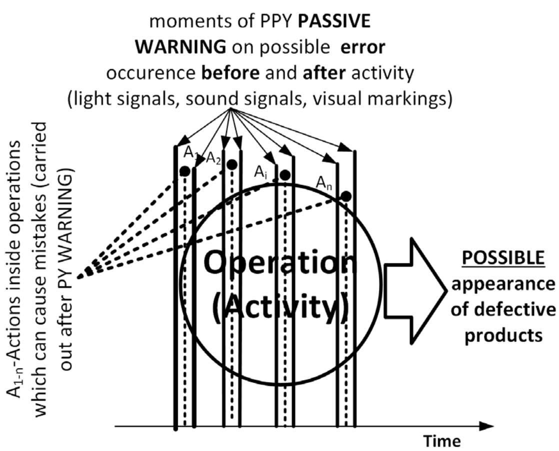
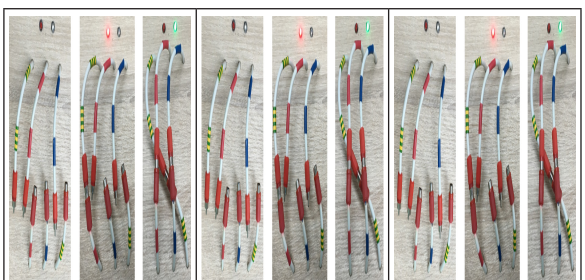


Fig. 3. *Passive PY - PPY*



Three activities (A_1, A_2 and A_3) are needed in order to complete the assembly operation. Visual signals are coloured tapes and led lights.	A_1 – action 1 is cause of error. Passive signal red light and marks on cables indicate where and when errors occurred.	A_3 – last action 3 is completed, operation is performed, and green light confirms correct operation without error.

Fig. 4. *Example of passive PY - PPY*

Figs. 3, 5 and 7 show an operation with time points where errors are possible, actions (A_1 to A_n) that can cause errors and white arrow, indicating operation output with or without defects. It is not possible to prevent the occurrence of an error by usage of audio-visual signals, but they can signal which steps are wrong and should therefore be avoided. As implied by the word, passive PY has no capacity of electro-mechanical reaction within process control.

3.2 Active Preventive PY - APPY

Active preventive PY is aimed at preventing error occurrence. This type of PY is active from the very beginning of work operation and springs into action before error-causing activities take place. Once work operation is finished, there is no occurrence of defective products. Thus, there is no need for product re-work, since PY prevented errors (Fig. 5).

It is important to emphasize that, if a particular operation requires execution of several activities, then within that operation several APPYs can be set up, prior to every activity which leads to a possible error (Fig. 6).

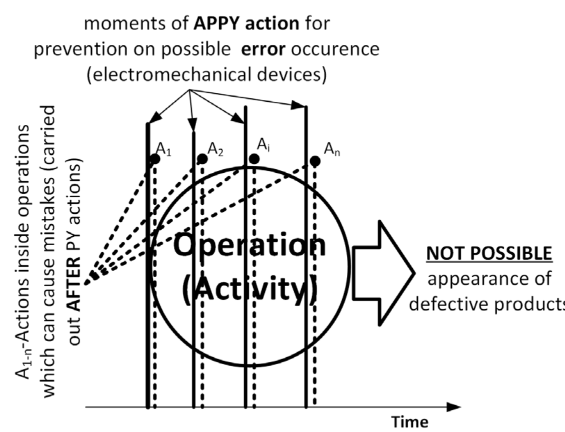
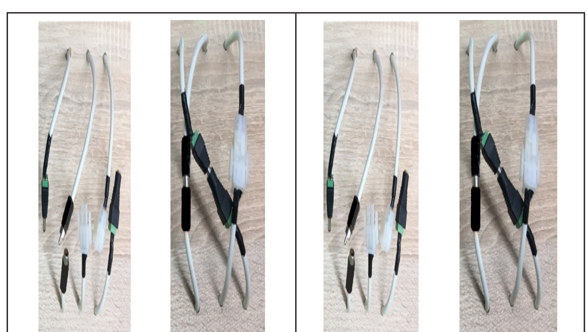


Fig. 5. *Active preventive PY - APPY*



In order to prevent errors, in this example, the mechanical characteristics of the elements for preventing the occurrence of the error are used in the illustration. Three activities (A_1, A_2 and A_3) are needed in order to complete the assembly operation.	There is no possibility to perform any of the three activities (A_1, A_2 and A_3) from the operation that will result in error. Mechanical construction of elements will not allow any error in the final product.

Fig. 6. *Example of active preventive PY - APPY*

3.3 Active Detection PY - ADPY

Active detection PY means that an appropriate electro-mechanical device is used to detect product defects (Fig. 7). Therefore, the PY device reacts by detecting defective products. A defective product is the result of execution of previous activities.

In that respect, ADPY device prevents the defective product from reaching buyers. However, the error and the resulting defective product or service, require adequate reaction and application of corrective measures to the products which do not comply with quality standards. That slows down the process, causing losses, which predominantly reflect in expenditure of extra time, materials, machine work, and labour, on the re-work required. Similar to APPY, should execution of a particular operation require several activities, it is possible to set up several ADPYs, practically, prior to any activity which is liable to cause errors.

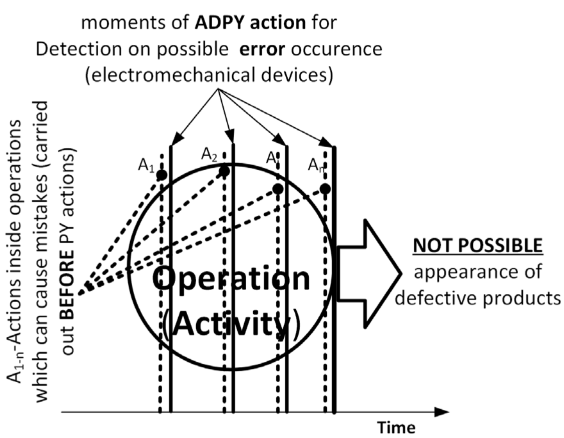


Fig. 7. *Active detection PY- ADPY*

Generally speaking, it is also possible to combine APPY with ADPY within an operation, depending on a particular operation and work process.

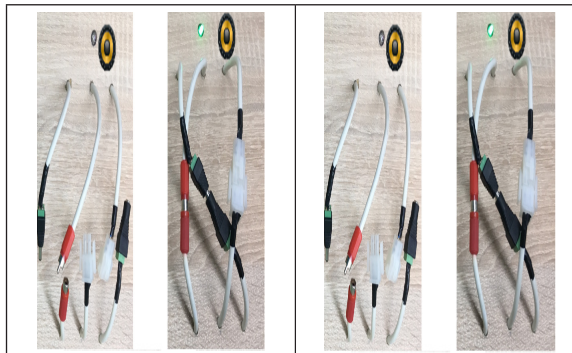
3.4 Hybrid - HAPPY and HADPY

Hybrid PY represents a combination of the discussed variants.

Thus, by combining passive PY (PPY) and active prevention (APPY), one derives a Hybrid active preventive PY (HAPPY). This is the best variant of the PY system for error inspection. The development and implementation costs of HAPPY are slightly higher in terms of passive and active. On the one side, it prevents errors, while on the other side it increases worker efficiency during execution of manual operations, through utilization of audio-visual signals. It is important to emphasize that workers trainings are much easier and faster. This is why HAPPY devices are most efficient, although their design is somewhat more complex.

Hybrid active detection PY (HADPY) evolved as a combination of ADPY and PPY.

Hybrid PY is, in any case, most desirable in the work processes (Fig. 8).



Visual signals are LED light and colour of connectors on cables. Audio signals are from beeper speaker. These are passive PY elements. Connectors are also mechanical enablers (means) for error prevention. This is active preventive PY.	Combination of audio-visual (passive) PY and active preventive (mechanical) PY. Basic characteristics are higher efficiency in certain activities execution, without the possibility of an error, while training is more simplified.

Fig. 8. *Example of hybrid active preventive PY HAPPY*

4 CONCLUSIONS

Conducted analyses have shown that the general principles and points of view are basically coherent, and are predominantly based on the works of Shingo [12] and [15]. Theoretical basis has significantly evolved in this area of expertise. Careful analysis also reveals certain contradictions and inconsistencies in the positions of some researchers, which gives ample space for different interpretations of particular issues.

Implementation of PY in production processes has so far given exquisite results, while PY has become a synonym for error prevention. However, through conversation with eminent experts in the area of product quality control, one often has the impression that the theoretical approach to this topic is too broadly defined, which the available literature corroborates. As the result of this situation, creating PY inspection solutions still takes intuition, while the final outcome depends on the quality of engineering approach.

Understanding of the previously discussed classification significantly facilitates application of PY in practice. According to that classification, PY can also be defined as the control system where the emergence of errors and their proliferation up to the customer can be prevented passively or actively. The passive system offers lower reliability and allows errors to reach buyers. Design of active PYs requires some PY devices to be used in order to prevent execution of bad actions by the workers or the detection of bad products which are the results of errors. In this way, errors are prevented from reaching customers. As shown in the previous figures, the moment of the possible occurrence of error during work process is very important for the understanding of the essence of PY. Moreover, the relationship between PY and process error is directly connected to the time flow, i.e., the time point at which the error is reacted to. Another important aspect is the approach towards treating errors, which can be classified into three categories: passive approach, active prevention of errors, and active detection of defective products.

This investigation was focused on a comprehensive review of the achievements in the PY domain, as well as on the innovative theoretical approaches to PY and the battle against errors during work process. This will allow wider application of PY as a lean tool in various processes. Furthermore, the discussed approach to PY classification should also facilitate the creation of a model for the development of PY systems. Finally, this investigation should allow identification of important areas which are still insufficiently researched, such as how to develop PY to keep PY running and prevent PY from failure, which is an interesting problem in its own way.

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