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Designing and planning training for employees of production companies based on FMEA results' analysis

Projektowanie i planowanie szkoleń dla pracowników firm produkcyjnych na podstawie wyników analizy FMEA

Key words: FMEA, risk analysis, TWI, OJT, for operators training.

Słowa kluczowe: FMEA, analiza ryzyka, szkolenia operatorów.

Streszczenie. Artykuł przedstawia koncepcję oparcia procesu projektowania i planowania szkoleń dla pracowników firm produkcyjnych na wynikach wykonanej analizy FMEA (*Failure Mode and Effects Analysis*) procesu produkcyjnego.

Analiza FMEA w zastosowaniu do procesu produkcyjnego (ang. PFMEA – *Process FMEA*) jest metodą analizy ryzyka, służącą do przewidywania i eliminacji problemów (głównie jakościowych) w procesie produkcyjnym przed jego uruchomieniem (na etapie projektowania), a następnie do ciągłej redukcji problemów w ramach ciągłego doskonalenia procesu po jego uruchomieniu.

Metoda jest powszechnie stosowana w wielu firmach produkcyjnych różnych branż jako wymagany przez odbiorcę dowód gotowości do uruchomienia produkcji seryjnej nowego wyrobu. Najpowszechniej metoda stosowana jest obecnie wśród dostawców branży motoryzacyjnej zgodnie z wymaganiami ISO/TS 16949 stanowiącymi podstawę certyfikacji systemu zarządzania jakością.

Uzyskany w ramach PFMEA opis źródeł ryzyk oraz wskaźniki ryzyka mogą być z powodzeniem wykorzystane dodatkowo do systematycznego projektowania i planowania szkoleń dla pracowników – uczestników procesu produkcyjnego – pod kątem redukcji głównych źródeł problemów jakościowych, które przypisuje się tzw. czynnikowi ludzkiemu. Opracowywany i okresowo aktualizowany w ten sposób plan szkoleń skutecznie redukowałby przyczyny problemów związane z aktualnie dominującymi zagrożeniami w procesie produkcyjnym, uwzględniając zabezpieczenia wprowadzane w trakcie doskonalenia procesu, w tym zabezpieczenia eliminujące prewencyjnie wpływ „czynnika ludzkiego" poprzez rozwiązania prewencyjne typu „Poka-Yoke" (ang. *error-proofing*).

Introduction. FMEA (Failure Mode and Effects Analysis) is one of the most popular method of risk analysis, widely used by various organizations to identify and reduce potential failures associated with a product or process. The method dates back to 1949, when military standard MIL-P-1629 (current version [1]) was developed by US Army. Then, since 1963, the method supported NASA Apollo projects and year after year was gaining increasing number of applications in various industries (e.g.

building of nuclear power plants, aircraft industry, telecommunication, medical devices, logistics, etc.). The most intense use of the method takes place in automotive industry, with Ford having started in 1977.

A few years after Quality Assurance Systems were standardized (ISO 9000 family of standards issued in 1987 [2.1,2.2,2.3]), car manufacturers have developed their own Quality Assurance System standards (QS 9000 [3], VDA 6.1 [4]) requiring that their key suppliers be certified against them in order to prove a required level of competence in ensuring required and long-term quality of delivered products. The standards have also required continuous improvement of supplier's products and processes (including cost reduction) through preventive and corrective actions, supported by risk analysis performed with FMEA method. Thus, the method became obligatory among automotive suppliers, being an important part in new product and process development projects. After over 10 years of experience, in order to unify requirements regarding Quality Assurance Systems for suppliers (now referred to as Quality Management Systems), majority of car manufacturers agreed to recognize a common standard as a basis for suppliers certification: ISO/TS 16949:1999, with the latest issue in 2009 [5]. This document maintained FMEA as a requirement, but do not indicate any specific procedure of performing the analysis. The most popular FMEA methodology, adopted not only by automotive industry now, is the one described in FMEA manual developed by the so called "Big Three" US car manufacturers [6], based on [7].

Nowadays, thousands of manufacturing companies cooperating in supply chains (from OEM downwards) adopted FMEA as a risk analysis tool, used to prevent poor quality of products and to demonstrate effective product and process development for (B2B) customers, which has become a condition of approving supplier's readiness to manufacture and deliver good products on time. The latter is often realized according to PPAP procedure [8], not only in automotive industry but also in vast variety of companies manufacturing e.g. processing machines, domestic appliances, medical devices, telecommunication equipment, etc. One can hardly find a manufacturing branch not using FMEA nowadays. It is also worth noting that there are also plenty of FMEA applications in service sector (e.g. medical services).

With the expected advent of a new issue of ISO 9001 standard [9] risk analysis will become a requirement. Although there are a few methods of risk analysis (e.g. SWOT, HAZOP, HACCP, FMECA) a new issue of the standard will further contribute to increasing range of FMEA applications in Quality Management Systems.

Types of FMEA. There are two major types of FMEA – design (DFMEA) and process (PFMEA). The first one addresses risks resulting from a product concept and design, the latter analyses risks of a process (manufacturing, assembly, inspection, delivery, service, etc.). The main differences between the two analyses are shown in table 1.

Tab. 1. Comparison between DFMEA and PFMEA

	DFMEA	PFMEA
Scope	Concept, design details	Process
Timing	Supports product design and validation phase	Supports process design and validation phase
Core FMEA team members (engineers)	Design, quality	Process, product, quality, maintenance
Decomposition of FMEA scope	Product (system), subsystems, components	Process steps, according to process flowchart,
Failure Mode	Not meeting a system / subsystem / component function (or specific requirement defined for the function)	Not meeting a process step function (or specific requirement defined for the function)
Causes of a Failure Mode	Weaknesses of a product design (e.g. material flaws, calculations, noise factors) resulting in a potential Failure Mode	Weaknesses of a process design (e.g. process parameters selection, process set-up, supplier errors, tool damages, human errors, training effectiveness) resulting in a potential Failure Mode
Dominant preventive actions (risk mitigation measures)	Changes of product design, changes in design validation plans	Changes of process design and control (process parameters, tooling / equipment design, sequence of operations, inspection methods, operator instructions, operators training, etc.)

Please note that preventive actions planned as an outcome of PFMEA include, among others, changes in operator instructions and trainings. This is quite an often scenario, in line with the topic of the paper.

PFMEA standard procedure and form. PFMEA is a team task. The team should be multidisciplinary to be able to analyze the process thoroughly, focusing on hazards arising from various sources of variation (e.g. man, machine, material, method – referred to as 4M process components [10]).

PFMEA is quite a time-consuming process. To make this process effective and worthwhile the FMEA team should be supported by factory top management by assuring necessary resources (professional team leader, convenient place and scheduled time for meetings). To manage the PFMEA process efficiently some companies develop relevant procedures defining tasks and responsibilities of the process participants.

The process of performing PFMEA can be divided into three main phases:

1. PFMEA initiation (setting up a team, defining a scope of analysis, scheduling, gathering necessary documents and information, e.g. specifications, complaints reports, etc.).
2. Team meetings (risk identification and assessment, working out suggestions of preventive and corrective actions).
3. Conducting preventive or corrective actions (including their validation and risk reassessment).

Each phase could be described as a set of steps, which should be performed in defined sequence, especially the risk analysis, which is carried out during team meetings. PFMEA procedure, according to [6, 7, 11] requires that for each step of manufacturing process the team identifies a few components of the process hazard, assess the risk, recommend and document improvement actions (table 2).

Tab. 2. Content of FMEA

	Component of process hazard description	Purpose
	Process Step / Function / Requirements	To define a scope of the analysis and relevant quality requirements.
	Potential Failure Mode	To identify all potential failures to meet quality requirements.
	Potential Effects of Failure	To anticipate the worst effects of each failure on customers (internal and external – e.g. users).
	Severity (S)	To assess the risk in terms of the worst effect a failure might have on customers (index within range 1÷10, 1 – no/negligible, 10 – critical).
	Classification	To assign a symbol of critical risk.
	Potential Causes of Failure	To anticipate potential causes of each potential failure.
	Occurrence (O)	To assess the risk in terms of a chance that a failure cause can happen (index within range 1÷10, 1 – not possible/negligible, 10 – almost certain).
	Current Controls – Prevention	To identify current prevention controls introduced (or having been planned to be introduced) in the process. The purpose of these controls is to prevent a failure cause or to reduce its chance (occurrence).
	Current Controls – Detection	To identify current detection controls introduced (or having been planned to be introduced) in the process. The purpose of these controls is to detect a failure and/or a failure cause in case they occurred during the process.
	Detection (D)	To assess the risk as a chance of a failure and a failure cause not being detected, if occurred (index within range 1÷10, 1 – detection certain, 10 – no chance / no detection).
	Risk Priority Number (RPN)	To present a final risk assessment; RPN = S·O·D
	Recommended Actions	To plan actions aimed to reduce risk through: minimizing the chance of a failure cause occurring, if not effective enough: maximizing the chance of a failure mode or a failure cause being detected (when occurred).
	Responsibility Target Completion Date	To define date and person responsible for implementation of recommended actions.
	Performed Actions	To document actions performed.
	Effects of Performed Actions (S, O, D, RPN).	To evaluate effectiveness of performed actions in terms of risk factors (S, O, D, RPN).

Figure 1 shows an example form widely used by PFMEA teams to perform and document risk analysis.

Potential
Potential Failure Mode and Effects Analysis
(Process FMEA)

Item:
Model Year(s)/Vehicle(s)
Core Team

Process Responsibility
Key Date

FMEA number
Page /
Prepared by
FMEA Date (Orig.)

Process Step Function	Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Classification	Potential Cause(s) of Failure	Current Process Controls - Prevention	Occurrence	Current Detection Process Controls - Cause	Current Detection Process Controls - Failure Mode	Detection	RPN	Recommended Action	Responsibility & Target Completion Day	Actions Taken & Effective Date	Severity	Occurrence	Detection	RPN

Figure 1. FMEA form (variant E by [6])

The PFMEA analysis should be started at the very start of a new process design so that actions, i.e. implemented changes be feasible and not costly. The later the process changes are recommended, the more expensive they are, if approved (e.g. changes in product specification, tool design, process parameters, component flow, clamping methods, inspection frequency, part handling method, packaging, etc.). Due to inevitable costs incurred, the method of selecting risks to be reduced seems crucial.

Preventive effects of PFMEA / Training as a risk prevention. There are two dominant strategies companies use to make decisions about preventive actions:

A. By RPN (traditional) – actions are required if RPN exceeds a predefined upper limit RPN_{max}, often set by a customer (e.g. RPNmax = 100),
B. by individual Severity, Occurrence, Detection values.

The first approach (A) is easy to manage (therefore still used) but gives not pertinent actions recommendations because RPN is calculated as product of S·O·D which, as such, ignores which risk index is high compared to others. The second approach (B) has been in place for a few years [6, 7, 10] and is said to give more accurate recommendations for risk reduction. It claims that the risk indices (S, O, D) are not equally important for planning actions. Hierarchy (order - #) of risk factors that arises from the contemporary FMEA guidelines [6, 10] is shown in table 3.

Tab. 3. Hierarchy of importance of FMEA risk indices (with respect to planning actions)

#	Risk index	Justification
1	Severity	Takes customer and financial effects into account
2	Occurrence	Refers to process capability to meet customer requirements. Depends on effectiveness of prevention controls used.
3	Detection	Refers to inspection ability to detect problems (failures or their causes after they occur). Depends on effectiveness of detection controls used.

This means that, when planning improvement actions for the process, one has to take perspective of customer first (external and internal), than consider process weaknesses in terms of its reliability (stability, capability), and, at the end, look at quality inspection incapability (errors).

The procedure of selecting risks to be reduced by actions, according to the above approach (B), meeting requirements of [6, 7, 10], might be as follows:

1. give the highest priority to critical failure modes (with S = 9÷10, i.e. failures causing safety issues for operators or product users) in order determined by failure cause probability (i.e. by Occurrence), then
2. consider failure modes with lower Severity (S < 9), sorting them by Occurrence, then
3. in case there are a few risks with the same Severity and Occurrence, sort them by Detection (starting with the highest value), then
4. plan actions for obtained ranking of hazards, implement actions, reassess risk, then
5. go back to 1 – i.e. update ranking and start next iteration of planning actions.

Thus, a risk ranking is created and continuously updated as PFMEA proceeds. The ranking becomes a primary input for planning improvement actions for the process, a basis for continual improvement. Some companies periodically select a few top risks (e.g. top 10, top 5) to be mitigated by actions. Some companies do this using Pareto analysis (according to Pareto rule appx. 20% of hazards make up appx. 80% of total process risk). After some of the planned actions are effectively introduced, the risk ranking is updated and other risks are considered to be the top ones to be reduced. Thus, a famous Deming / Shewhart PDCA (Plan-Do-Check-Act) cycle is realized, as a method of obtaining continuous process improvement.

Instead of the ranking, risk matrices can be used to assist in making improvement decisions. An example of such a risk matrix is shown in figure 2.

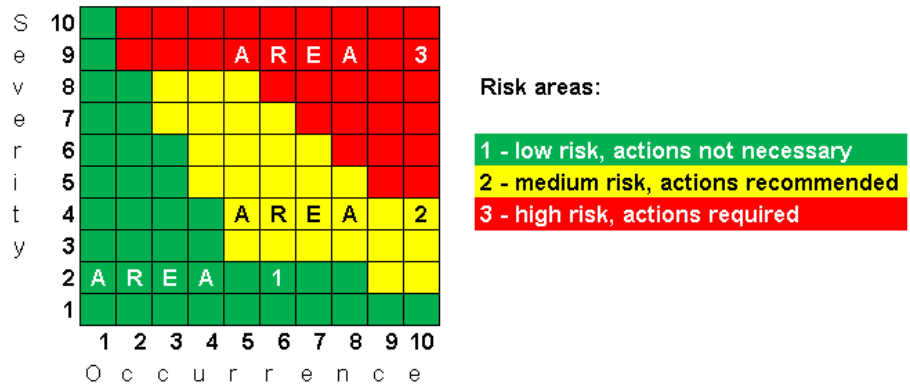

Figure 2. FMEA risk matrix example

It is crucial to realize that approach (B) recommends process improvement achieved by prevention controls (reducing Occurrence) rather than by detection controls (reducing Detection). The concept of indices measuring which type of controls dominate in (long-term) process improvement is presented in [12].

One can distinguish between two types of prevention controls: soft and hard ones. The latter include technical and organizational measures aimed to reduce occurrence of failure causes (e.g. product design, tool design, process parameters selection, workstation setup, flow of parts, tools changeover periods, etc.). The purpose of the soft type prevention controls is the same, but realized by affecting process personnel skills, awareness, motivation or knowledge (e.g. trainings, manuals, visualization, etc.). The main differences between the two types of prevention is summed up in table 4.

Tab. 4. Comparison between soft and hard types of prevention controls

#	Criteria	Prevention controls – soft	Prevention controls – hard
1	Cost of implementation at process design phase	Low	Medium or low
2	Cost of implementation / change at process validation phase	Low	Medium or high
	Cost of implementation / change after SOP date	Low or medium	High or very high
3	Effectiveness	Low or medium	High or very high

SOP – Start Of Production.

The longer is a forecast period of manufacturing, the more profitable it seems to apply prevention controls of hard type. However, the later necessary process changes are identified (e.g. during validation tests or after start of serial production), the more costly they are (late change requests are usually due to poor quality of process risk analysis). Thus, instead of process/product redesign, companies turn to soft prevention controls to reduce risk and assure expected process (product) quality.

Problem statement. Each manufacturing company plans and performs trainings for operators. The trainings address obligatory topics (e.g. Health and Safety rules) and many other operational skills, in accordance with HR training and development plans. Number of required skills, expected to be mastered by operators tends to grow. Operators should be able to operate tools / machines, carry out process control / quality control, perform maintenance tasks, participate in problem solving, no mention being well aware of process risks [13].

Trainings for operators are typically planned as a result of:

- new operators being employed,
- operators development (exchangeability of operators – polyvalence matrices),
- new manufacturing projects (processes) being implemented,
- observations done by supervising personnel, e.g. team leader (complementary trainings),
- customer complaints (training as part of corrective actions after a problem occurred),
- PFMEA (training as planned soft prevention for a new project/process).

  The latter is usually used ineffectively or not used at all.

Apparently, there are many sources of training decisions. This makes a planning process quite complex and difficult to optimize. Consequently, there is a risk that training plans are:

1. reactive to problems rather than proactive,
2. too general with respect to training objectives, not pointing out the specific skills or awareness necessary to prevent operator errors,
3. not addressing the most risky operator errors,
4. delayed in taking into consideration process changes / improvements (planned or having been introduced).

Table 5 shows the above risks, comparing the usual, current situation in many companies to the desired one.

Tab. 5. Operator training plans – actual vs desired situation (with examples)

#	Problems with training plan	Typical specification of training objectives	Desired specification of training objectives
1	Reactive to problems rather than proactive	Training objectives with respect to time problems starts to occur	
		Re/train operators on how to perform an operation to avoid encountered problems, e.g.: *carry out extra operator training on how to assembly part X (corrective actions after customer complaint concerning erroneously assembled part X)*	Train operators how to assembly part X before they make non-conforming product, (paying special attention to potential, specific errors in order to reduce the chance they occur)
2	Too general with respect to training objectives	Training objectives with respect to a level of detail	
		Train operators how to perform an operation, e.g.: *assembly part X*	Train operators how to make conforming product, paying special attention to potential, specific errors, e.g.: *train operators how to assembly part X, especially:* *- how to correctly position the subassembly on a prism before assembling the component,* *- how to handle part X to eliminate deformations when inserting into a container.*
3	Not addressing the most risky operator errors	Training objectives with respect to selection of operator errors addressed	
		Focus on the most probable and/or evident ones	Focus on the most serious in effects, than most probable, than least likely to be detected
4	Delayed to process changes	Training objectives with respect to time process changes are introduced	
		Train operators how to perform an operation as originally designed (according to standard operation instructions)	Retrain operators after each process change affecting current risk of operator error (i.e. cover skills necessary to keep the top risks under control, according to modified risk indices)

Specialists and practitioners claim that training objectives should be identified based on thorough process analysis, especially for high risk processes [14, 15, 16]. However, these recommendations seems to be rarely followed.

Proposed solution. In order to prevent the above described problems, results of PFMEA can be effectively used for planning of operator trainings. It would be an additional, significant benefit from performed PFMEA, helping to:

A. identify current and expected training needs for operators (topics, target group),
B. design training programs in detail,
C. update training plans systematically (PDCA cycle), according to current process risk.

A general procedure, integrating PFMEA process with operator training process, is shown in figure 3.

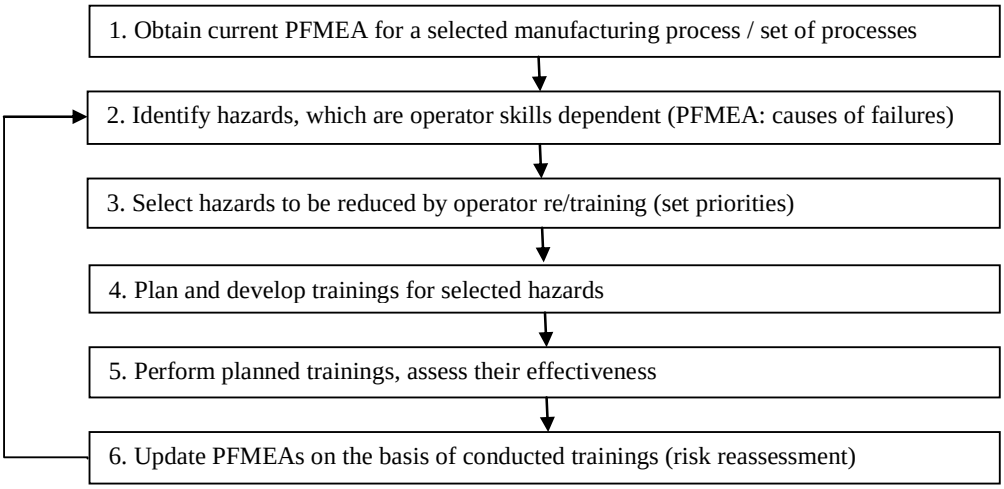

Figure 3. A concept of PFMEA based planning of operator trainings

To start (step 1), one needs access to current PFMEA.

The next steps, performed cyclically, each time focus on current risk state in analyzed process.

The second and third steps should be performed with participation of PFMEA team members to assure profound knowledge of the analysis scope, necessary to: – indicate failure causes, which occurrence or detection depends on operators skills (step 2), – selects those, whose risk should be reduced (lower occurrence, eventually detection indices), paying special attention to special characteristics, using tools like risk rankings (by S,O,D) or risk matrices (step 3). The selected hazards define current, most important training needs, serving as a basis for planning and development of operator trainings (step 4).

The fourth step comprise:

– definition and development of a training (objectives, target group, program, methods, date/frequency),

– assignment of responsibilities (e.g. person responsible for including the training into a training plan, person responsible for developing a detailed training program/scenario, person responsible for technical preparation of the training, person responsible for conducting the training.).

Development of each training requires deep understanding of hazards selected in step 3. The most important components of hazard description are failure causes because the main purpose of operator trainings is to eliminate them or reduce their occurrence. Of course, associated failures and their effects should also be addressed while developing operator trainings in order to increase their motivation to eliminate errors (main training objectives!). It can be achieved by increasing operators awareness of errors consequences, which can be read from PFMEA (i.e. resulting failures, failures effects and severity index, measuring their impact on safety, quality, costs). Therefore it is recommended that this crucial step of operator training planning and development should also be assisted by PFMEA team members.

After planning and development phase, the trainings have to be conducted and assessed, according to company's procedures (step 5).

On the basis of assessment of performed trainings (effectiveness), resulting risk has to be reevaluated and PFMEA updated accordingly (step 6). In case the training addressed the selected failure causes (step 3) effectively in terms of their prevention, the risk occurrence index for the covered failure causes can be reduced. If the training addressed the selected failure causes effectively in terms of detection only, the risk detection index can be reduced. The firs scenario is highly recommended (see: tab. 3).

Updated PFMEA is an input for another risk reduction (quality improvement) cycle. Performed trainings is not the only reason for PFMEA changes. In the meantime, some process changes might have been introduced (e.g. elimination of a specific operator error through error-proof tool design) which affect risk state of the process and consequently training needs for next planning period. Some hazards might have been reduced effectively enough (e.g. by process redesign) making trainings addressing them no longer necessary. Resultant, current PFMEA should be a basis for next training planning cycle (beginning from step 2).

Example. In order to visualise the proposed method, an example has been presented below. Table 6 shows an excerpt of PFMEA for cutting process (with additional column "Op?" to point out operator dependant hazards, i.e. hazards which can be reduced by operator trainings). Table 7 shows the same PFMEA sorted by risk (Severity, Occurrence, Detection), ignoring hazards not belonging to "Op" type. Obtained document serves as an input for a training plan. Training objectives and target groups can be directly imported from current PFMEA – see table 8. For better legibility some PFMEA columns (not important for the purpose of the example) have been hidden.

Tab. 6. PFMEA for a cutting process (fragment)

Failure Mode	Failure Effects	S	Causes of Failure	O	Prevention Controls	Detection Controls	D	Actions →...	Op?
Length incorrect	Scrap, cannot assembly	8	Set-up error by setter (length misadjustment)	4	Set-up instruction	Piece length measurement, 3pcs after set-up, then 1 pc/hr	5		X
			Locking element worn out	5	Periodical change by Maintenance acc. to instruction	Piece length measurement, 1 pc/hr	9		
			Operator fails to fully lock a piece	6	Working instruction, introductory training	Piece length measurement, 1 pc/hr; manual check of locking, each piece.	7		X
			Operator holds a piece manually to save time	8	Working instruction	Piece length measurement, 1 pc/hr	9		X
Burrs on cut edge	Danger of harm, rework.	10	Excessively worn tool – operator changes it too late	5	Working instruction, periodical general operator trainings.	Visual check of cut edge, operator, 1 pc/hr	9		X
			Drop of cutting speed due to drive unit failure	2	Periodical recalibration of driving unit by Maintenance	Visual check of cut edge, operator, 1 pc/hr	9		
			To early loosening of lock by operator (before cutting finishes)	7	Working instruction	Visual check of cut edge, operator, 1 pc/hr	9		X

Tab. 7. PFMEA for a cutting process (fragment) – a report for a training plan

Failure Mode	Failure Effects	S	Causes of Failure	O	Prevention Controls	Detection Controls	D	Actions →...	Op?
Burrs on cut edge	Danger of harm, rework.	10	To early loosening of lock by operator (before cutting finishes)	7	Working instruction	Visual check of cut edge, operator, 1 pc/hr	9		X
Burrs on cut edge	Danger of harm, rework.	10	Excessively worn tool – operator changes it too late	5	Working instruction, periodical general operator trainings	Visual check of cut edge, operator, 1 pc/hr	9		X
Length incorrect	Scrap, cannot assembly	8	Operator holds a piece manually to save time	8	Working instruction	Piece length measurement, 1 pc/hr	9		X
Length incorrect	Scrap, cannot assembly	8	Operator fails to fully lock a piece	6	Working instruction, introductory training	Piece length measurement, 1 pc/hr; manual check of locking, each piece.	7		X
Length incorrect	Scrap, cannot assembly	8	Set-up error by setter (length misadjustment)	4	Set-up instruction	Piece length measurement, 3pcs after set-up, then 1 pc/hr	5		X

Tab. 8. Training plan based on PFMEA report

Topic	Target group	Training objectives	Priority (SOD by PFMEA)	Time, frequency, responsible	Program, methods, trainer, assessment, etc.
Cutting process	Cutter operators	Train to properly loose a lock (after cutting finishes)	10 7 9	2 hrs, monthly, Team Leader	
Cutting process	Cutter operators	Train to change tool on time (by instruction, before excessive wear appears)	10 5 9		
Cutting process	Cutter operators	Train how to handle a piece (not manually, despite it saves time)	8 8 9	1 hr, quarterly, Team Leader	
Cutting process	Cutter operators	Train how to fully lock a piece	8 6 7		
Cutting process	Setter	Train how to correctly make a set-up of cutting length	8 4 5	2 hrs, quarterly, Maintenance Eng.	

Please note the importance of clear and detailed failure cause description for training planning. Each training (program, time, methods) can be accurately designed, starting from very specific training objectives – to eliminate failure causes with the highest priority risks in current PFMEA. One training program can address a few failure causes relating to the same manufacturing operation, product or target group. After performing the planned trainings (step 5 in fig. 3), a PFMEA review is recommended (step 6 in fig. 3) to update training plans so that they permanently address current, highest risks in the manufacturing process.

Anticipated effects and obstacles. There are a few significant benefits arising from the proposed method of planning operator trainings:

1. Better Return on Investment resulting from PFMEA. Companies performing PFMEA can obtain additional advantage from this time-consuming activity, contributing to its faster pay-off and increased motivation for implementing PFMEA for new projects / processes.
2. Accurate and relevant training programs, easily defined and clearly justified. Training objectives are determined with reference to specified causes of the highest process risks, selected from the current PFMEA. Thanks to that training programs address the most important issues, accurately identified.
3. Support for on-the-job training (OJT). PFMEA is dedicated to a specified process step (operation) and product (product family). Thus, training objectives are defined for a given work place, facilitating OJT, in accordance with contemporary trends in operator trainings [18, 19].
4. Pertinent and adequate updates of training plans and programs. Training plans and training programs can be reviewed basing on changes in PFMEA (i.e. changes of a risk state of the process) to address the currently highest risks.
5. Problems prevention for new processes / projects through trainings. The most important trainings can be identified, accurately planned and designed as preventive measures, before SOP (Start of Production) date, based on early PFMEA. Thus, the possibility of any important training objective being overlooked or not achieved before SOP, is significantly reduced.
6. Increased motivation of trainers and trainees. Due to positive justification of training plan and programs and thanks to very specific training objectives, both trainers (e.g. engineers, team leaders, supervisors, internal trainers) and trainees (operators) are more motivated to train and be trained.
7. Easier training assessment. Particular training objectives make trainings and trainers very effect-oriented. This facilitates the assessment of training results, pointing out ineffective trainings which have to be repeated, redesigned or in other way supported to achieve defined objectives.
8. Additional input for qualifications requirements. Training objectives derived from PFMEA can be used as input for defining (and updating) of obligatory qualification requirements for operators before they are allowed to take responsibility for a given working place (operation, machine). This is crucial in processes where exchangeability of operators is necessary, managed e.g. through polyvalence

matrices. In the latter case training objectives could be imported from PFMEA and set as requirements depending on operator skills level required, e.g. beginner (can work only under supervision), master (can work without supervision), trainer (can train others). This kind of approach is popular among companies applying Lean Manufacturing or TPS (Toyota Production System).

9. Support for Kaizen. Detailed, dedicated training programs enhance trainees' profound understanding of trained issues, connected with specific hazards. Thanks to that awareness, operators are more likely to come up with process improvement ideas expected by Kaizen program. Risk reduction obtained through operators' ideas are promptly reflected in updated PFMEA and resulting training program, which gives operators recognition and increases motivation for seeking next process improvement ideas.
10. Auditing support. Operator training programs would result from and be justified by relevant PFMEAs. Thus, when planning internal quality audits in a company one can wish to additionally assess a training process by adding an important point to an audit check-list: does operator training programs address current training needs, i.e. does it conform to current PFMEA?

On implementation, one has to be aware of potential problems reducing effectiveness of the method. If realised in time, the following obstacles can be prevented:

1. Not updated PFMEA. Failure to keep PFMEA up to date can cause wrong decisions regarding trainings. Training plan and training programs might be not relevant to current process risks.
2. PFMEA too general. Poor quality of risk analysis, i.e. ambiguous failure and failure causes descriptions (e.g. operator error during assembly) can make training objectives too general (e.g. train to correctly assembly a product) and consequently not addressing specific and most risky process hazards, while unnecessarily addressing small or medium hazards, well prevented in the process.
3. Incomplete target group. Not all personnel associated with the hazard and resulting training objective might be identified and comprised by training plan. Special care has to be given not to overlook anybody "participating" in the hazard (failure and failure cause) identified in PFMEA, otherwise conducted trainings can fail to give expected effects.
4. Ineffective training performance. Despite having been well designed, conducted trainings may have low effectiveness with respect to risk mitigation. Thus, a special attention should be paid to training methods and trainer's level of professionalism.
5. No training effectiveness assessment. In case a performed training is no assessed with respect to its effectiveness, no PFMEA update can take place or is updated incorrectly (risk reduction assessment), assuming the risk has been mitigated as planned thanks to performed trainings. Consequently current risk state of the process can be not up to date, causing decisions regarding next training plans be based on not relevant process risk analysis.
6. Too extensive training programs. In case PFMEA identifies a large number of hazards which are intended to be addressed by operator trainings (e.g. due to lack of technical possibilities of applying hard type prevention – Tab 4.), the set of

training objectives might become quite a long list, difficult to be achieved. Consequently, training programs and corresponding training time will be relatively long, which increases costs of trainings and reduces their effectiveness. Such ambitious training plans might also cause loss of trainees and trainers motivation affecting training effectiveness. The overall effects might boil down to poor preventive effects of costly, extensive training plan. Lack of expected risk reduction will cause product / process quality problems and might require intense retraining plan, unless hard-type of prevention is introduced in the process and PFMEA updated accordingly.

Conclusion. The proposed method may significantly improve operator training design and planning in manufacturing companies using PFMEA as a standard risk analysis tool. Comparing efforts spent to develop good quality PFMEA to work involved in preparing a relevant report (e.g. PFMEA hazards ranking) serving as a basis for operator trainings design and plan, one will certainly come to a conclusion that this additional advantage drawn from PFMEA is evidently worthwhile. Author hopes this paper will encourage Quality Managers to promote / continue PFMEA development and HR Managers to start using it for operator training optimisation, e.g. as TWI (Training Within Industry) improvement program.
Assuming deployment of PFMEA beyond manufacturing processes (e.g. to logistics), the proposed method could support optimisation of training process of personnel participating in many other company processes, covered by PFMEA.

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