

# Dynamic management of detected factory events and estimated risks using FMECA

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**Abstract** – In most of the modern production factories, manufacturing events are capitalized inside the manufacturing information system. To address Overall Equipment Efficiency (OEE), Yield, cost and to reduce actual events impact, action plans are defined by the engineering organization. To secure and manage the action plan process in a preventive way, risk analysis methodology can be used. This paper proposes an approach which establishes a continuous bond between factory events, risk analysis and related action plan with minimal and under control human intervention. A unified management method is proposed. Deployment uses cases from semiconductor industry using the proposed method are shown.

**Keywords** – Risk analysis, knowledge management, action plan.

## I. INTRODUCTION

Risk analysis is one of the best known practice and approach for preventing dysfunctions. Developed initially for military domain, this method was then used in many industrial sectors and applied for different manufacturing processes. FMECA [1] is the ISOTS recommended method for risk analysis and action plan elaboration. Risk definition and assessment aims to minimize or eliminate the cause/effect of dysfunction. Initially used in order to improve equipment reliability in the military domain [2], FMECA is now applied in a broad range of application, managed mainly by quality department to secure processes (internal customer) and product quality (external customer). Using FMECA, each identified risk (on equipment, process or product) is detailed and if required (critical risk evaluated), actions have to be defined in order to:

- minimize actual effects ,
- prevent from other potentials causes,
- improve detection.

FMECA is today also known as a reference method for knowledge and human expertise capitalization. By following now the FMECA method step by step, we can see that:

- A risk event is highlighted by the detection of undesired event or by anticipation.

- This event is then analyzed and a severity ranking is associated by experts.
- As a result of this analysis, a recovery action plan is defined based on actual expertise know-how.

Human expertise is the unique link between manufacturing event, associated risk analysis and related actions plans. So, the following question mark can be asked: *Is it possible to make a dynamic link between daily factory events, associated risk and action plan in order to simplify and make more reliable the complex FMECA procedure?*

Various researches have been started on the problematic, aimed to improve the classical method of risk management coming historically from military domain. Product quality insurance is the result of continuous controls during production cycle. These controls concerns product, equipment and processes steps [3]. All process steps upstream final quality tests might be under control in order to decrease or suppress non-conformities and failure rate. Literature review [4-5] shows that FMECA accuracy is based on human expertise and that documentation update is irregular despite huge efforts spent on actions plan deployment and follow-up. On the other hand, in most of the cases, users are obliged to sustain two action plan types:

- Risk action plan (rAP) issued from FMECA studies.
- Engineering action plans (eAP) issued from actual and real time manufacturing events.

Risk analysis methodology allows dysfunctions prevention and control of risk level [7]. Several studies were developed around risk improvement, assessment and management [6-8-9]. Models based on quantitative analysis (QRA: Quantitative Risk Analysis) or probabilistic analyses (PRA: Probabilistic Risk Analysis) [10] are recommended to improve the analysis quality and the hazard assessment. Other studies were focused on maintenance or quality process improvement through risk analysis approach [11-12-13].

Most of the literature about risk management and improvement turns around risk identification methods and more precise ranking evaluation. For all the method steps described, they all still need human intervention. Experts have to estimate hazard, define risk ranking, and if required elaborate action plans.

This paper propose an approach which establish a continuous bonds between factory events, risk analysis and related action plan with minimal and under control human intervention. This approach needs mind set change concerning FMECA usage on the following aspects:

- FMECA can be used like an operational knowledge management tool.
- It can then be used has a reliable operational action plan by operational actors.
- Quality and process improvement can be prioritized based on risk classification.
- It constitutes a managerial method to measure production performance.

This study proposes a method which enhances risks management in a manufacturing facility. The aim can be summarized by: Integrating FMECA risk analysis and classification in the real time industrial information system by defining bounds with real time manufacturing events.

We will first clarify the problem definition and based on use cases studies identifying faintness of the classic method, we will highlight improvement opportunities. Then proposed approach will be described. Results will be finally discussed as well as prospect for future work.

## II. NOMENCLATUE AND PROBLEM DEFINITION

### A. Nomenclature:

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R: Risk (Estimated)
E: Event (Actually detected)
IS: Information System
Dr: Definition of risk (Item / Function, cause and effect)
Ro: estimated occurrence of the Risk
Rs: estimated severity of the Risk
Rd: estimated detection of the Risk
RPN = Ro * Rs * Rd: Risk Priority Number
Rpo= Rs*Ro: Risk priority occurrence affect cycle time and cost
Eo: Event occurrence
Es: Event severity
Ed: Event detection
AP: Action Plan
eAP: engineering Action Plan
rAP: risk Action Plan

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### B. Definitions:

A risk is characterized by its Definition (**Dr**), Occurrence (**Ro**), Severity (**Rs**) and Detection level (**Rd**).  
 R (Dr, Ro, Rs, Rd)

To evaluate the level of risk, FMECA method uses an **RPN** (Risk Priority Number) obtained by multiplying the three risk parameters: *Severity* – **Rs** (Impact on the process, equipment or product), *Occurrence* – **Ro** (the risk probability) and *Detection* – **Rd** (probability that failure is detected). **Rs** and **Ro** are graded within a range

of 1 to 10 (1, low; 10 high) as well as **Rd** (1, high detection capability; 10 low detection capability). The calculated risk level is:

$$RPN = R_s * R_o * R_d$$

$R_s$ ,  $R_o$ ,  $R_d$  grades are determined using risk ranking grids defined by domains (Product, Process block or Equipment block). These ranking grids with they associated RPN limit level are based on standard coming from automotive industry, they are sometime slightly adjusted to be usable in regard to the specificity of the company domain. Risk is estimated. On the other hand, based on actual failures of the manufacturing line, events can be also quantified. There is of course a link between these actual failures managed and addressed by Action Plan (AP) and line manufacturing risk (R).

$$R_i \Leftrightarrow \sum_{j=0}^n rAP_j \quad (\text{n: number associated action plan to the risk } i)$$

Each estimated risk (R) can be associated to one or several action plans called risk action plan (rAP). It depends generally on risk criticality (RPN value).

An actual event (**E**) is characterized by its Definition (**De**) which represents the event description and its identification parameters: the Occurrence (**Eo**) and the Severity (**Es**). **Eo** is determined according to the number of actual event occurrence. **Es** is estimated according to the measured effect on cycle time or yield thru ranking tables

To reduce event occurrence or severity and improve event detection, action plan called engineering action plan (eAP) can be associated.

$$E_i \Leftrightarrow \sum_{j=0}^n eAP_j \quad (\text{n: number associated action plan to the event } i)$$

E (De, Eo, Es)

Risk represents an *estimation* of hazard and its probable effects on manufacturing objectives. Event is a detected occurrence during production process. Its effects can be measured.

### Estimated Risk Example:

This example describes the risk Definition and ranking quotation for a wafer carrier (Called FOUP) identified automatically by an electronic Identity Reader (Called ID READER) which can be the root cause of a failure.

#### Risk definition (**Dr**):

Item/Function: FOUP ID READER

This is the name of the Equipment module that can fail.

Potential Failure Mode: ID READER DOWN

This describes the name of the failure associated to the failing equipment.

#### Risk Severity (**Rs**):

The impact of the equipment failure associated to the ID READER Failure is *estimated* to less than 30 minutes of

down time. The equivalent severity value is 2 (according to risk evaluation company restricted grid).  
 $R_s = 2$

**Risk occurrence (Ro):**  
 The occurrence *estimated* for this risk is from one to six per week. The equivalent occurrence rank is 7.  
 $R_o = 7$

**Risk detection (Rd):**  
 The current controls and detection system consist in performing maintenance when a failure occurs. So the *estimated* detection level is 8.  
 $R_d = 8$   
 (The Risk evaluation parameters:  $R_s$ ,  $R_o$  and  $R_d$  are fixed according to company restricted quotation grids)

$RPN = 2 * 7 * 8 = 112$   
 By comparison with the recommended RPN limit level at 125, we can say that this issue is close to the limit and still not a priority to address. It can be seen also that with a slight modification in the occurrence RPN level can easily pass the limit.

**Detected Event example:**  
 This example describe the event definition and evaluation for a wafer carrier identified automatically by an electronic identity reader as for the risk example but here, the event represents a real detected failure.

**Event definition (De):**  
 This failure consists of a FOUP rejection at loading step. The identified cause can be the FOUP not properly positioned or an ID reader failure.  
 This event is codified into CMMS (Computerised Maintenance Management System) as:  
 Module Function: FOUP ID READER  
 Failure description: FOUP EJECTED AND LOADING MODULE DOWN  
 Failure Cause: ID READER DOWN

**Event occurrence (Eo):**  
 This failure occurred 8 times by week.  
 $E_o = 32$  events over one month.

**Event Severity (Es):**  
 The effect of this failure is that the load port module is stopped. The downtime measured over a one week period is then 4.92 hours.  
 $E_s = 4.92$  hours.

Analyzing event severity and occurrence, according to the risk ranking grid tables, shows a mismatch between the estimated values and the detected event reality. The estimated Risk severity  $R_s$  (linked to cycle time lost) was estimated at 2. The mean downtime value is 37 minutes (4.92hrs/8times) which correspond to a ranking value of 3. The occurrence passes also from 7 to 8 due to underestimation versus actual events. So the updated

$RPN = 3 * 8 * 8 = 192$  shows that this risk is critical ( $>125$ ) and risk action plan must be defined. Through this example, pointing out a typical FMECA ranking mismatch, it is highlighted the need of an aided decision tool in order to improve the analysis quality level linked to actual manufacturing risks and action plan coherence between Estimated risk and actual fab Events.

*C. Problem definition:*

Generally, in most of the modern production factories, event data codification is predefined inside the manufacturing Information System (IS). Events are standardized in order to make them usable and efficient information, simplifying by this way there usage for on line action tools (SPC, equipment actions, etc ...) or later for analysis correlation usage (link between yield, equipment downtime, cycle time, etc...). Literature on industrial practices shows that FMECA data and associated risk codification are generally not standardized and heavily linked to human intervention and assessment [4]. So, actual factory event representation inside risk management system is sometime far from the reality. It is also very difficult to sustain the reliability and the accuracy of risk data based on engineer's expertise. From this basis, it will be described now the aim of this paper is to present an alternative approach which improve FMECA methodology and resulted action plans. By using real events from the enterprise information system as well as minimizing human intervention it can be possible to makes actual event and the risks analyzed more efficiently linked.

$$E \begin{cases} De \\ Eo \\ Es \end{cases} \begin{matrix} Link ? \\ \Leftrightarrow \end{matrix} R \begin{cases} Dr \\ Ro \\ Rs \\ Rd \end{cases}$$

As presented in literature review, FMECA is never *directly* linked to manufacturing IS and no continuous bounds with manufacturing parameters exists. Enterprise information system makes possible to extract all data related to product, tool and process but no direct bounds exists between these data and the process Action Plan (AP) inputs. Today, only human expertise is involved to make these connections. Action Plans (AP) elaboration is supposed to be based on actual events or identified preventive actions and focused on reducing events impact on Yield, Cycle time and cost. Engineering added value might be on supervising the process, implementing methods for controlling or improving products quality. For that purpose, they have to use statistical analysis in order to take the appropriated decisions based on facts before acting.

In reality today in the field, two different action plans supposed based on manufacturing events are generated; Engineering (eAP) and Risk (rAP) action plans (Fig 1). An AP is associated to an event or (exclusive) a risk.

$$AP \Leftrightarrow \sum_{j=0}^n eAP_j \text{ XOR } \sum_{k=0}^n rAP_k$$

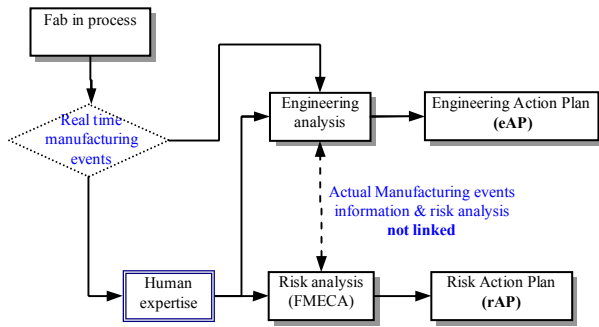


Fig1. General process for action plan management.

Fig. 1, show the actual process of action plan management. Human factor is present during all process steps from data collection to action plan definition.

Action plans are supposed to be linked to yield, cost or cycle time improvement programs. They are normally ranked by pareto graphs based on event severity or occurrence. eAP Actions are generally difficult to classify in terms of risk and giving priority can be sometime not easy for the management who needs to address yield, cycle time and cost improvement in parallel. On top of that, FMECA analysis is a quite static and difficult to be used on daily basis by the engineering group. Is it possible by using manufacturing events to improve risk analysis, improve and simplify engineering and management operational visibility?

### III. PROPOSAL

The proposal described below increase the level of computerized and automated tasks in the flow described fig 1 in order to replace human intervention on some activities. Engineering remains crucial for some steps like data analysis and associated decisions. The capability to use real time manufacturing events associated to the ability to generate automated report simplifies and makes more efficient the Engineering and risk management process which are followed by eAP and rAP. In fact the two process becomes merged and by this fact, coherent. By using the proposed method, it was shown also that FMECA can be built from scratch, updated automatically and frequently, based on actual production events.

The object model and suggested links between risk and manufacturing events will be first explained. Then, manufacturing data treatment and classification issues will be addressed. Finally the merged Action Plan (AP) with its prioritized method by risk level is described.

#### A. Object model and suggested links between risk and manufacturing events

Risk analysis is performed in order to identify undesirable or unauthorized events that could have a negative impact on product quality, process securization or equipment reliability. As presented in object model (Fig.2), starting from Potential\_Undesired\_Event (risk) analysis is

associated directly to manufacturing Process\_Part (Equipment, Product, and Process Steps). Engineers must do a Risk\_Evaluation (RPN) in order to prevent actual event through action described in rAP. Risk ranking estimations are based on their know-how. Identifying a risk is not sufficient to suppress it. It is necessary then to put in place controls (Process Control Tool) on Process Parts to reduce or eliminate the Detected\_Manuf\_Events occurrence. As shown in the above example (III.b), risk estimation and event measurement can be completely different on the occurrence point of view. This is a first reason why eAP and rAP can't be similar without a unified approach. Today, manufacturing process performance and quality are improved by integrating control tools and data analysis (Process control tools: Statistical Process Control (SPC), Engineering Data Analysis, Fault Detection and Classification (FDC)...). These tools help in identifying and classifying manufacturing data according to process, product or equipment variance root causes. eAP is the result of these analysis.

State that actual event are known in the IS, analyzed in eAP through Detected\_Manufacturing\_Event if they are properly codified. That one goal of rAP is to prevent also from Detected\_Manufacturing\_Event. It may be very efficient to computerize the link with Potential\_Undesired\_Event and by consequence merge eAP and rAP.

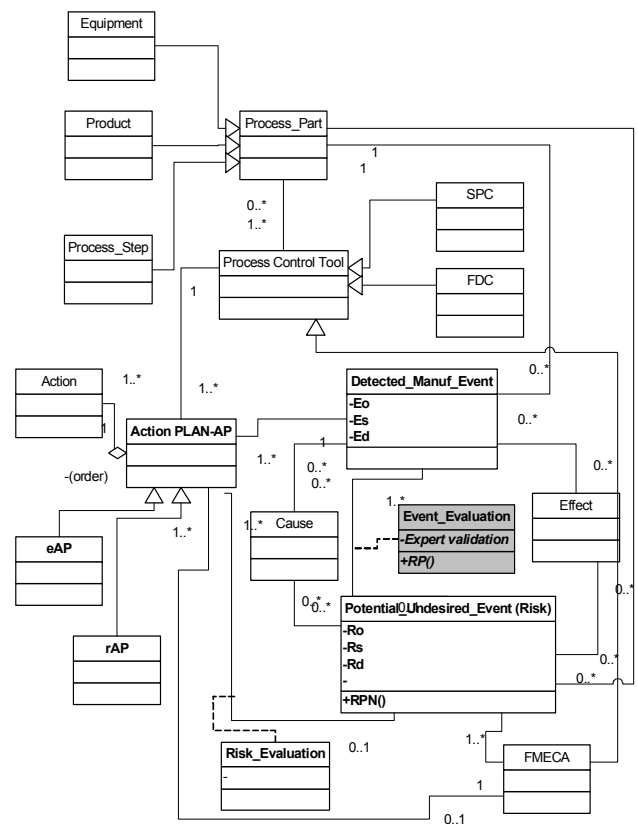


Fig2. Object model management for factory events and risks

Our proposal consists in developing a tool (In Black Bold on Fig-2 Event\_evaluation) to assist engineers during the risk analyze phase and prioritize actions based on actual manufacturing events. Direct links are created between IS collected data (Detected\_Manuf\_Events) and FMECA database (Potential\_Undesired\_Event). Each event is considered as a risk that can occur again. In our model, we use the Severity - Occurrence product (Rs\*Ro) to evaluate cycle time and cost impact and to define risks priorities:

$$Rpo = Rs * Ro$$

By setting watermark on this Rpo parameter, risks to be integrated into FMECA database can be highlighted. This model shows how to connect risks and events by imposing a conditional step for data history treatment and expertise validation.

But in order to associate an event to a risk, the event information must be treated and converted to FMECA formalism. The detail of this transfer formalism from event to risk is detailed in next section.

*B. Manufacturing data treatment and classification*

As seen above, risks are evaluated using standard ranking grids [1] defined at company corporate level. Establishing continuous bounds between risk analyses and manufacturing events requires looking more deeply to data formats and codification. Manufacturing events may be a tool failure, product non-conformity or a customer claim. These events information need to be evaluated in terms of risk for the line using risk rankings rules (severity and occurrence). The proposed data treatment and classification process is composed of four steps:

- Collect manufacturing event data (Detected\_Manuf\_Event).
- Identify affected item function for each event (Process\_Part).
- Specify failure mode and effect according to event data (Cause/Effect).
- Calculate event probability Eo and severity Es and then deduce Ro & Rs based on standard risk evaluation table (Event\_Evaluation).

This process depends strongly on enterprise information system and data management structure. For the success of the method, a preliminary study of manufacturing data and FMECA database structure facilitates the information treatment and it's classification as risk elements. Today the majority of production data are already managed using databases and computerized tools. Event occurrence (Eo) can be calculated using the count of event and event severity (Es) is calculated using the downtime duration. If the events are validated (Event\_Evaluation: Expert validation in Fig-2) they are classified by the computerized tool. Corresponding risk occurrence "Ro" is

deduced according to Risk occurrence grid as well as risk Severity level "Rs".

At the end of this computerized process we obtain, starting from manufacturing events history, coherent and classified data which are validated and transferable in FMECA formalism.

*C. Action plan based on risk level*

With common and coherent data source information coming from Detected\_Manufacturing\_Event and Potential\_Undesired\_Event (Risk), we can fill properly FMECA database. Then eAP and rAP can be merged in a single action plan AP:

$$AP \Leftrightarrow \sum_{j=0}^n eAP_j \text{ AND } \sum_{k=0}^n rAP_k$$

This resulted AP is simultaneously based on actual manufacturing events and risk evaluation validated by human expertise. FMECA are updated with potential risks coming from manufacturing actual events.

It is now possible to develop an aided decision tool for defining actions priorities by calculating Rpo values and optimizing in coherent way corrective and preventive actions above a fixed watermark limit (40: company risk criticality specification). Events pareto can be reported based on Rpo. Only risks with  $Rpo \geq 40$  are integrated or updated in FMECA database. The computerized tool treats three possible cases:

- If the risk already exists in FMECA and rankings are coherent with events history: no actions required.
- If the risk already exists in FMECA, but its ranking is not coherent with the events history: an updated ranking is proposed for engineering validation. AP is updated if the RPN is above a defined watermark limit.
- If the risk is a new one: a new line is added with its risk description, occurrence and severity value. An expert has to finish filling the line.

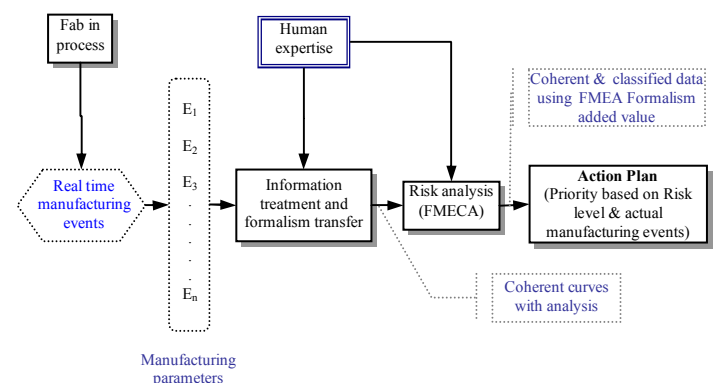


Fig3. Proposed process for action plan management.

Fig3. describes the proposed approach for action plan including risk knowledge management. This unified

processes and associated weekly reports point out the critical and potential events, it simplifies engineer's task. Human expertise added value is still used and remains key for action plan validation.

This new approach can also be said auto-regulated. In fact if a potential undesired event is over or under estimated in FMECA, detected manufacturing event analysis on a continuous way will compensate for it. This system allows controlling risk evolution because ranking is updated on a regular basis.

#### IV. RESULTS AND DISCUSSION

The method described, by using a dynamic and computerized bound between daily factory events, associated risk (FMECA) and creation of unified action plan simplify and enhance risks management in a manufacturing environment. By this approach, FMECA can be used as an operational knowledge management tool. Quality and process improvement can be prioritized based on risk classification. Impact of the action taken and associated risk can be followed at management level. Human expertise added value is still used and remains key for action plan validation. The new approach can also be said auto-regulated. In fact if a risk is over or under estimated in FMECA, event analysis on a continuous way will compensate for it. This system allows controlling risk evolution because quotation is updated on a regular basis. The method was deployed in a specific semiconductor area and about 20 new events and associated action plan (AP) where edited over a period of three weeks. Implementation success was mainly due to the fact that risks and real manufacturing events are merged and classified which simplify engineer's task and allows management to supervise in an efficient way actions linked to cycle time and cost issues.

This approach can be improved by including also detection aspects as it was done for occurrence ones. The decision taken for event-risk priority will then be based on overall risk priority number (RPN) and not only on risk priority occurrence (Rpo) value. Other prospects for this work are:

- The use of this developed knowledge (event analysis, decisions...) at technology development stage of new product or process change.
- Extension of object model (Fig.2) to include action plan management process.

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