From FMEA as a problem solving method to a design-oriented process: Toward a design perspective of FMEA

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FROM FMEA AS A PROBLEM SOLVING METHOD TO A DESIGN-ORIENTED PROCESS: TOWARD A DESIGN PERSPECTIVE OF FMEA

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1. Introduction

In a highly competitive industry, the management of quality and reliability in product design and manufacturing is becoming a fundamental issue. More and more, the main challenges on the new product development (NPD) are on identifying solutions and methods for the reduction, control and elimination of risk [Stamatis 2003]. According to Stamatis [2003], the focus of identifying and analyzing risks is mainly due to competition, time to market, market pressure, customer requirements, continual improvement philosophy, warranty and service cost. Thus, one of the main objective of risk analysis is to focus on prevention of problems, elimination of waste and reduction of unreliability [Stamatis 2003]. This means that the goal is to anticipate and understand what can be the probability, the consequences and the causes of potential problems and errors. In many high-tech sectors, such as automotive, aerospace, defense and semiconductor, the Failure Mode and Effect Analysis (FMEA) methodology is now one of the main used tools to identify and reduce risks during product design and manufacturing development [Lodgaard et al. 2011]. The FMEA is a systematic procedure to identify, anticipate and evaluate failure mode and their consequences on the system, product, technology, process, services, etc. Failure mode can be understood as deviations between actual and desired status of a system property [Wurtenberger et al. 2014]. However, practitioners (engineers, quality managers, etc.) and the literature in engineering design and quality management [Teng and Ho 1996], [Lodgaard et al. 2011] highlight many difficulties to implement and efficiently generate FMEA and to use the FMEA information to improve the quality of product and process design. We identify three main weaknesses and limits. The first one is that "unexpected" problems still happen even if the right FMEA procedures have been respected, the right knowledge has been used and the right design verifications have been done [Teng and Ho 1996]. The second one is that the FMEA methodology does not allow creating new learning. In complex engineering systems, the integration of a multitude of sub-systems, system-element and modules, from different engineering disciplines, increase the risk of product failures [Punz et al. 2011]. Indeed, each system is carrier of different effects, and these effects may involve undesired effects and problems in other modules and sub-systems. Thus, the main issue is not only sharing information between multidisciplinary teams to anticipate "well-structured problems" [Simon 1973], but to create new knowledge at the interface between interdisciplinary teams to propose creative redefinition of the situation. The third one is that FMEA methodologies have major difficulties in social interactions. These include the establishment of well-trained and balanced FMEA team, the coordination of individual departments in generating and accurate FMEA report [Teng and Ho 1996] and the collaboration between multidisciplinary teams in the design activity of FMEA report. Therefore, the main question of this paper tries to answers: How to explain FMEA difficulties and how to improve FMEA methodology in order to be able to design a better risk management strategy in NPD? First, this research will discuss the FMEA procedure, its history, its main concepts and its current weaknesses. Then, we propose to highlight that the limits of FMEA procedure can be linked to the limits of a problem-solving paradigm [Dorst 1997, 2006]. We reveal that current vision of engineering design, and particularly FMEA procedure, is based on problem solving perspective, which is restricted by the "bounded-rationality" model, proposed by Simon [1996], [Yassine and Braha 2003]. From the work of Hatchuel [2001], and its concept of "expandable rationality" we propose to revisit the theoretical framework of the FMEA to explain why FMEA cannot be reduced to problem solving. Finally, we argue that FMEA procedure is a full design activity and we propose to extend the initial FMEA methodology, by using C-K design theory [Hatchuel and Weil 2003, 2009]. The research was carried out in STMicroelectronics manufacturing department, more specifically in the Engineering Competences Center located in Crolles (France).

2. Theoretical background

2.1 The FMEA methodology: a general overview

In 1949, the U.S. Armed Forces (Military Procedures document MIL-P-1629) introduced for the first time the FMEA methodology to analyze and organize failures according to their impact on mission success and equipment safety [Stone et al. 2005]. Since that time, the use of FMEA methodology increased considerably across the industry, from Apollo space program (1960s) to the semiconductor industry, foodservice, software, as well as automotive industry (1980s). In major industries, problem prevention and design/process improvement are the main focus of FMEA [Lodgaard et al. 2011]. Indeed, prevent problems is clearly more advantageous—in terms of cost, quality and reliability—than fixing problems. As a tool, FMEA allows to prevent problems before design reach testing, and it allows to drive design and process improvements. To obtain safe, stable, trouble-free designs and error-proof manufacturing process are the main important objectives [Punz et al. 2011]. Moreover, given that effective product testing and manufacturing process controls are critical elements of successful product development, FMEA is also used to improve test plans and process controls. At last, other benefits of conducting FMEA include the following issues: helps to select alternatives (in system, design, process, and service), helps to define opportunity for achieving fundamental differentiation, helps to improve the company's image and competitiveness, helps to increase customer satisfaction [Stamatis 2003]. Usually, in many industrial sectors, FMEA are divided into three FMEA processes (Figure 1): system FMEA, design FMEA and process FMEA [Teng and Ho 1996], [Stamatis 2003], [Carlson 2012], [Wurtenberger et al. 2014].

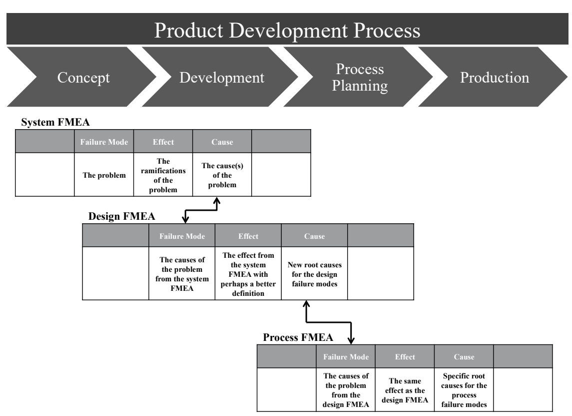

Figure 1. Relationship of system, design, and process FMEA [Stamatis 2003], [Wurtenberger et al. 2014]

System FMEA (also called concept FMEA) is the highest-level analysis of an *entire system,* composed of different subsystems [Carlson 2012]. Thus, in system FMEA, the focus is to convert operational needs into a formal description of technical parameters and technical configurations. Indeed, the aims are to ensure an optimal compatibility between technical parameters, physical parameters, functional topic, and to integrate reliability, quality, maintainability, safety, security, etc. [Tumer and Stone 2003]. Design FMEA–usually managed by product/design engineers–aims to identify and demonstrate engineering solutions to conform to system FMEA requirements and customer specifications [Teng and Ho 1996], [Stamatis 2003]. Finally, process FMEA deals with manufacturing processes. The focus is to define how manufacturing and assembly process can be developed to ensure that products or technologies are built according to design requirements, whilst maximizing quality, reliability, productivity, and the efficiency of the different process [Tumer and Stone 2003], [Wagner et al. 2008]. Each type of FMEA are used to support the product development process.

2.2 How to design a FMEA: preparation and procedure

To clarify the FMEA procedure, we propose to introduce its key concepts and definitions. As mentioned above, the main goal of a FMEA is to improve product design and process design. That means that main objectives are to identify significant product and process characteristics, to identify and prevent potential failures, to improve test and verification plans, to improve process control plan, to minimize loss of product performance and performance degradation [Carlson 2012]. FMEA methodology is based on a tabular method of presenting data. Information from the analysis are visually displayed in a series of worksheet rows and columns (Table 1).

Table 1. Generic FMEA worksheet

Item	Function	Potential Failure Mode	Potential Effect(s) of failure	Severity	Potential Cause(s) of failure	Occurrence	Prevention & Detection method	Risk Priority Number (RPN)	Recommended action	Actions taken

By *item*, it must be understood the main topic: the system itself for a system FMEA, the subsystem for a design FMEA and a manufacturing step for a process FMEA. A *function* corresponds to the task that the system, design, process must be perform. Usually, a function is described by an active verb. A *failure mode* characterizes the problem, i.e the way in which the *item* fails to perform the intended *function.* Each *function* could have many different *failure modes.* Moreover, it's important to highlight that a *failure mode* has to describe the physical description of the manner in which a failure occurs [Stamatis 2003]. An *effect* is the outcome and the consequence of the failure on the system, design and process, i.e. this is what happens when a failure occurs. *Effects of failure* must be analyzed from two perspectives: local consequences and global consequences. Local consequences mean that the failure can be isolated and it does not affect anything else. Global consequences mean that the failure can affect other functions. A *cause* is defined as the reason of the failure, i.e. the root cause of the failure. In most industries, FMEA procedures are recommended in case of new products or processes development, modifications of existing products or processes, customer's requests, quality improvement, and reliability management. There is no standard procedure for the FMEA method, however many examples in the literature use the following systematic approach [Teng and Ho 1996], [Stamatis 2003], [Carlson 2012]:

1. *Selection of the team*–FMEA cannot be done by an individual person. FMEA must be created by a team, and this team has to be defined depending on the nature of the project. Moreover, it's fundamental to ensure the cross-functional and multidisciplinary nature of the team [Stamatis 2003]. Then, the team tries to organize the opportunities of improvement by using brainstorming method, storybook method, cause-and-effect diagram, etc. What kinds of problems are there? What kinds are anticipated with particular situation?
2. *Selection of the functions*–Functional block diagram (for system and design FMEA) and process flowchart (for process FMEA) are used to make sure that everyone is on the same wavelength.

Does everyone understand the system, the problems associated with the design and process? Does everyone share an overview and a working model of the relationships and interactions of the systems, subsystems, processes, etc.?

3. *Failure mode collection*–The team has to collect and categorize the data of the failure mode.
4. *Effect investigation*–Enter all the primary functions for the item under analysis. Then, beginning with the first function, enter all the failure modes and corresponding effects with severity rankings. This step has to be done for all functions.
5. *Causes investigation*–For each *failure mode-effects* couple, enter all the causes, with occurrence ranking for each cause
6. *Detection analysis*-For each cause, enter prevention-type controls and detection-type controls.
7. *Recommended actions proposition*-By using different types of methods, such as brainstorming, cause-and-effect analysis, simulation, another FMEA, etc.; the objective is to evaluate and exploit the data for a resolution: Data ➔ Information ➔ Knowledge ➔ Decision.

FMEA method is a continual improvement method, so it's important to pursue improvement in each step.

2.3 The current weaknesses of the FMEA

Even if the FMEA is a widespread method used across industries, practitioners (engineers, quality managers, etc.) and the academic research highlight many difficulties to efficiently implement FMEA. In many cases, it's difficult to demonstrate that FMEA information improve the quality of product and process design. We identify three main weaknesses and limits.

2.3.1 The unexpected problems identification

Shortcomings are related to the difficulties in identifying key failures, to the fact that the analysis is subjective, based on the user's experience, and that the procedure is tedious and laborious for designers/engineers [Stone et al. 2005]. Moreover, academic researches highlight that "unexpected" problems still happen, even if the right FMEA procedures have been respected, the right knowledge has been used and the right design verifications have been done [Teng and Ho 1996]. On the one hand, this may partly be explained, by the fact that FMEA is performed too late in the design cycle [Stone et al. 2005]. In another hand, it also could be explained by the fact that designers/engineers don't really think about manufacturing issues during the design stages [Teng and Ho 1996]. Carlson [2012] also underlines the limitations of using generic listings of failure modes, effects, and causes. These types of listing provide standardized descriptions and limit the creativity of the FMEA team to "think outside the box" and to identify problems not previously observed [Carlson 2012].

2.3.2 Managing collective learning in multidisciplinary environment and at the interface between subsystem

To identify "unexpected" problems or new issues which are not already seen, this will necessarily involve managing collective learning capacities. However, the FMEA procedure does not achieve this fundamental objective. Indeed, as an inductive method, the FMEA is restricted to examine consequences (*effects & causes*) of an already known unwanted event (*failure mode*). This weakness makes it also difficult to support dynamic update of the FMEA report, i.e it's difficult to achieve FMEA as a living document [Lodgaard et al. 2011]. Moreover, in high-tech industries, the work environment is composed of a constellation of different practices and expertise. Thus, the analysis of complex systems to succeed in conducting an FMEA involves managing learning capabilities and support interdisciplinary collaboration. In addition, empirical data show that at least 50% of field problems occur at interfaces between sub-systems [Carlson 2012]. FMEA methodology tends to study the risks on a per-system basis, regardless of a global vision. Indeed, each system is carriers of different effects, and these effects may involve undesired effects and problems in other modules and sub-systems [Punz et al. 2011], [Wurtenberger et al. 2014].

2.3.3 Collaboration in the unknown: coordination and social interactions

Finally, the main issue is not only sharing information between multidisciplinary teams to anticipate "well-structured problems" [Simon 1973], but to create new knowledge at the interface of systems, between interdisciplinary teams, to propose creative redefinition of the situation, i.e. to give shape to the unknown. However, FMEA methodologies have major difficulties to take into consideration social interactions. These include the establishment of well-trained and balanced FMEA team, the co-ordination of each departments in generating and accurate FMEA report [Teng and Ho 1996] and the collaboration between multidisciplinary teams in the design activity of FMEA report.

2.4 FMEA methodology: From "bounded rationality" to "expandable rationality"

In high tech industries, Concurrent Engineering (CE) is becoming the main management philosophy in product and process development. CE is a set of operating principles allowing simultaneous development of product or process through an accelerated successful completion [Salomone 1995]. The main principles of CE–as *iteration principle, parallelism principle, decomposition principle and stability principle*–are derived from the fundamental characteristics of design decision-making and the "bounded rationality" paradigm [Yassine and Braha 2003]. "Bounded rationality" [Simon 1973, 1996] was a conceptual weapon against the "pure-rationality" based models of the decision paradigm [Hatchuel 2001]. This new model of rationality proposed to introduce the "satisficing" principle to introduce subjectivity, heuristics, uncertainty, imprecision in problem-solving and to illustrate that agents have a limited information-processing capacity. Today, the problem-solving paradigm, based on the conceptual framework proposed by Simon, is still the dominant paradigm in engineering design [Dorst 1997, 2006], [Yassine and Braha 2003]. As mentioned by Teng and Ho [1996] FMEA is a key instrument used in CE. Indeed, FMEA is one the main design and manufacturing engineering tool allowing to reduce product life cycle cost and to speed up the development of new product and process, i.e. one the main tool to manage and control CE [Teng and Ho 1996]. However, as mentioned above, the FMEA procedure has many weaknesses and limits. Thus, our main hypothesis in this article is that the weaknesses and limitations of FMEA are directly linked to the legacy of the problem-solving paradigm. Even if, the problem-solving paradigm and the "bounded rationality" were powerful concepts for the modeling of design, recent publications highlight fundamental weaknesses of this conceptual framework [Dorst 1997, 2006], [Hatchuel 2001]. In our opinion, one of the main contributions aiming to renew the problem-solving paradigm is the concept of "expandable rationality" [Hatchuel 2001] and the C-K design theory [Hatchuel and Weil 2003, 2009]. For these authors, design includes problem-solving, but it cannot be reduced to problem-solving [Dorst 2006]. To illustrate this argument, Hatchuel [2001] propose two examples. The first one is considered as problem-solving situation: *"looking for a good movie in town"*. The second one is considered as a real design project: *"have a nice party"*. Hatchuel explains that there are three important differences between these situations:

- The first difference is that in the design situation (example 2) there is no dominant design for what a *"good party"* should be. Hence, in example 2, there is something more: *"unexpected designs of what is a party can emerge from the process"* [Hatchuel 2001]. Finally, if unexpected expansions of the initial concepts are integral to a design process, design situation cannot be reduced to problem-solving.
- The second difference concerns collective learning. In example 1, collective learning results from exploration of already recognized knowing areas (films, theaters, member preferences, etc.). However, in case 2, collective learning determines the generation of problems and has to be considered as a design area. Hatchuel uses the term of *"learning devices"*, sort of sub-process that help designers to *"learn about what has to be learned or should be learned"* [Hatchuel 2001].
- Finally, social interaction is not just a design resource like in the case 1. In design situation, social interaction is a design resource and also a designable area. Thus, the understanding and the designing of social interactions is part of the design itself [Dorst 2006].

According to Hatchuel, this covey a new perspective on rationality: *"what means rational behavior in infinitely expandable and non-countable sets of actions?"* [Hatchuel 2001]. Hatchuel propose the concept of "expandable rationality" to highlight the "*designer ability to manipulate (individually and* *collectively) infinitely expandable concepts"* [Hatchuel 2001]. Based on the Hatchuel proposition, we aim to revisit the theoretical framework of the FMEA to explain why FMEA cannot be reduced to problem solving. Moreover, we demonstrate that the FMEA failures are the consequences of the dominant conceptual framework, which is based on the "bounded-rationality" model. Then, to explain FMEA difficulties, in order to be able to design a better risk management strategy in NPD [Said et al. 2016], we argue that FMEA procedure is a full design activity. Finally, to improve FMEA methodology, we propose to extend the initial FMEA methodology, by using C-K design theory [Hatchuel and Weil 2003, 2009].

3. Research Methods and theoretical framework

3.1 Collaborative management research in semiconductor industry

3.1.1 Collaborative management research methodology

This qualitative research was conducted from January 2014 to August 2015, in STMicroelectronics, one of the European leaders in semiconductor industry. The present study is based on a collaborative management research [Shani et al. 2008], conducted by academics and practitioners in order to create actionable knowledge for the organization and new theoretical models in management research [David and Hatchuel 2008]. The research was carried out by a researcher in management science and by a STMicroelectronics senior expert in manufacturing science. The purpose of this research was to investigate FMEA methodology and it uses in STMicroelectronics manufacturing department, more specifically in the Engineering Competences Center located in Crolles (France). From the company perspective, the goal is to understand and explain the weaknesses of the FMEA procedure, in order to improve the process to augment the performances of the firm. From the academic perspective, the FMEA tool is an interesting research object. Indeed, it is used from the 80s by the main important industries, however practitioners and research agree that this tool is poorly efficient: How can we explain this paradox? Thus, the challenge is to bring new theoretical frameworks and new knowledge in the field of engineering design and management science.

3.1.2 Data collection process and data analysis

Collaborative management research methodology enables access to a large set of data and allows researchers to adjust their investigation in order to make sens of the field. During our interventions, data have been collected in several ways: observations and analysis of internal process, interviews with key actors, analysis of internal documentation (checklists, FMEA, standard operating procedure, etc.), and participation of internal meeting and working group. Unfortunately, it is impossible for us to present the exact information because of confidentiality issues. The collaborative management research began from the development of a shared view of a critical issue of interest to both senior expert and the researcher. This is followed by the exploration of alternative ways to design the inquiry process. We decided to proceed as follows. First we propose to model FMEA with the most recent models of design reasoning (C-K theory). Then, we highlight new solutions to improve FMEA procedure. Finally, we propose to implement these new solutions in an empirical study and we evaluate its performances.

3.2 An analytical framework based on C-K design theory

C-K design theory aims to provide a unified and rigorous framework for design [Hatchuel and Weil 2003, 2009]. According to C-K design theory, design is defined as the interaction between two interdependent spaces. On the one hand, K Space incorporates all the propositions with a logical status, i.e. all available knowledge that the designers are able to prove or disprove. On the other hand, C Space includes all the propositions neither true nor false in K space, i.e. concepts about partially unknown objects. Propositions in C space are qualified as "undecidable" relative to the content of a space K if it is not possible to prove that these propositions are true or false in K space. When designers are faced with concepts, designers cannot affirm whether such a thing may be possible or that this would never be the case. Design starts when an initial concept is created. Design process proceeds by expansion of this initial concept into other concepts (by partitioning the concept) and/or into new knowledge (Figure

2). During the design process, both C and K spaces are expandable and these transformations between spaces and in the same spaces take place through four operations: C➔C, C➔K, K➔K and K➔C.

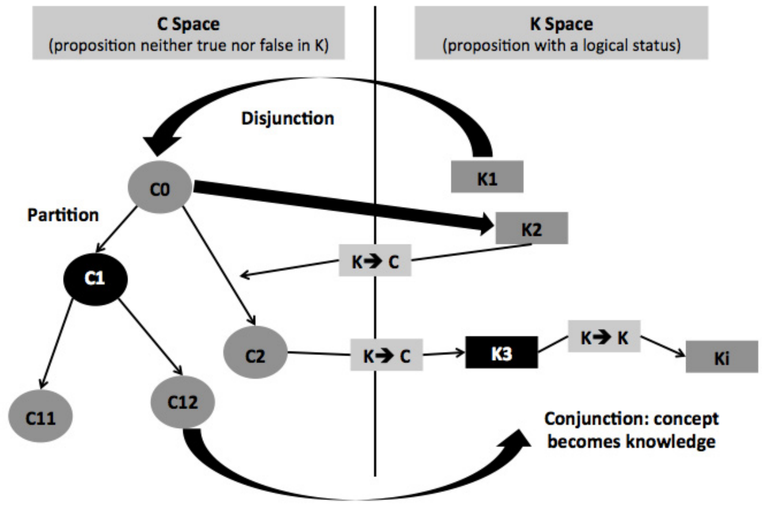

Figure 2. C-K Design Formalism [Hatchuel and Weil 2003]

The design process attempts to transform *"undecidable"* propositions into logical propositions in K, i.e. the design solution is when *"the first concept become a true proposition in K"* (a conjunction). The theory claims that C space has a determined structure: this space has a tree structure. Each node represents a partition in divers sub-concepts [Hatchuel and Weil 2003], and only partitioning or inclusions are allowed in C space. The theory introduces two different types for partitioning for concepts: *restrictive partitions* and *expanding partitions* [Hatchuel and Weil 2003]. Restrictive partitions add a property to a concept already known, unlike expanding partitions, which add properties not know in K as a property of the entities concerned. Therefore, *"creativity and innovation are due to expanding partitions of concepts"*. Then, design process has to be understood as interactions between these two spaces. Knowledge is used to elaborate concepts in C space, and concepts are used to expand knowledge in K space. Design process ends when *undecidable* proposition (concept) become *decidable* in K space. Moreover, using a color code (Table 2) can describe the various stages of the design process.

Table 2. Grayscale code for C-K framework [Agogué et al. 2013]

	Color code	Industrial implications	Theoretical foundations
C space	**Known concept**	The concept refers to a set of known technical solutions, whose performance is also known	There are many conjunctions
	Unexpected concept	The concept is far from the dominant design	Expansive partition
K space	**Validated knowledge**	Knowledge and validated in-house	Stabilized knowledge base (including dominant design)
	Ongoing knowledge	Knowledge being acquired	K identified, conditions of validity and evaluation to define
	Missing knowledge	Absent or non-actionable knowledge in-house	Identification of need for K (expansion of the knowledge base)

4. Results and discussion

4.1 "Expandable rationality" to identify the "unexpected" problems

The figure below (Figure 3) illustrates the FMEA design process with the C-K framework. As mentioned above, we can model the seven steps of the classic systematic approach.

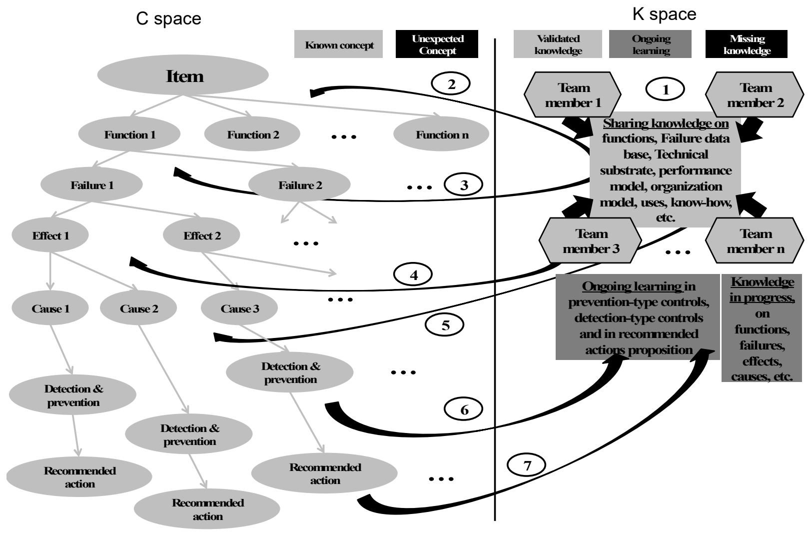

Figure 3. FMEA design process with C-K framework

As a problem solving method, FMEA does not allow to generate new concept which are nevertheless essential to identify "unexpected" problems. Indeed, sharing validated knowledge to constitute a "problem space" as a general starting point of a problem-solving process is not enough. Hence, it seems essential to not restrict the analysis to formal listing of failure modes and to already known unwanted phenomenon. The challenge is to develop learning capabilities to create new knowledge (*missing knowledge* in the figure below) in order to generate "unexpected concept" (Figure 4). Finally, this new activity shall therefore be regarded as a new and crucial objective of the FMEA procedure.

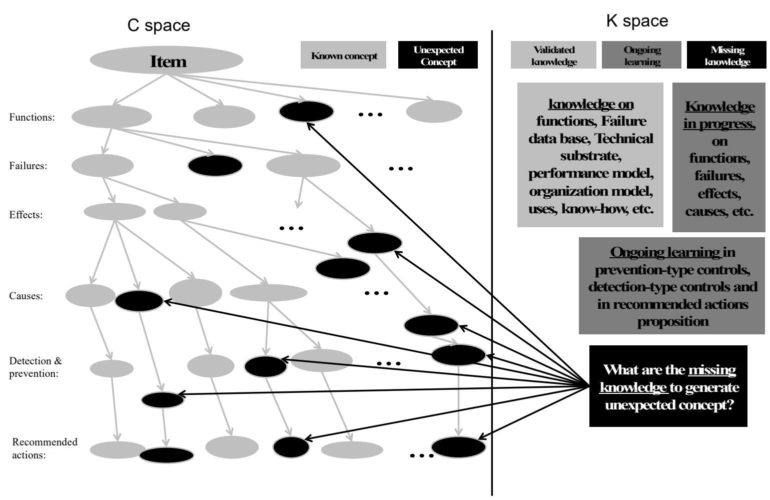

Figure 4. Unexpected concepts identification with C-K framework

4.2 The *"Measurement Space"* as a *"learning devices"* to improve collective learning in multidisciplinary environment

The parallelism principles and decomposition principle are the main key concepts of CE [Yassine and Braha 2003]. The first one is required for short development times and the second one allows decomposing complex system into a number of simpler subsystems that can be controlled independently. However, as we mentioned before, at least 50% problems occur at the interfaces between sub-systems. Most of FMEA designers focus on part or sub-system failures and miss the interfaces. Even if, the FMEA manuals specify that is fundamental to analyze the links between different types of

FMEA (System FMEA, design FMEA and process FMEA); in practice, this relationship is extremely difficult to capture (in theory, the causes in the system FMEA become the failure modes in the design, which in turn generate their own causes, which ultimately become the failure modes in the process FMEA [Stamatis 2003]). The reasons are that the design issues are different and the expertise of FMEA designers (knowledge, technical substrate, performance model, uses, know-how, methods, etc.) are often totally different (this is what we call an multidisciplinary environment) (Figure 5).

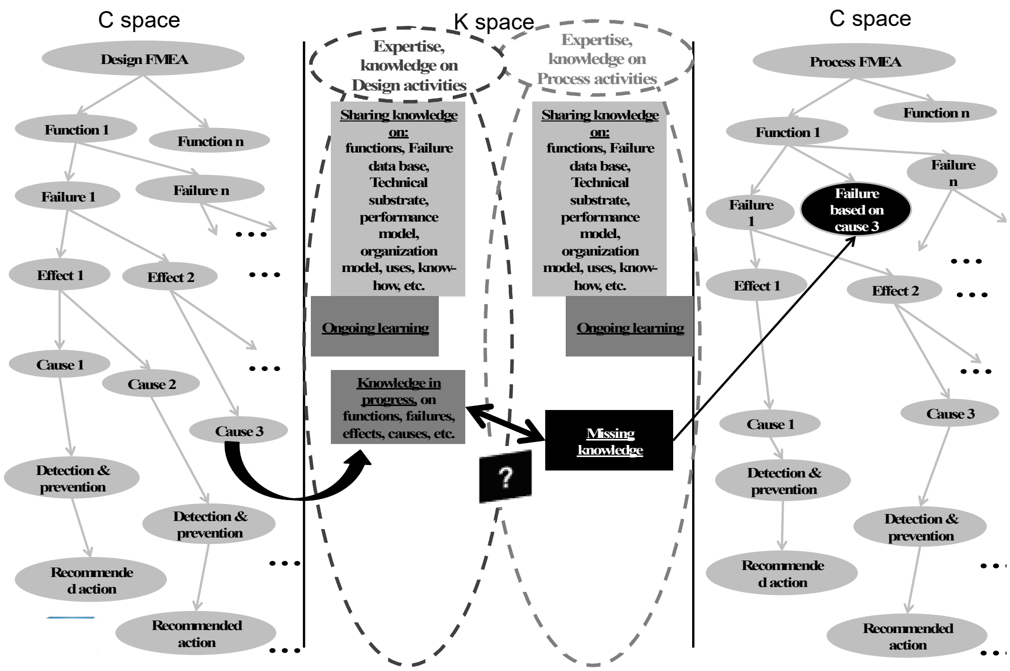

Figure 5. Relationship of system, design, and process FMEA with C-K framework

Moreover, our analysis at STMicroelectronics showed that for a same type of FMEA (process FMEA for example), which the content is at 90% similar (for same process category, the majority of the functions are identical), we observe more than 50% of mismatch. This means that for the same functions from different FMEA, the data into the FMEA (effects, causes, detection, etc.) are totally different and inconsistent. This observation illustrate that the FMEA design process is heavily dependent of the team and of the expertise mobilized by the team of designers. From the concept of "learning devices", proposed by Hatchuel [2001], we suggest to add a sub-process to help designers to structure knowledge and to give them the opportunity to learn in order to improve the their capacity to generate consistent analysis and consistent solutions. Moreover, the objective is taking into account that each system is carriers of different effects, and these effects may involve undesired effects and problems in other modules and sub-systems. In addition, the teams of FMEA designers are composed of different, complex and multiple expertise, and can be understood as a constellation of interconnected practices and expertise. Thus, the main issue is to create learning capabilities at the interface between interdisciplinary teams to propose creative redefinition of the situation. However, each expertise (for example, maintenance, manufacturing, process integration, process development, physics, materials, electronics, photonics, statistics, software, etc.) uses its own unique characteristics, as technical substrate, performance model, organization model, uses, know-how, etc. Thus, we propose the concept of "measurement space" to determine quantifiable and detectable value criteria for each field of expertise (what are the relevant data to fill the function? what are the measurable data? How do I measure? Which instruments? etc.). First, these value criteria allow to determine if the function is filled. Second, the determination of these value criteria allow to initiate learning between interdisciplinary teams to determine what has to be learned or should be learned and allow to propose creative redefinition of the failure mode and effects analysis issues. Finally, this value criteria are collected by category, according to each expertise. Thus, each FMEA designers can engage collective discussions and can learn from each other, even if their competencies and knowledge are different (Figure 6). Table 3 illustrates the new FMEA worksheet used by STMicroelectronics.

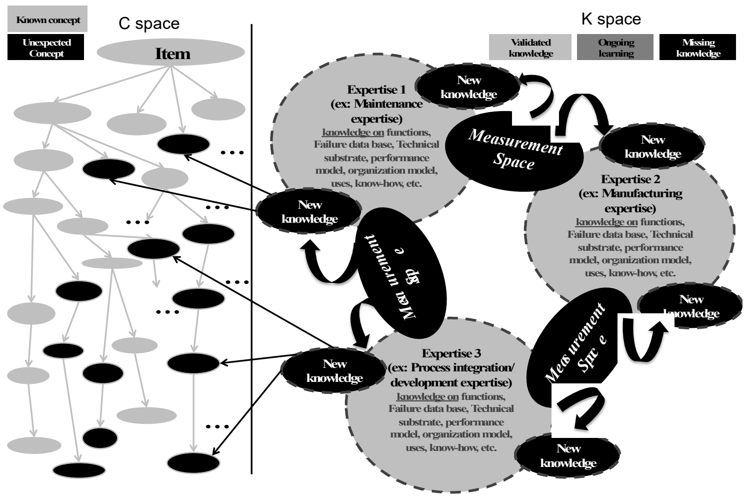

Figure 6. The "Measurement Space" as a "learning devices" with C-K framework

Table 3. STMicroelectronics FMEA worksheet with measurement space and value criteria in three categories

Item/Function What is the Item used for ?	**Measurement space** quantifiable and detectable value criteria for each field of expertise.	**Potential Failure Mode** Negation of (each) value criteria
Item : **TRFX** Function : * Transfer the wafer to chamber * Transfer the wafer (FI/Xfer => process chamber) at well balanced pressure	**Product**	
	Equipement	
	Manufacturing * Good wafer handling setup * Lift pins at good level * Well balanced pressure during wafer transfer	* Bad wafer handling setup
		* Lift pins at wrong level
		* Pressure not well balanced during wafer transfer
		* Wrong setting of Prestep (or header)
Item : **HOP (Heat On Pins)** Function : * Preheat the wafer on lift pins to prevent thermal stress and deformation during landing on edge ring. This preheat must be adjusted to wafer substrate and wafer technology (time, power on zones) * No rotation of the wafer to be maintained * Set and stabilize the pressure at process target value * Set and stabilize gases flows N2,02,N2_Mag	**Product** * No defectivity * Resistivity in control * Good visual beharvior	* Defectivity level too high
		* Resistivity out of control (Mean, range, uniformity)
		* Bad visual beharvior: warp,…
	Equipement * Correct zones power gradient adapted to wafer's sustrate and technology * Sufficient time (>= xx second) to complete chamber thermalisation * Pressure stable at process target value: - Atmos < target value (800 Torr) => enough delta pressure to evacuate gases without impact of weather condition (no pump)	* Bad settings for zones power (not adapted to wafer, sustrate, technology)
		* Insufficient time to thermalize the chamber
		* Pressure not at process value or instable
		* Process pressure setpoint too low
		* Process pressure setpoint too high
		* N2 flow not at process target or unstable
		* O2 flow not at process target or unstable
		* N2_Mag flow not at process target or unstable
		* Rotation in first step
	Manufacturing * Correct wafer hand off * Good prestep (header) setup	* Bad wafer hand-off
		* Wrong setting of Prestep (or header)

4.3 Creating and reordering knowledge to collaborate in the unknown

As mentioned above, the challenge is not only sharing information between multidisciplinary teams, but it's to create new knowledge at the interface of interdisciplinary teams and to give shape to the unknown. For this purpose, social interactions have not to be only considered as design resource but also as a part of the design itself. The social interaction conditions have to be designed to ensure well-trained and balanced FMEA team, the co-ordination of each department in generating and accurate FMEA report and the collaboration between multidisciplinary teams in the design activity of FMEA report. Thus, we propose to extend the initial FMEA methodology, as follows (Figure 7):

1. Per each expertise: creation of a knowledge base on functions, failure modes, effects and causes. Then, determination of value criteria for each expertise.

2. Sharing knowledge: unification of knowledge and collective learning phase through the value criteria identified in the “measurement space”.
3. Selection of the functions and failure modes identification. This phase must enable to generate new functions and new failure modes previously unidentified.
4. Effects-causes-detection investigation: For each *function-failure mode* couple, determination of corresponding effects with severity rankings. Then, identification of causes, with occurrence ranking for each cause. Finally, estimation of prevention-type controls and detection-type controls.

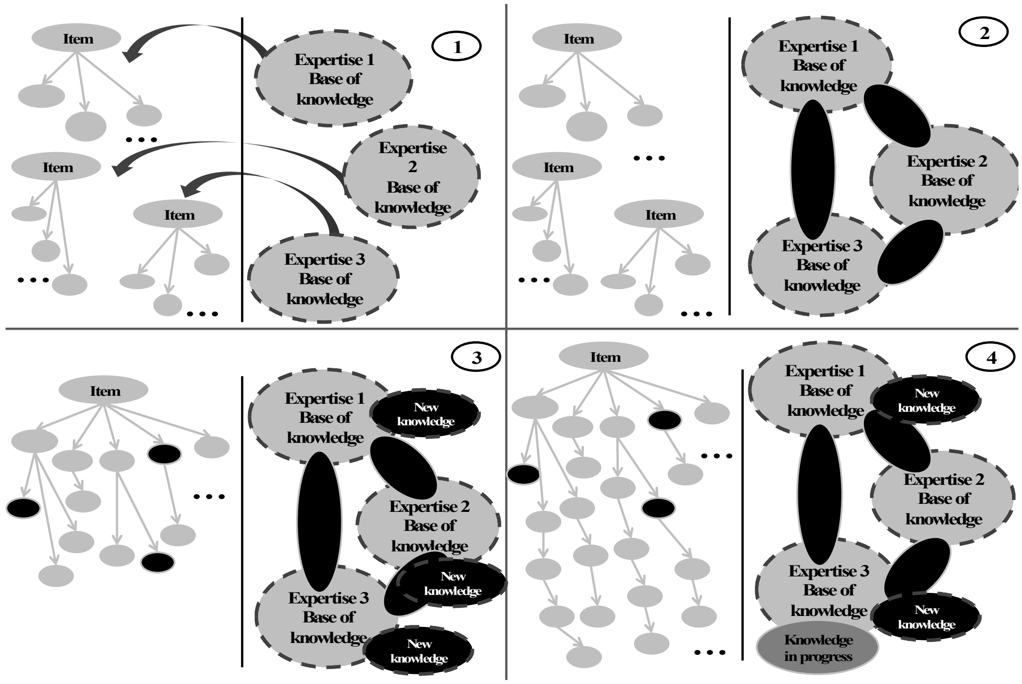

Figure 7. FMEA Methodology with C-K design theory

5. Conclusion

This paper analyses the FMEA method and identifies the main limits and difficulties of the traditional way of performing FMEA. Based on recent researches and on in-depth analysis at STMicroelectronics, we highlight three main weaknesses: the unexpected problems identification, the management of collective learning and the management of social interactions. This research was carried out to explain FMEA difficulties and to provide valuable findings to enhance the traditional FMEA method. For this purpose, we mobilize an original theoretical framework in order to demonstrate that the weaknesses of FMEA are directly linked to the legacy of the problem-solving paradigm. Then, from the work of Hatchuel [2001], and its concept of “expandable rationality” we propose to revisit the theoretical framework of the FMEA. Our main contributions are: to use design theory as a “reverse engineering” methodology to study existing process; to use C-K design theory as a framework to improve FMEA method; to introduce the concept of “measurement space” in the methodology to transform FMEA into a boundary object allowing new collective learning, better social cohesion and strong coordination between FMEA designers. These contributions allow extending the FMEA from a problem-solving method to a design-oriented process. Today, we observe real improvements at STMicroelectronics (see [Said et al. 2016] to have a complete overview of the deployment strategy at STMicroelectronics). Even if, we don’t have yet the necessary hindsight to properly assess the effectiveness of the proposed new method, our preliminary results are more than encouraging. Indeed, on STMicroelectronics specific processes we have already shown more than 50% gain in FMEA accuracy allowing significant gains on Overall Equipment Efficiency (OEE gain >15%) and lower maintenance costs (the maintenance cost for power generators equipment's decreased by 50% due to better reliability). Of course, further researches should be done to secure validity of the proposed method, in semiconductor industries and also in other industrial contexts.

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