

Integration of economic criticality in the context of FMEA analysis

دمج الأهمية الاقتصادية في سياق تحليل FMEA

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Abstract

The Failure Mode and Effects Analysis (FMEA) method serves as a prevalent tool for assessing risks and potential failures within various operational activities. Traditionally, risk prioritization hinges on three primary factors: severity (S), occurrence (O), and detection (D), largely disregarding the economic dimension. However, the reality is that risks carry differing economic implications. Recognizing the disparity in economic impact among risks, we advocate for the inclusion of an economic aspect as a fourth parameter in the risk prioritization framework. By incorporating this economic facet alongside the conventional three factors, our modified approach augments the risk priority index computation. This integration serves a vital purpose: to furnish decision-makers with a comprehensive economic perspective on risk significance. By incorporating economic considerations into the prioritization process, we aim to empower decision-makers in industrial enterprises with a more informed basis for effective decision-making. The implementation of our modified FMEA method promises to facilitate the hierarchical classification of risks within industrial enterprises. Through this adapted approach, we aspire to enhance the accuracy and depth of risk assessment, thereby aiding in strategic decision-making processes for improved operational outcomes.

Keywords: Risk management, FMEA, Economic impact, Risk identification, Risk prioritization

ملخص :

تعمل طريقة تحليل نمط الفشل والآثار (FMEA) كأداة سائدة لتقييم المخاطر والفشل المحتمل في مختلف الأنشطة التشغيلية. تقليدياً، تعتمد أولوية المخاطر على ثلاثة عوامل أساسية: الشدة (S)، والحدوث (O)، والاكتشاف (D)، مع تجاهل البعد الاقتصادي إلى حد كبير. ومع ذلك، فإن الواقع هو أن المخاطر تحمل آثاراً اقتصادية مختلفة. وإدراكاً للتفاوت في التأثير الاقتصادي بين المخاطر، فإننا ندعو إلى إدراج جانب اقتصادي كمعلمة رابعة في إطار تحديد أولويات المخاطر. من خلال دمج هذا الجانب الاقتصادي جنباً إلى جنب مع العوامل الثلاثة التقليدية، يعمل نهجنا المعدل على تعزيز حساب مؤشر أولوية المخاطر. يخدم هذا التكامل غرضاً حيويًا: تزويد صناع القرار بمنظور اقتصادي شامل حول أهمية المخاطر. من خلال دمج الاعتبارات الاقتصادية في عملية تحديد الأولويات، نهدف إلى تمكين صناع القرار في المؤسسات الصناعية من أساس أكثر استنارة لاتخاذ القرارات الفعالة. يعد تنفيذ طريقة FMEA المعدلة لدينا بتسهيل التصنيف الهرمي للمخاطر داخل المؤسسات الصناعية. ومن خلال هذا النهج المتكيف، نطمح إلى تعزيز دقة وعمق تقييم المخاطر، وبالتالي المساعدة في عمليات اتخاذ القرار الاستراتيجي لتحسين النتائج التشغيلية.

الكلمات المفتاحية : إدارة المخاطر، تحليل FMEA، التأثير الاقتصادي، تحديد المخاطر، تحديد أولويات المخاطر.

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I. Introduction

The gravity of overlooking the meticulous consideration of risks in the realm of management decisions cannot be overstated. It reverberates across an organization, impacting its financial stability, operational integrity, and reputational standing. Consequently, there exists an imperative need to institute robust risk management processes that permeate the core of decision-making. Over time, risk management has evolved from a rudimentary managerial activity into a sophisticated discipline, because the intricate of modern companies. This evolution has engendered a plethora of risk management methodologies, each tailored to address the multifaceted challenges posed by today's dynamic business environment (Ennouri, 2023). Among the arsenal of risk management methods at one's disposal, the FMEA method has risen to prominence. Its efficacy in systematically identifying and mitigating potential failure points has rendered it indispensable ([1], [2], [3], [4], [5], [6], [7], [8]). Indeed, the FMEA methodology stands as a cornerstone in scientific research, widely employed for risk assessment across diverse fields; we can found more than 535000 research concerning Failure Mode and Effect Analysis in sciencedirect database². Despite its prevalence, there exists an ongoing drive to enhance and refine this method for example use the fuzzy theory ([6], Ribas et al 2023) Balaraju et al 2019) or even adding a fourth quantity [3]. A notable observation lies in the conspicuous lack of consideration given to the economic impact when prioritizing risks through this approach. This absence overlooks a crucial dimension, as risks inherently vary in their economic ramifications. As such, we attempt to address this limitation, aiming to augment the FMEA framework by integrating the economic aspect into the risk prioritization process. Recognizing this, our initiative delves into a comprehensive restructuring of risk prioritization using the FMEA methodology, imbued with an astute integration of economic dimensions. This approach aims to transcend conventional risk hierarchies by amalgamating financial implications within risk evaluations, thus elevating the precision of risk prioritization. Applied within an industrial enterprise, our method delineates a strategic path forward, where risk mitigation strategies are not only aligned with operational exigencies but are also cognizant of their economic repercussions, ensuring a holistic approach to risk management that resonates throughout the organization's ethos.

II. Background and related research

The FMEA methodology has long served as a pivotal tool in various industries, offering a structured approach to identify and mitigate potential risks within operational processes. Its widespread adoption is rooted in its ability to systematically evaluate failure modes, their severities, occurrences, and detection capabilities. We find that this method has been used to assess risks in quite diverse domains, such as: finance (Spasenic et al 2022, Ochmana et al 2015), cybersecurity (Park et al 2023, Hecht and Baum 2019), industry (Aydin et al 2022, Ervural and Ayaz 2023), health and medical (Minguito and Banluta 2023, ELithy et al 2023), Energy and environment (Ceylan et al 2023, Karatop et al 2020). However, we notice a limitation in considering the economic impact of identified risks. Traditional FMEA models predominantly prioritize risks based on severity, occurrence, and detection without factoring in the economic implications. This criterion creates a substantial gap in the holistic assessment of risks, as not all failures carry an equal economic burden. Acknowledging the

² Research realized in science direct web site with « Failure Mode and Effect Analysis» terms on 15/11/2023

significance of the economic dimension in risk prioritization, we try to integrate the economic impact as a crucial parameter within the FMEA framework. This integration aims to elevate the methodology's efficacy by providing decision-makers with a more comprehensive understanding of the financial consequences associated with different failure modes. We focus on devising models that incorporate cost-analysis mechanisms alongside conventional risk assessment factors which allows bridging the gap between conventional risk prioritization and economic feasibility. This step not only enriches the depth of risk assessment but also empowers decision-makers with a more comprehensive basis for informed and economically viable risk management strategies.

III. Methodology

The FMEA method serves as a pivotal tool in prioritizing potential risks by utilizing the Risk Priority Number (RPN), which is derived from the multiplication of three critical factors: Severity (S), Occurrence (O), and Detection (D). This numerical assessment aids decision-makers in discerning whether a risk is negligible or intolerable. However, in practical business scenarios, decision-makers often rely on economic metrics when evaluating these outcomes. Specifically, they base their judgments on the estimated cost of mitigating an intolerable risk in comparison to the potential loss incurred if the risk materializes. Generally, when the projected cost of risk mitigation surpasses the potential loss, decision-makers tend to confront the risk rather than opting for mitigation strategies. This economic perspective significantly influences the ultimate decision-making process within an organization. The traditional FMEA framework might overlook the economic impact of identified risk modes. It doesn't inherently consider the financial consequences associated with each failure, potentially leading to suboptimal resource allocation and decision-making. For this reason, and to address this weakness, we will attempt to enhancement to the traditional FMEA involves integrating an economic criterion as a fourth parameter for risk prioritization. This parameter assesses the potential financial impact of a risk on the organization, considering factors like the cost of downtime, production losses, customer dissatisfaction, legal ramifications, etc. By multiplying the scores of severity, occurrence, detection, and economic impact, a more comprehensive risk prioritization is achieved. This modification allows decision-makers to not only focus on the technical aspects of risk but also consider the financial implications, leading to more informed risk management strategies and resource allocation. By integrating the economic aspect as a fourth parameter, this enhanced FMEA framework enables organizations to make more holistic and strategic decisions in managing risks, considering both technical and financial perspectives. This risk assessment methodology is illustrated in the following figure.

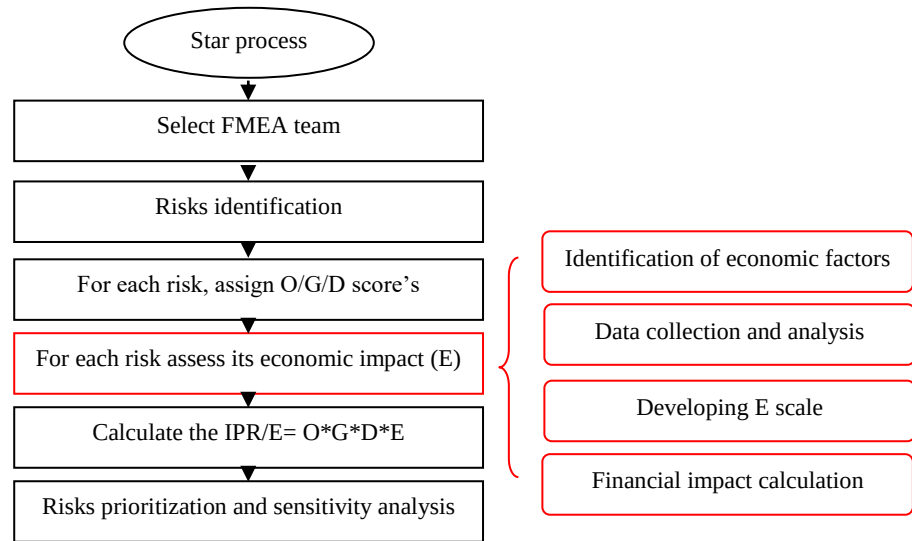


Figure 1: Proposed methodology

Estimating the economic criterion involves a structured approach to quantifying the potential financial impact of identified risks on the organization. This process entails several steps:

- **Identification of relevant economic factors:** Begin by identifying the key economic factors that could be affected by the occurrence of each risk. These may include costs associated with downtime, production losses, and resource allocation for recovery efforts, customer dissatisfaction leading to revenue loss, potential legal liabilities, and any other financial implications specific to the organization or industry.
- **Data collection and analysis:** Gather relevant data to quantify the potential financial impact of each economic factor. This may involve historical data, industry benchmarks, expert opinions, or scenario analysis to assess the range of possible outcomes.
- **Developing a formal scale for evaluating the economic criterion:** involves defining a structured framework that allows for the systematic assessment of the potential financial impact of identified risks.
- **Financial impact calculation:** Once the economic factors and risk probabilities are determined, calculate the potential financial impact of each risk. This can be done by multiplying the estimated cost associated with each economic factor by the probability of occurrence of the risk.
- **Sensitivity analysis:** Conduct sensitivity analysis to understand the impact of variations in assumptions or inputs on the estimated financial impact. This helps in identifying key drivers of financial risk and uncertainties that may affect the accuracy of the estimates.
- **Documentation and reporting:** Document the estimation process, including assumptions made, data sources, calculations, and sensitivity analysis results.

IV. Case study

The Tunisian companies demonstrate a keen awareness of the profound impact that risks can exert on its logistic operations. This cognizance has prompted the initiation of a comprehensive risk management approach that encompasses various stages, each designed to systematically address potential vulnerabilities. The risk management process is composed with 4 steps : Risk identification, Risk assessment, Risk management and Risk monitoring [9], [10]. Within the ambit of this study, our primary focus centers on the initial phases of this risk management framework, specifically the stages dedicated to the identification and prioritization of risks. Our research methodology is characterized by a meticulous and structured approach. It involves the collection of relevant data through comprehensive literature review and on-site data gathering within the Tunisian company. Subsequently, we employ recognized risk assessment techniques, including Failure Mode and Effect Analysis (FMEA) to identify, evaluate, and prioritize the array of risks inherent in the company's. These stages of risk identification and prioritization are integral to the broader risk management process, as they serve as the cornerstone upon which subsequent risk mitigation strategies are formulated and implemented. Initially, we commenced our study by modeling the entire logistics chain and its constituent entities, which encompass suppliers, the company itself, intermediaries, and customers. We delved into available historical data and conducted a series of interviews and brainstorming sessions involving the director, department heads, as well as various strategic intermediaries with whom Globe International Business (GIB) maintains relations. This concerted effort yielded the creation of a Failure Mode and Effects Analysis (FMEA) table. To pinpoint the principal risks lurking within the logistics chain, we pursued an exhaustive exploration of the company's historical records and those of its key partners, coupled with rigorous interviews and brainstorming sessions. Building upon the findings of this intensive phase, we constructed the FMEA table. Within this table, each subsystem of the GIB chain, treated individually in the first column, may be subjected to potential risks as delineated in the second column. Each identified risk carries the potential to trigger effects that could imperil GIB's operations, signifying the attainment of its objectives, as specified in the third column. These effects, in turn, have their possible causes as elucidated in the fourth column, which may or may not be easily detectable, as indicated in the fifth column. Following this stage, we embarked on an in-depth examination of risk severity, effects, and consequences. This examination was conducted in adherence to the evaluation scales chosen by GIB's leadership from a selection of scales provided ([11], [12], [13]). These scales draw inspiration from the scholarly literature on Supply Chain Risk Management (SCRM). Specifically, the management allocated a score for risk severity (G) based on its effects, another for its historical occurrence (O), and yet another for its detectability based on its causes (D). This comprehensive assessment resulted in Risk Priority Indices (RPN), representing the multiplicative outcome of $G \cdot O \cdot D$. These RPN values assist us in categorizing and prioritizing the identified risks. In the following Table 3, we present the outcomes of implementing the FMEA method within the GIB chain. A comprehensive breakdown of the scales used to assign scores for D, O, and G is provided in Table 1. After applying the classic Failure Modes and Effects Analysis (FMEA) method, we proceeded to assess the economic criterion associated with each identified risk (Table 4). Building upon an internally developed scale tailored to gauge this criterion Table 2, we assigned a relative score

to each risk. Subsequently, we computed the revised criticality of each risk by integrating this economic dimension into our analysis. This comprehensive approach enabled us to not only prioritize risks based on their technical implications but also to account for their potential financial impact, thereby enhancing our decision-making process and risk management strategy.

Tableau 1: Scales of D,O and S

Occurrence (O)	1	2	3	4	5	6	7	8	9	10
	Nearly impossible					Risk almost inevitable				
Servity (G)	1	2	3	4	5	6	7	8	9	10
	No effect					Hazardous effect				
Detectability (D)	1	2	3	4	5	6	7	8	9	10
	Almost certain					Absolute uncertainty				

We have chosen the ratio of potential loss to social capital as a key indicator of risk severity. This decision stems from its ability to provide a comprehensive assessment of the potential impact of risks on the financial health and stability of the companies. By calculating this ratio, we aim to gauge the magnitude of potential losses relative to the available social capital, thereby offering insights into the company's resilience to adverse events. This indicator encapsulates the essence of risk management by highlighting the proportionality between potential loss exposure and the resources at the company's disposal to mitigate such risks. Additionally, this ratio allows for a standardized comparison across risks, facilitating a meaningful analysis of risk management practices and vulnerabilities. This creates a graded scale from 1 to 10 to assess the level of risk based on the ratio (potential loss / social capital), where higher scores indicate higher levels of risk.

Intervals:

Less than 0.1:1

0.1 - 0.14: 2

0.15 - 0.19: 3

0.2 - 0.24: 4

0.25-0.29: 5

0.30-0.34: 6

0.35-0.39: 7

0.40-0.44: 8.

0.45 - 0.49: 9

0.5 and above: 10

Table 2: Classical FMEA application

Entity	Risks	Possible Effects	Possible Causes	Detection Measures	G	O	D	RPN	Rank
Suppliers	Decrease in Business Relations	Stockout, contract termination, production halt	Innovation, competition	Quantity delivered, trade fairs, benchmarking, collaboration	5	3	4	60	6
	Loss of Competitiveness	Quantity shortage, quality deterioration, price increase	Innovation, competition	Technological watch	6	3	4	72	3
	Quantity, quality, and delivery issues	Stockout, production problems	Human error, transportation issues	Quality control, traceability system	4	4	5	80	2
	Bankruptcy of specific material supplier	Contract cancellation, stockout, production halt	Economic conditions, financial loss	Supplier monitoring	9	2	3	54	7
	Bankruptcy of ordinary material supplier	Stockout, contract cancellation	Financial loss, economic conditions	Supplier monitoring	2	2	3	12	16
GB	Machine breakdown or technical issues	Extra costs, production halt, commitment breach	Human error, poor maintenance	Maintenance reports, employee training	7	4	5	140	1
	Human error	Production halt, commitment breach	Stress, low motivation	Training, complaints reports	6	4	3	72	3
	Non-compliance with the designed model	Financial loss	Human error	Programming control	9	2	1	18	13
Carriers	Human error	Accidents, damage, commitment breach	Stress, workload, misinformation	Specifications, contract clauses	4	3	3	36	11
	Technical problems	Damage, commitment breach	Maintenance, loading conditions	Contract clauses, specifications	3	4	6	72	3
	Non-compliance with deadlines	Stockout, production problems, delay	Human error, misinformation	Traceability system	7	2	3	42	9
Clients	Contract cancellation	Financial loss, financial imbalance	Deadline non-compliance, economic crisis	Economic monitoring	8	2	3	48	8
	Quality complaints	Penalties, brand image deterioration	Poor execution, model non-compliance	After-sales service, staff training	5	3	2	30	12
Extended Environment	Political instability	Financial loss, commitment breach, production halt	Political crisis, strikes	Political monitoring	2	1	8	16	14
	Exchange rate fluctuations	Increased purchase prices, decreased profit margins	Monetary policy, political crisis, central bank decisions	Central bank reports	2	4	2	16	14
	Pollution	Penalties	Materials used, production processes, project execution	Environmental monitoring	2	5	4	40	10

Tableau 3 : New FMEA application

Entity	Risks	Possible Effects	Possible Causes	Detection Measures	G	O	D	E	RPN	Rank
Suppliers	Decrease in Business Relations	Stockout, contract termination, production halt	Innovation, competition	Quantity delivered, trade fairs, benchmarking, collaboration	5	3	4	5	300	4
	Loss of Competitiveness	Quantity shortage, quality deterioration, price increase	Innovation, competition	Technological watch	6	3	4	2	144	6
	Quantity, quality, and delivery issues	Stockout, production problems	Human error, transportation issues	Quality control, traceability system	4	4	5	6	480	2
	Bankruptcy of specific material supplier	Contract cancellation, stockout, production halt	Economic conditions, financial loss	Supplier monitoring	9	2	3	4	216	5
	Bankruptcy of ordinary material supplier	Stockout, contract cancellation	Financial loss, economic conditions	Supplier monitoring	2	2	3	2	24	15
GIB	Machine breakdown or technical issues	Extra costs, production halt, commitment breach	Human error, poor maintenance	Maintenance reports, employee training	7	4	5	7	980	1
	Human error	Production halt, commitment breach	Stress, low motivation	Training, complaints reports	6	4	3	2	144	6
	Non-compliance with the designed model	Financial loss	Human error	Programming control	9	2	1	1	18	16
Carriers	Human error	Accidents, damage, commitment breach	Stress, workload, misinformation	Specifications, contract clauses	4	3	3	1	36	14
	Technical problems	Damage, commitment breach	Maintenance, loading conditions	Contract clauses, specifications	3	4	6	2	144	6
	Non-compliance with deadlines	Stockout, production problems, delay	Human error, misinformation	Traceability system	7	2	3	2	84	11
Clients	Contract cancellation	Financial loss, financial imbalance	Deadline non-compliance, economic crisis	Economic monitoring	8	2	3	8	384	3
	Quality complaints	Penalties, brand image deterioration	Poor execution, model non-compliance	After-sales service, staff training	5	3	2	4	120	10
Extended Environment	Political instability	Financial loss, commitment breach, production halt	Political crisis, strikes	Political monitoring	2	1	8	8	128	9
	Exchange rate fluctuations	Increased purchase prices, decreased profit margins	Monetary policy, political crisis, central bank decisions	Central bank reports	2	4	2	3	48	12
	Pollution	Penalties	Materials used, production processes, project execution	Environmental monitoring	2	5	4	1	40	13

V. Discussion

In comparing the outcomes of the classic Failure Modes and Effects Analysis (FMEA) and the enhanced version integrating economic criteria, several notable distinctions emerge. The classic FMEA primarily focuses on identifying failure modes, assessing their severity, occurrence probability, and detection capability to determine the risk priority number (RPN). This approach is invaluable for prioritizing technical risks based on their potential impact on product quality or safety. However, the addition of economic criteria in the latter approach introduces a more comprehensive perspective. By evaluating the economic implications associated with each identified risk, such as potential cost of failure, downtime, or market impact, organizations can make more informed decisions. This augmented methodology allows for a deeper understanding of the true risk landscape, going beyond technical considerations to encompass financial ramifications. Moreover, integrating economic criteria into the analysis enables organizations to prioritize mitigation efforts more effectively. Risks with significant economic consequences may warrant more immediate attention and resource allocation compared to those with primarily technical implications but lesser financial impact. This targeted approach enhances resource utilization and risk management efficacy. Furthermore, considering economic criteria fosters alignment between technical teams and business stakeholders. It facilitates communication by translating technical risk assessments into financial terms, enabling more meaningful discussions about risk tolerance, investment priorities, and strategic decision-making. In essence, while the classic FMEA remains a fundamental tool for identifying and prioritizing technical risks, integrating economic criteria enhances its utility by providing a more holistic view of risk. By considering both technical and financial dimensions, organizations can better anticipate and mitigate potential challenges, ultimately fostering more resilient and sustainable operations.

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enhances its utility by providing a more holistic view of risk. By considering both technical and financial dimensions, organizations can better anticipate and mitigate potential challenges, ultimately fostering more resilient and sustainable operations.

The risk prioritization phase in the FMEA method can benefit significantly from the incorporation of multi-criteria decision support techniques like the Analytic Hierarchy Process (AHP) or the Delphi method. These methods introduce a structured and comprehensive way to consider various criteria and expert insights, enhancing the precision of risk assessment. Furthermore, to establish a truly robust risk management process, it is imperative to introduce methods that align with the stochastic approach.

VI. Conclusion

The integration of an economic criterion as a fourth dimension in the AMDEC analysis represents a significant advancement in the field of risk management within supply chains. By incorporating economic considerations alongside technical, functional, and operational factors, this expanded framework offers a more comprehensive understanding of risk and its potential impacts on organizational performance. Through our research, we have demonstrated the feasibility and value of this approach, showcasing its ability to enhance decision-making processes by providing stakeholders with a holistic view of risk. Furthermore, the inclusion of economic criteria facilitates the prioritization of risk mitigation efforts based not only on technical severity but also on the potential financial consequences, aligning risk management strategies more closely with organizational objectives and resource allocation. As we move forward, it is essential to continue refining and validating this integrated approach, ensuring its applicability across diverse industries and contexts. By leveraging the synergies between technical, functional, operational, and economic dimensions, we can foster more resilient and adaptive supply chains capable of navigating the complexities of today's global business environment.

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