AHP-FMEA-DA multi-criteria method for NPD project launch analysis

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Abstract: Nowadays, new product development (NPD) process, demands the shortest development cycle-time to introduce new products into global markets, likewise, NPD helps firms to offer better products for their consumers, for this reason, different tools and methods are used to assure product launched on time without failures, failure mode and effect analysis (FMEA) is a useful tool in risk analysis and multicriteria decision making (MCDM). However, NPD requires an accurate risk assessment to assign the resources and optimise them during the process. This document aims to introduce a modified FMEA method used in combination with Analytic Hierarchical Process (AHP) and Dimensional Analysis (DA), offering an accurate risk assessment. The AHP-FMEA-DA method intends to help Engineers and NPD Project Managers handling risks identified, besides, to make better decisions to allocate the resources available wisely. Additionally, this document contains a practical example of an NPD project to validate the proposed method.

Keywords: NPD; new product development; FMEA; failure mode and effect analysis; DA; dimensional analysis; AHP; analytic hierarchy process.

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1 Introduction

New product development (NPD) is an essential activity for the industry nowadays (Fang and Chyu, 2014), and it is required to keep the global economy healthy, most of the companies have important investments in new product research and development area, because it helps to launch products at different markets with the main objective to launch the products in the fastest way as possible (Chen et al., 2015), as well as containingthe customer desired quality. Moreover the companies struggle getting right tools to simplify the NPD process and assure the expected results on the final products, even specialised companies have custom made manuals and procedures to operate and control the product development process (Kahan, 2012).

Failures in the field are other critical constant concerns for new product developers (Zhao et al., 2018). The designers have activities to validate the product and to avoid these possible failures, but these validations take time that can cause delays on the product launch, and even worst for the companies, if the product is launched into the market without the proper validations, the product can fall into a failure in the field causing in some cases, millionaire loses and sometimes loss of reputation for the companies. Global companies are constantly trying to improve their NPD procedures, keeping the experience, reducing the time to learn in their experimental activities and teaching better their developers (Ahmed et al., 2003), the competence between companies also is forcing the companies to implement novel NPD Processes in order to be more efficient and profitable. This effort includes mixing different methodologies like quality functional deployment (QFD) and theory of the resolution of invention-related tasks (TRIZ, by Russian acronym) (Vongvit et al., 2017). Other companies bet to other proven methodologies, like design for manufacturing and assembly (DFMA) which is a combination of design for assembly (DFA) and design for manufacturing (DFM) methodologies (Gupta and Kumar, 2019), later Chia-Chung et al. proposed Multi-Criteria Decision Making (MCDM) to evaluate the NPD performance (Hsiang et al., 2011).

In the literature there are various NPD tools and methodologies, and the global companies are trying to get the most effective process, due to our current rapid global markets. One of the NPD most used process is the stage gate process by copper (Cooper, 2008), and from this, other NPD tools and methodologies was deployed as a variant of it, modifying the stages adding fail safe steps, and trying to reduce the process time, even with the modifications to the NPD process, one of the noted inconvenient with this methodology, is that usually takes too long to launch a product into the field.

According each business strategy, the companies have their own NPD procedures, but a common tool between almost all the companies used during their NPD process, the failure mode and effect analysis (FMEA) (Fahmy et al., 2012), this is a common tool used to identify product risks before, during, and after product NPD process, moreover applying new techniques to this tool is also common to improve the outputs, like FMEA and multi-criteria (Liu et al., 2016), and also combining FMEA with Fuzzy Sets as Pillay and Wang (2003). Later, Dağdeviren et al. (2008) introduces Fuzzy-AHP, a tool to rank the process risks.

FMEA is a systematic tool used to analyse the inputs and outputs contained on each stage of product development. The details about the FMEA method can be find at the Automotive Industry Action Group (AIAG) (AIAG, 2020). FMEA method general explanation starts getting more scientific attention since 1996, when the risk priority number (RPN) appears in this method (Pillay and Wang, 2003), RPN is obtained from the product of three single numeric values ranked by the cross-functional experts in the matter, this numbers are choose according ranking tables form different categories, severity (S), occurrence (O), and detection (D). The RPN is used to identify the relevant factors that affects the portion of the process under analysis. Additionally, different authors are combining FMEA along with different methodologies, to improve or complement a specific analysis in the different industries (Sotoodeh, 2020), as well as some other combination of methods to improve the assessment, (Zhou and Thai, 2016; Garcia et al., 2021; Takahashi et al., 2021). Concerning the Analytic Hierarchical Process (AHP), it was introduced first time by Saaty(Saaty, 1987), he uses the AHP to compare different scales like the continuous and discontinues. In the recent literature, AHP is combined with QFD in product design process (Ginting and Ishak, 2020), as well as AHP mixed with FMEA, (Karatop et al., 2021; Kulcsár et al., 2020).

Dimensional Analysis (DA) was first introduced by Professor Bridgman in the early 1920s (Bridgman, 1922). According Perez-Dominguez et al, DA has advantages to solve problems within multiple criteria applied (Bridgman et al., 2018). Silva et al. (2019) used dimensional analysis to solve multi-criteria problems.

FMEA is used at different industries for risk assessment proposes, moreover, FMEA has some gaps identified, main gaps in the literature are listed next based on (Mzougui et al., 2019; Ghadage et al., 2020).

- RPN value can be the same in two different risks identified, although, each risk should have different priority.
- Analysing the FMEA results, is difficult to agree on what is the most important risk when RPN has same value on different risks identified.
- Difficulty to prioritise identified risks while same RPN is obtained, creating an extra use of resources in some cases.

This document presents an integral model using AHP, FMEA, and DA methodologies. The new method AHP-FMEA-DA is proposed to full fill the gaps in risk ranking at the current FMEA assessment method, presented previously. The AHP-FMEA-DA method is capable to accept quantitative and qualitative inputs, as well as multi-criteria inputs at the assessment, giving an accurate output. A practical example is included to demonstrate the method applied to the NPD process.

This document is organised as follows. Section 2 is showing the basic concepts, subsequently in Section 3 is showed the proposed method AHP-FMEA-DA, afterwards a practical example is in Section 4, Later the Section 5 is related to the results analysis and discussion, and finally Section 5 comes up with the conclusions and recommendations.

2 Basic concepts

This section contains the basic concepts.

2.1 Failure mode and effect analysis – FMEA

The FMEA method, is currently utilised in almost all the different industries, used to identify risks in any process, from design, manufacturing, and administrative processes. A short description of the method is per as follows.

Process to be assessed is identified, then the potential failure modes in the process are identified, as well as their severity (S) and occurrence (O) in the process, and the detection (D) controls, then based in a 1 to 10 scale there are assigned values to the S, O, and D, finally the product of S, O, and D gives the RPN used to rank the potential failure modes identified.

2.2 Analytical hierarchy process – AHP

AHP method is used to assign values depending on the importance of the characteristic under study. In this document Saaty's scale (Saaty, 1987) is used enhancing the assessment while giving more accuracy over the multiple experts decisions. Saaty's scale is shown in Table 1.

Table 1 The fundamental scale by Saaty (1987)

Intensity of importance on an absolute scale	*Definition*
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgements

2.3 Dimensional analysis – DA

Dimensional analysis allow us to use different type of values, qualitative and quantitative in this method, providing as result a normalised final output. Equation (1) by Willis et al. (1993) and later used in Bridgman et al. (2018).

$$\prod_{j=1}^{m}\left(\frac{a_l^i}{S_l^*}\right)^{wj} \tag{1}$$

where a_l^i signifies the value to be analysed. Where $i = 1,2,\ldots,n$, and $l = 1,2,\ldots,m$, then S_l^* represents the value of the ideal alternative, likewise knows as Similitude index.

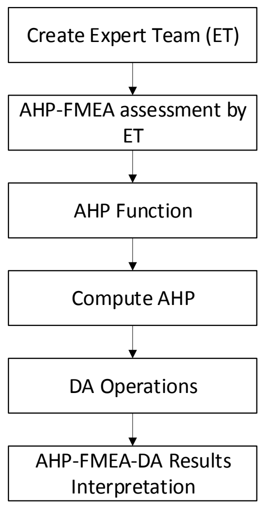
Following wj is the weight assigned, where $\sum wj = 1$.

3 AHP-FMEA-DA method proposed

AHP-FMEA-DA proposed method is an integration of AHP, FMEA, and DA methodologies, where the AHP will help to improve the way to assess the NPD process risks, then the FMEA methodology will be used as a main base for the risk assessment, later the DA methodology will help to normalise the data and giving a clear view of the obtained results. AHP-FMEA-DA method is aiming to cover the identified gaps mentioned at the introduction of this document, in specific at NPD process risk assessment, allowing the NPD leaders to assign the project resources accordingly.

AHP-FMEA-DA method is illustrated in Figure 1, then general steps of AHP-FMEA-DA method are listed as per following.

Figure 1 AHP-FMEA-DA method flow



Step 1. Create expert team (ET). Generally, the NPD Project Manager selects a group of experts in the field to be analysed, these experts can be senior experts inside the same company where the assessment will be executed, as well as external experts, or a combination of these options, the recommended ET size is around 2–5 experts to have multiple inputs during the assessment.

*Step 2.*AHP-FMEA assessment by ET. Identify the failure mode (FM) and controls based on conventional FMEA assessment. Here the ET will consider the FMEA rules and general format, where the identified risks, their possible effects, and the current controls will be captured.

*Step 3.*AHP function. Assign S, O, and D values using the AHP method. It is important that each Expert assigns a separate value on each S, O, and D. This step should be performed emulating the FMEA method, except because of the S, O, and D values, should be considering the AHP scale in Table 1.

Step 4. Compute AHP. Determine the average for S, O, and D, for each independent failure mode registered. For example, if the ET is a group of three experts, the expectation is to get the average of the three S's, then the average of the three O's, and the average of the three D's, these averages on each FM identified.

*Step 5.*DA operations. Make the computations applying DA to obtain the AHP-FMEA-DA ranking. Apply equation (1). Here the previous data is used to integrate DA methodology, the previous matrix obtained in step 4, as well as the weights are assigned to the experts, it is recommended to consider the expertise of the team member to assign the weight according to it, also considering the restriction to sum all the expert weights in the team and obtain the unity.

Step 6. AHP-FMEA-DA results interpretation. Analyse the final AHP-FMEA-DA ranking where the highest values are the high risks. This method is differenced from others because of the precise data resulting, the experts will consider even the decimal values to agree on what should be the main risks to be addressed. This also will help to the experts to identify where to assign resources intelligently to mitigate the risks.

4 Practical example

The practical example is based on an electronic device NPD project at electronic company. As a background, a new electronic device is planned to be launched into the market. A group of experts in the NPD area were selected to perform the AHP-FMEA-DA risk assessment. Following, the steps providing detailed information about the application of the AHP-FMEA-DA method assessing risks at NPD product launch.

Step 1. Select ET. A team of tree experts were selected by the NPD Project Leader, considering that all the experts have experience in NPD projects for electronic devices. The group was integrated by the NPD Program Manager, a group of three members was created, including a R&D Leader, then incorporating a Marketing Leader, and the Program Manager Leader.

Step 2. The ET performs the assessment, following the conventional FMEA method. The assessment at this step will covers the FMs, the potential failure effect, the potential cause of failure, prevention control, and detection control, finding nine main potential risks. This step in the process is excepting assign the values for S, O, and D. Table 2 illustrates the core evaluation by the ET.

Table 2 FMEA assessmentby ET excluding the S, O, and D values assignation

FM #	*Failure mode*	*Potential failure effect*	*Potential cause of failure*	*Prevention control*	*Detection control*
1	Lack of experts	Failure in field	New hires	Training programs	Team assessment
2	Budget increase	Exceed budget	Lack of analysis on VOC	Design reviews	Budget tracking
3	Long lead times	Launch delay	Market behaviour	Inventories	BOM analysis
4	No tech available	Launch delay	Customer requirements (VOC)	New tech. investment	VOC reviews
5	Lack of capabilities	Launch delay	Customer requirements (VOC)	Mfg. investment	VOC reviews
6	Long regulatory validation	Launch delay	Customer requirements (VOC)	Early design frozen	VOC reviews
7	Market segment low	Lack of sales	Lack of marketing predictions	Deep market analysis	Customer surveys
8	Better competitors	Low revenue	Lack of market monitoring	Market surveys	Customer surveys
9	Bad components sources	Low quality	Bad method to choose suppliers	Supplier seminars	Product assessment

*Step 3.*AHP function. Each expert assign values to the S, O, and D, where the AHP scale is used considering Table 1. It is important that the experts designate their own separate value for each S, O, and D. Table 3 illustrates the final assessment at this point in the process.

Table 3 ET assessment, values of S, O, and D based on AHP scale

FM #	*S ET1*	*S ET2*	*S ET3*	*O ET1*	*O ET2*	*O ET3*	*D ET1*	*D ET2*	*D ET3*
1	9	8	9	8	8	8	8	7	5
2	9	7	5	8	7	5	7	5	3
3	3	4	3	4	6	7	7	5	6
4	6	5	4	5	6	5	8	8	9
5	9	2	1	3	4	5	2	7	4
6	2	3	2	1	6	8	2	3	2
7	5	7	8	5	4	5	9	8	7
8	4	5	7	8	7	6	7	4	5
9	8	5	6	7	6	5	4	3	2

Step 4. Obtain AHP. Calculate the average on each row for S, O, and D, the average will consider the tree experts values assigned. The results are presented in Table 4.

Table 4 ET assessment and average for S, O, and D

FM #	*S ET1*	*S ET2*	*S ET3*	*S Avg*	*O ET1*	*O ET2*	*O ET3*	*O Avg*	*D ET1*	*D ET2*	*D ET3*	*D Avg*
1	9	8	9	8.7	8	8	8	8.0	8	7	5	6.7
2	9	7	5	7.0	8	7	5	6.7	7	5	3	5.0
3	3	4	3	3.3	4	6	7	5.7	7	5	6	6.0
4	6	5	4	5.0	5	6	5	5.3	8	8	9	8.3
5	9	2	1	4.0	3	4	5	4.0	2	7	4	4.3
6	2	3	2	2.3	1	6	8	5.0	2	3	2	2.3
7	5	7	8	6.7	5	4	5	4.7	9	8	7	8.0
8	4	5	7	5.3	8	7	6	7.0	7	4	5	5.3
9	8	5	6	6.3	7	6	5	6.0	4	3	2	3.0

*Step 5.*DA operations. Complete the computation applying DA, to obtain the AHP-FMEA-DA ranking. Using equation (1), where the average values of S, O, and D are a_l^i values. Following, the same S, O, and D averages are categorised as cost or benefit according to DA methodology, in this example criteria 1 (C1), is the Severity average categorised as a cost, later criteria 2 (C2) is the Occurrence average considered as a cost, then criteria 3 (C3) is the Detection average classified as a benefit. DA criteria in Table 5, is following the serial on the FMEA assessment and it was changed in the table for better tracking reference during the calculations. Table 5 is showing the full dimensional analysis criteria matrix.

Table 5 Dimensional analysis criteria matrix

DA criteria	*Cost C1*	*Cost C2*	*Benefit C3*
A1 = Z1	8.7	8.0	6.7
A2 = Z2	7.0	6.7	5.0
A3 = Z3	3.3	5.7	6.0
A4 = Z4	5.0	5.3	8.3
A5 = Z5	4.0	4.0	4.3
A6 = Z6	2.3	5.0	2.3
A7 = Z7	6.7	4.7	8.0
A8 = Z8	5.3	7.0	5.3
A9 = Z9	6.3	6.0	3.0

As part of the DA method, DA criteria matrix is analysed getting the S_l^* of each criteria (C1, C2, and C3), finding the smallest value from the cost criteria, and the highest value from the benefit criteria. The S_l^* values obtained from the Matrix are $S_l^* = \{2.3, 4.0, 8.3\}$.

Continuing with the DA method, DA Matrix is normalised to allow us to compare the different criteria. Each matrix value is divided by their corresponding S_l^* value. DA Normalised Matrix results are revealed in Table 6.

Table 6 Normalised matrix $R_{ij\ Norm}$

$$R_{ij\ Norm} = \begin{bmatrix} 3.71 & 2.00 & 0.80 \\ 3.00 & 1.67 & 0.60 \\ 1.43 & 1.42 & 0.72 \\ 2.14 & 1.33 & 1.00 \\ 1.71 & 1.00 & 0.52 \\ 1.00 & 1.25 & 0.28 \\ 2.86 & 1.17 & 0.96 \\ 2.29 & 1.75 & 0.64 \\ 2.71 & 1.50 & 0.36 \end{bmatrix}$$

Continuing with DA method, the weights are assigned to each ET, in this practical example the Project Leader, based on the experience of the experts mentioned earlier at Section 1, assigned $\frac{1}{3}$ as a weight to each expert, this follows the rule to keep $\sum wj = 1$.

Later, following equation (1), the weighs are applied to the $R_{ij\ Norm}$, Table 6, finally resulting in the $R_{ij\ Norm} Si$ matrix, Table 7.

Following, Table 8 is showing the AHP-FMEA-DA S, O, and D, including the FM number for reference and to facilitate the use of the data later at the analysis step.

Table 7 Resulting matrix $R_{ij\ Norm}Si$

$$R_{ij\ Norm}Si = \begin{bmatrix} 1.55 & 1.26 & 0.93 \\ 1.44 & 1.19 & 0.84 \\ 1.13 & 1.12 & 0.90 \\ 1.29 & 1.10 & 1.00 \\ 1.20 & 1.00 & 0.80 \\ 1.00 & 1.08 & 0.65 \\ 1.42 & 1.05 & 0.99 \\ 1.32 & 1.21 & 0.86 \\ 1.40 & 1.14 & 0.71 \end{bmatrix}$$

Table 8 AHP-FMEA-DA S, O, and D results

FM #	*S AHP-FMEA-DA*	*O AHP-FMEA-DA*	*D AHP-FMEA-DA*
1	1.55	1.26	0.93
2	1.44	1.19	0.84
3	1.13	1.12	0.90
4	1.29	1.10	1.00
5	1.20	1.00	0.80
6	1.00	1.08	0.65
7	1.42	1.05	0.99
8	1.32	1.21	0.86
9	1.40	1.14	0.71

Step 6. AHP-FMEA-DA results interpretation. Analyse the final AHP-FMEA-DA ranking where the highest values are the high risks. Table 9 displays the AHP-FMEA-DA ranking. After the experts analyse this Table 9, they can suggest where to add resources to mitigate the risk over the selected FMs, also the experts can suggest what is the critical risk where the resources should be allocated to mitigate the possible effects on the NPD project.

Table 9 AHP-FMEA-DA rank scaled

FM #	*AHP-FMEA-DA **rank***	*AHP-FMEA-DA Rank scaled*
1	3.74	1
2	3.47	2
7	3.46	3
4	3.39	4
8	3.38	5
9	3.25	6
3	3.15	7
5	3.00	8
6	2.73	9

5 Results analysis and discussion

Not as part of the method, but with the intention to represent the differences between the conventional FMEA method and the proposed AHP-FMEA-DA method, a conventional FMEA was performed by the same ET. Table 10 depicts the FMEA assessment for control proposes.

Table 10 FMEA ranked by ET using conventional FMEA ranking rules – used as a control for AHP-FMEA-DA validation

FM #	*Failure mode*	*Potential failure effect*	*Potential cause of failure*	*Prevention control*	*Detection control*	*S*	*O*	*D*	*RPN*
1	Lack of experts	Failure in field	New hires	Training programs	Team assessment	8	7	5	280
2	Budget increase	Exceed budget	Lack of analysis on VOC	Design reviews	Budget tracking	7	5	7	245
3	Long lead times	Launch delay	Market behaviour	Inventories	BOM analysis	7	5	3	105
4	No tech available	Launch delay	Customer requirements (VOC)	New tech. investment	VOC reviews	8	8	2	128
5	Lack of capabilities	Launch delay	Customer requirements (VOC)	Mfg. investment	VOC reviews	2	7	6	84
6	Long regulatory validation	Launch delay	Customer requirements (VOC)	Early design frozen	VOC reviews	2	3	7	42
7	Market segment low	Lack of sales	Lack of marketing predictions	Deep market analysis	Customer surveys	9	8	3	216
8	Better competitors	Low revenue	Lack of market monitoring	Market surveys	Customer surveys	7	4	5	140
9	Bad components sources	Low quality	Bad method to choose suppliers	Supplier seminars	Product assessment	4	3	8	96

Table 11 depicts the AHP-FMEA-DA rank scaled and FMEA rank scaled, this last from previous Table 10, where the final values was ranked from 1 to 9 to facilitate the analysis, as well as to organise the data, where minimum the number, higher is the risk.

Although it is visible in Table 11, the ranks are near one to the other, it is noticed that differences are in key elements analysed, like FM number 4, regarding “No technology available”, considered critical for the experts, where the AHP-FMEA-DA rank is 4, and the FMEA rank is 5, meaning the FMEA rank scale can omit some important risks during the analysis. Consistently, can occur the inverse, as the FM number 3, “Long Lead Times”, AHP-FMEA-DA rank is 7, and FMEA rank shows 6, this phenomenon accepts to consider FMs as important risk to consider, while the AHP methodology shows the opposite.

Table11 AHP-FMEA-DA and FMEA ranking comparison

FM#	*AHP-FMEA-DA rank*	*AHP-FMEA-DA rank scaled*	*Conventional FMEA RPN*	*FEMA rank scaled*
1	3.74	1	280	1
2	3.47	2	245	2
3	3.15	7	105	6
4	3.39	4	128	5
5	3.00	8	84	8
6	2.73	9	42	9
7	3.46	3	216	3
8	3.38	5	140	4
9	3.25	6	96	7

It is also observed that FM 2 and 7, ranked 2 and 3 by the AHP-FMEA-DA method, have just a small difference, 0.01 in AHP-FMEA-DA rank and 29 points in FMEA rank, afterward, this accuracy on the AHP-FMEA-DA method, is giving a better direction to the experts at the time to take the decision on what could be the limits to apply resources based on the rank. Stating it in another words, when the experts consider to what risks should add resources to mitigate the risks. Said that last, it is fair to argue that the granularity of the AHP-FMEA-DA rank helps to take better decision to consider risks and to administrate resources.

An identified opportunity that could limit the use of this method, is the time required to perform the assessment, compared with the current method, AHP-FMEA-DA takes too long, adding the complexity, because of the calculations, moreover, is possible to solve this inconvenient using a programmed template or software.

6 Conclusions and recommendations

Currently, the FMEA method has some drawbacks regarding to the accuracy because of the consensus of the group ranking the assessment, in addition, there is a concern while capturing the opinions of the cross functional team. In this manner, we carry out this MCDM problem using AHP-FMEA-DA method.

AHP-FMEA-DA method is covering the identified gaps, giving a unique RPN value on each identified risk, helping to assign priorities to address the risks according to their relevance. Likewise, the proposed method is making easier the analysis in the results while is not common to have repeated AHP-FMEA-DA rank. Because of the AHP-FMEA-DA is helping to take the decision about where the available project resources need to be allocated.

This study confirms that the proposed method AHP-FMEA-DA, is giving a full granularity on the assessment, allowing to optimise the resources to be applied to mitigate the risks identified. Additionally, DA helps to use qualitative and quantitative inputs, allowing to have normalised outputs, providing precision and confidence at the time to take the decision based on risks. Furthermore, a more accurate analysis is obtained, and when the assessment confirms tight ranks, it can help to take the decision on the resource's assignation, to mitigate the specific risk identified.

This study demonstrates the integration of FMEA, AHP, and DA works for NPD projects, but even though, AHP-FMEA-DA method has the potential to be used on any industry and process where more accuracy is required on the risk assessment, like medicine, aerospace, and nanotechnology processes. Future works can be the application of this method at other industries and processes, and the generation of an intelligent template to make easier and faster the application use of AHP-FMEA-DA method.

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