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Abstract	To enhance industrial activities and achieve revenue goals, manufacturing firms have accepted the Outsourcing Process (OP), and, as a result, risk analysis (RA) methods are persistently utilized to guarantee the results. Likewise, the most popular RA tool is the FMEA method. Nonetheless, it has been identified that FMEA contains uncertainty because people are involved in the RA analysis. In this sense, our proposal presents the application of PFDA-FMEA-VSM applied in a real-life case. Furthermore, it allows stakeholders to identify the key risks in a thorough diagram. The results depict that our proposal has the potential to map the vague information due to human inference into the RA process.

Keywords (separated by '-')	FMEA - Pythagorean Fuzzy Dimensional Analysis (PFDA) - VSM - MCDM-Fuzzy risk analysis

Chapter 13
Fuzzy Risk Analysis Assessment Applied to Value Stream Mapping

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1 Introduction

The Outsourcing Process (OP) is nowadays used by the industrial corporations with the intention to simplify their internal manufacturing activities, and to get the expected revenue while a third party manufactures their products [1]. Risk for customers and new products are also important aspects to consider during the OP process [2], likewise, the recent global COVID-19 situation is driving the firms to use OP [3]; in addition, global companies look for OP as a business model [4]. Though OP represents several risks because the intervention of different processes and cross-functional areas are interconnected [6], adding new risks for the firms to manage, making them to look for new Risk Analysis (RA) tools to mitigate the risks and archive the projected goals [7, 8].

Failure Mode and Effect Analysis (FMEA) is a potent to handle the risks in order to perform an extended RA. The FMEA method is also a frequently employed technique throughout the OP [6]. Nevertheless, FMEA attempts to define to the RA since the human ultimate judgment on what the risks are [9–11]. Likewise, diverse studies are screening how to handle the vagueness of the FMEA with Multicriteria methods [12–16]. Moreover, Pythagorean MCDM-Fuzzy risk analysis, [17], is a potential and true strategy for addressing ambiguity during RA. Furthermore, it adds the advantage to allow the stakeholders take better decisions before the OP execution, meanwhile improving where to allocate the budget using just the required resources at the right process step, and risk is identified.

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This document presents a real-life case taken from an industrial company. In this mode, the PFDA-FMEA-VSM method is used to perform a RA before manufacturing OP. Furthermore, a comparison between conventional FMEA and PFDA-FMEA-VSM analyzes the differences.

The rest of this document is organized as follows. Section 2 describes the basic concepts required to apply the PFDA-FMEA-VSM method. Then Sect. 3 contains the real-case scenario, applying the PFDA-FMEA-VSM method in a manufacturing company for an OP. Later, Sect. 4 covers the results and discussion. Finally, Sect. 5 includes the conclusion of this work.

2 Basic Concepts

This section discusses the fundamental principles involved in delivering the PFDA-FMEA-VSM approach.

Definition 1 The SMEt should be created by the project leader considering at least three experts, desirable from different functional areas.

Definition 2 SME weights (SMEw) assignation refers to a value determined for each SME associate, based on their OP know-how. The sum of the SME weights must be equal to 1. It is suggested that the project leader assign the SME weights.

During this exercise, the SMEt is formed by three senior managers from different functional areas; since the three experts have similar experience in OP, the SMEw are divided equally.

The PFDA-FMEA-VSM method is originally suggested for new product development process risk management, then to allow the adjustment of this methodology to a manufacturing OP, it is required to use next analogies.

- Phase 1 represents the period between planning stage to the kickoff meeting
- Phase 2 is the initial segment of the project
- Phase 3 symbolizes the project implementation.

3 PFDA-FMEA-VSM Application

This section shows the steps to complete the PFDA-FMEA-VSM method application for an OP in a manufacturing company. Figure 1 depicts the main steps followed to apply the PFDA-FMEA-VSM methodology.

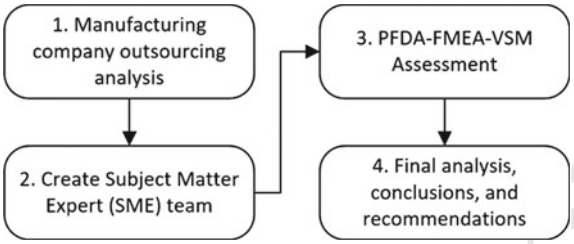

Fig. 1 PFDA-FMEA-VSM application summary diagram

4 Results and Discussion

This section shows the PFDA-FMEA-VSM application result, along with the comparison between the conventional FMEA analysis and the PFDA-FMEA-VSM analysis; this comparison is just for reference and to remark the advantages of the PFDA-FMEA-VSM method. Table 1 shows the list of the risks identified during the SMEt assessment.

Likewise, Fig. 2 illustrates the VSM current state (Table 2). AQ4

Following the VSM, future state is executed. SMEt agreed to select the top 15 risks as potential threads, highlighted in Fig. 3.

Moreover, it allows stakeholders to comprehend the main risks in a thorough diagram, making it easier to make better decisions on where to allocate resources and reduce risks in OP. This document depicts a real-world case situation in a manufacturing company using the PFDA-FMEA-VSM technique.

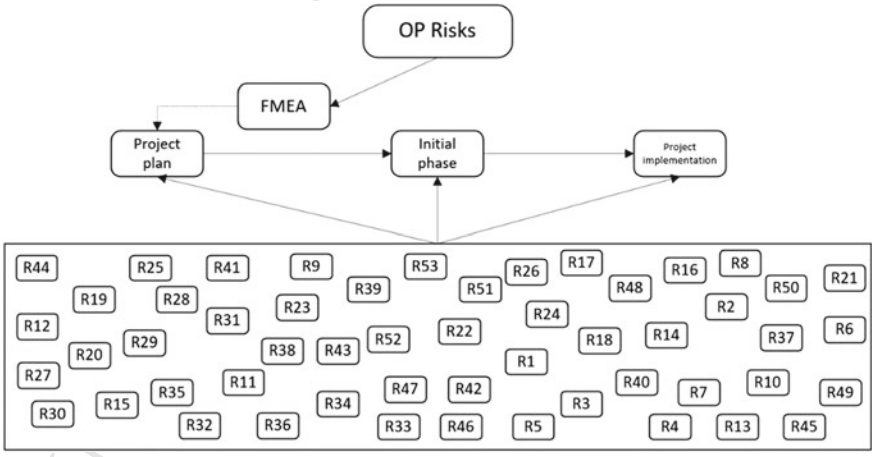

Fig. 2 OP VSM current scenario

Table 1 Potential failure modes (risks) identified by the SMEt

ID	Risk	ID	Risk	ID	Risk
1	Schedule Execution issues	19	Raw material long leadtime	36	Confidential information in risk
2	Continuous improvement versus targets	20	Lack of administrative resources	37	Raw material obsolescence not identified
3	People turnover	21	Slow hiring process	38	Single manufacturing source
4	Product validation	22	People not hired on time	39	Lack of manufacturing space because of budget
5	Supplier capacity issues	23	Lack of right equipment	40	Process capability issues
6	Sales projection inaccurate	24	People turnover during transition	41	Schedule execution issues
7	Product changes not communicated	25	Poor process documentation	42	Poor infrastructure at supplier
8	Poor supplier quality	26	Production forecast not well communicated	43	Poor engineering changes implementation
9	Manufacturing issues not communicated	27	Product quality does not meet prior transition	44	People not hired on time
10	Manufacturing errors, bad execution	28	Poor raw material management	45	Supplier decommit
11	Poor engineering changes implementation	29	External agency approval long leadtime	46	Supplier lack of capacity
12	Project scope changes	30	Poor communication customer-supplier	47	Logistics issues
13	KPI bad results from supplier	31	Missing information during transition	48	Manufacturing certification issues
14	Lack of right resources assigned	32	Poor training on new processes	49	ERP system issues
15	Lack of product history tracking at supplier	33	Poor transition product information	50	Lack of expertise on manufacturing services
16	Product specs not shared	34	Poor knowledge transfer	51	Financial issues (supplier)
17	Slow response to peak of demand	35	Administrative resources not properly assigned	52	Lack of administrative resources
18	Raw material long leadtime			53	Project transition delay

For comparison proposes, a conventional FMEA was performed by the same SMEt; Table 3 depicts the FMEA results. SMEt is considered to mitigate any risk above RPN of 25.

Conventional FMEA assessment shows 31 identified risks above 25 RPN value, while PFDA-FMEA-VSM shows top 15 rankings capturing the main risks to consider as potential real threats for the OP project. Using conventional FMEA method, all risks with RPN above 25 should have a mitigation recommended activity, besides, PFDA-FMEA-VSM top 15 optimize the resources in the mitigation process, just by

Table 2 FMEA versus PFDA-FMEA-VSM ranking comparison

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
1	Schedule Execution issues	5	5	3	75	17	19	Raw material long leadtime	5	5	1	25	49	36	Confidential information in risk	5	3	1	15	1
2	Continuous improvement versus targets	4	2	4	32	13	20	Lack of administrative resources	5	5	1	25	3	37	Raw material obsolescence not identified	1	3	3	9	33
3	People turnover	5	3	5	75	37	21	Slow hiring process	5	5	1	25	3	38	Single manufacturing source	3	3	1	9	41
4	Product validation	5	5	3	75	35	22	People not hired on time	1	2	3	6	16	39	Lack of manufacturing space because of budget	1	3	3	9	18
5	Supplier capacity issues	5	5	3	75	25	23	Lack of right equipment	1	2	3	6	6	40	Process capability issues	4	2	4	32	45
6	Sales projection inaccurate	5	5	3	75	40	24	People turnover during transition	1	2	3	6	31	41	Schedule execution issues	4	2	4	32	42
7	Product changes not communicated	5	3	3	45	42	25	Poor process documentation	5	3	1	15	7	42	Poor infrastructure at supplier	5	1	1	5	22
8	Poor supplier quality	5	3	3	45	48	26	Production forecast not well communicated	5	2	3	30	27	43	Poor engineering changes implementation	3	1	1	3	34

(continued)

Table 2 (continued)

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
9	Manufacturing issues not communicated	3	2	3	18	25	27	Product quality not meet prior transition	1	5	3	15	8	44	People not hired on time	1	3	1	3	32
10	Manufacturing errors, bad execution	3	2	3	18	8	28	Poor raw material management	3	1	5	15	36	45	Supplier decommit	5	3	2	30	51
11	Poor engineering changes implementation	3	3	3	27	18	29	External agency approval long leadtime	1	1	1	1	12	46	Supplier lack of capacity	5	3	2	30	21
12	Project scope changes	3	3	3	27	46	30	Poor communication customer-supplier	5	1	3	15	1	47	Logistics issues	5	3	2	30	28
13	KPI bad results from supplier	5	5	1	25	47	31	Missing information during transition	5	3	1	15	11	48	Manufacturing certification issues	5	3	2	30	20
14	Lack of right resources assigned	5	5	2	50	5	32	Poor training on new processes	5	3	1	15	38	49	ERP system issues	5	3	2	30	39
15	Lack of product history tracking at supplier	5	5	1	25	10	33	Poor transition product information	3	5	1	15	30	50	Lack of expertise on manufacturing services	5	3	2	30	14

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Table 2 (continued)

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
16	Product specs not shared	5	5	1	25	24	34	Poor knowledge transfer	5	3	1	15	15	51	Financial issues (supplier)	5	3	2	30	29
17	Slow response to peak of demand	5	5	1	25	52	35	Administrative resources not properly assigned	5	3	1	15	23	52	Lack of administrative resources	5	3	2	30	44
18	Raw material long leadtime	5	5	1	25	50								53	Project transition delay	5	3	2	30	53

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Table 3 Conventional FMEA assessment by SME

ID	Risk	S	O	D	RPN	ID	Risk	S	O	D	RPN	Risk	S	O	D	RPN	Risk
1	Schedule Execution issues	5	5	3	75	19	Raw material long leadtime	5	5	1	25	36	Confidential information in risk	5	3	1	15
2	Continuous improvement versus targets	4	2	4	32	20	Lack of administrative resources	5	5	1	25	37	Raw material obsolescence not identified	1	3	3	9
3	People turnover	5	3	5	75	21	Slow hiring process	5	5	1	25	38	Single manufacturing source	3	3	1	9
4	Product validation	5	5	3	75	22	People not hired on time	1	2	3	6	39	Lack of manufacturing space because of budget	1	3	3	9
5	Supplier capacity issues	5	5	3	75	23	Lack of right equipment	1	2	3	6	40	Process capability issues	4	2	4	32
6	Sales projection inaccurate	5	5	3	75	24	People turnover during transition	1	2	3	6	41	Schedule execution issues	4	2	4	32
7	Product changes not communi-cated	5	3	3	45	25	Poor process documenta-tion	5	3	1	15	42	Poor infrastructure at supplier	5	1	1	5

(continued)

Table 3 (continued)

ID	Risk	S	O	D	RPN	ID	Risk	S	O	D	RPN	Risk	S	O	D	RPN	Risk
8	Poor supplier quality	5	3	3	45	26	Production forecast not well communicated	5	2	3	30	43	Poor engineering changes implementation	3	1	1	3
9	Manufacturing issues not communicated	3	2	3	18	27	Product quality does not meet prior transition	1	5	3	15	44	People not hired on time	1	3	1	3
10	Manufacturing errors, bad execution	3	2	3	18	28	Poor raw material management	3	1	5	15	45	Supplier decommit	5	3	2	30
11	Poor engineering changes implementation	3	3	3	27	29	External agency approval long leadtime	1	1	1	1	46	Supplier lack of capacity	5	3	2	30
12	Project scope changes	3	3	3	27	30	Poor communication customer-supplier	5	1	3	15	47	Logistics issues	5	3	2	30
13	KPI bad results from supplier	5	5	1	25	31	Missing information during transition	5	3	1	15	48	Manufacturing certification issues	5	3	2	30
14	Lack of right resources assigned	5	5	2	50	32	Poor training on new processes	5	3	1	15	49	ERP system issues	5	3	2	30
15	Lack of product history tracking at supplier	5	5	1	25	33	Poor transition product information	3	5	1	15	50	Lack of expertise on manufacturing services	5	3	2	30

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Table 3 (continued)

ID	Risk	S	O	D	RPN	ID	Risk	S	O	D	RPN	Risk	S	O	D	RPN	Risk
16	Product specs not shared	5	5	1	25	34	Poor knowledge transfer	5	3	1	15	51	Financial issues (supplier)	5	3	2	30
17	Slow response to peak of demand	5	5	1	25	35	Administrative resources not properly assigned	5	3	1	15	52	Lack of administrative resources	5	3	2	30
18	Raw material long leadtime	5	5	1	25							53	Project transition delay	5	3	2	30

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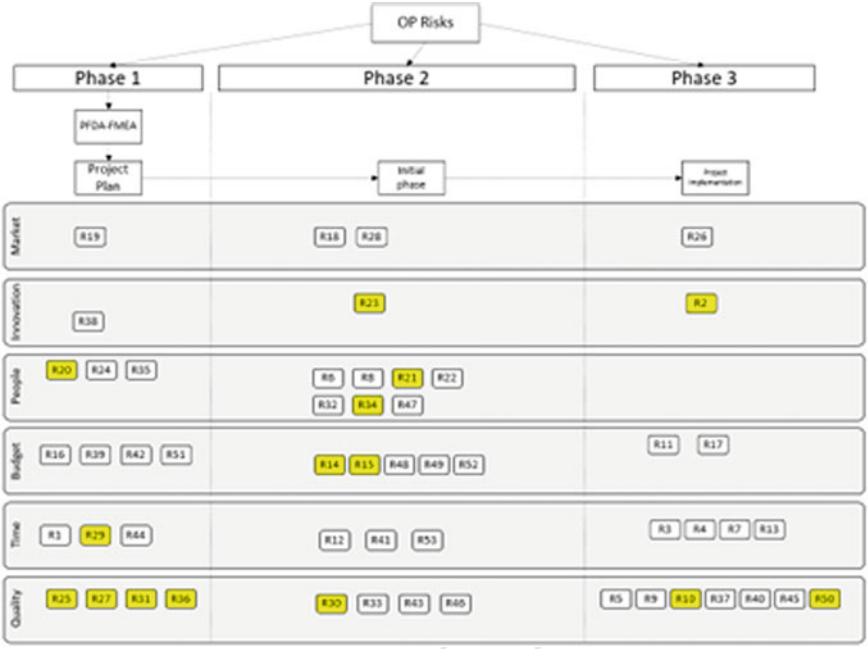

Fig. 3 PFDA-FMEA-VSM future state chart result

applying preventive methods where and when required. Table 4 reveals the comparison between PFDA-FMEA-VSM and FMEA.

5 Conclusions

A recurrent issue identifying risks in OP is the uncertainty added by the human intervention ranking the risks; moreover, by using the PFDA-FMEA-VSM method, this problem is solved and improves OP with significant advantages over the conventional FMEA. Following is a list of the primary benefits of using PFDA-FMEA-VSM for OP.

- Ranking uncertainty manipulated with Pythagorean Fuzzy Sets
- Clear visibility on the risks to be mitigated
- Optimize resources by mitigating just the major risks
- Visual risk identification, where and when is the risk.

The PFDA-FMEA-VSM method was at first used to a new product introduction process; moreover, this application reveals that it is well adapted to OP making clear and easier the OP. Likewise, there is a value added using this method, because of the risk classification by area and the project period.

Table 4 FMEA versus PFDA-FMEA-VSM ranking comparison

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O		RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
1	Schedule Execution issues	5	5	3	75	17	19	Raw material long leadtime	5	5	1	25	49	36	Confidential information in risk	5	3	1	15	1
2	Continuous improvement versus targets	4	2	4	32	13	20	Lack of administrative resources	5	5	1	25	3	37	Raw material obsolescence not identified	1	3	3	9	33
3	People turnover	5	3	5	75	37	21	Slow hiring process	5	5	1	25	3	38	Single manufacturing source	3	3	1	9	41
4	Product validation	5	5	3	75	35	22	People not hired on time	1	2	3	6	16	39	Lack of manufacturing space because of budget	1	3	3	9	18
5	Supplier capacity issues	5	5	3	75	25	23	Lack of right equipment	1	2	3	6	6	40	Process capability issues	4	2	4	32	45
6	Sales projection inaccurate	5	5	3	75	40	24	People turnover during transition	1	2	3	6	31	41	Schedule execution issues	4	2	4	32	42
7	Product changes not communi-cated	5	3	3	45	42	25	Poor process documenta-tion	5	3	1	15	7	42	Poor infrastructure at supplier	5	1	1	5	22

(continued)

Table 4 (continued)

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O		RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
8	Poor supplier quality	5	3	3	45	48	26	Production forecast not well communicated	5	2	3	30	27	43	Poor engineering changes implementation	3	1	1	3	34
9	Manufacturing issues not communicated	3	2	3	18	25	27	Product quality not meet prior transition	1	5	3	15	8	44	People not hired on time	1	3	1	3	32
10	Manufacturing errors, bad execution	3	2	3	18	8	28	Poor raw material management	3	1	5	15	36	45	Supplier decommit	5	3	2	30	51
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12	Project scope changes	3	3	3	27	46	30	Poor communication customer-supplier	5	1	3	15	1	47	Logistics issues	5	3	2	30	28
13	KPI bad results from supplier	5	5	1	25	47	31	Missing information during transition	5	3	1	15	11	48	Manufacturing certification issues	5	3	2	30	20
14	Lack of right resources assigned	5	5	2	50	5	32	Poor training on new processes	5	3	1	15	38	49	ERP system issues	5	3	2	30	39

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Table 4 (continued)

ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O		RPN	PFDA-FMEA-VSM Ranking	ID	Risk	S	O	D	RPN	PFDA-FMEA-VSM Ranking
15	Lack of product history tracking at supplier	5	5	1	25	10	33	Poor transition product information	3	5	1	15	30	50	Lack of expertise on manufacturing services	5	3	2	30	14
16	Product specs not shared	5	5	1	25	24	34	Poor knowledge transfer	5	3	1	15	15	51	Financial issues (supplier)	5	3	2	30	29
17	Slow response to peak of demand	5	5	1	25	52	35	Administrative resources not properly assigned	5	3	1	15	23	52	Lack of administrative resources	5	3	2	30	44
18	Raw material long leadtime	5	5	1	25	50								53	Project transition delay	5	3	2	30	53

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Furthermore, future works are considered by applying and adapting PFDA-FMEA-VSM to other processes, as well as trying to automate the process using a programmed software.

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Chapter 13

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