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Failure Mode and Effect Analysis of Knitting Machines in the Textile Industry

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Abstract: Failure mode and effect analysis (FMEA) is a structured technique widely used to identify risks in a system; due to its great potential, it allows evaluating the impact and planning corrective actions. Analyzing the risks in the textile industry is vital to ensure the quality of the product and the correct operation of the process. This case study aims to identify the risks that arise in the knitting machines of the knitting department through the development of an FMEA. With the support of a multidisciplinary team of experts, observation and discussion sessions were held; based on their knowledge, they identified the failure modes of the machinery subsystem called *the carriage*. The results show that there are critical failures in electronic and mechanical components; It was identified that the effects of failures mainly alter the quality of the product (canvas) and the operation of the machinery. It was also detected that the causes are mostly related to parts wear and the lack of revision and preventive maintenance plans. With the results of this analysis, it was possible to prioritize the failure modes to focus initial efforts, correct or reduce the level of occurrence and establish the necessary mechanisms to implement controls. The present work was applied in a company in the textile sector in the southern state of Guanajuato dedicated to the manufacture of children's clothing.

Keywords: FMEA, Textile industry, Prioritization

1. Introduction

Organizations motivated to offer products and services according to customer expectations use evaluation techniques to identify potential risks (Rezaee *et al.*, 2018). Applying risk assessment approaches is essential to improve quality in companies, especially for sectors that require intensive labor and, therefore, frequently encounter failures (Karasan and Erdogan, 2021). The Failure Mode and Effect Analysis (FMEA) is a technique commonly used in various industries to ensure the safety and reliability of systems, services, and projects (Huang *et al.*, 2020); mainly, it is a prior evaluation technique for avoiding risks during the design and manufacturing phases of the product (Jang and Min, 2019).

The textile sector, given its importance in different areas of consumption, requires approaches that allow the increase in the competitiveness of companies and the improvement in their production processes; in that sense, Mexico is a major textile producer, with an industry based on competitive labor costs and geographic proximity to the United States. U.S. (ITA, 2020). In a pre-pandemic scenario, the textile and clothing industry contributed 3.2% of the GDP of the manufacturing industries and occupied the tenth position among the most crucial manufacturing economic activities in 2019 (INEGI, 2020).

An outstanding activity within this sector is the manufacture of knitted clothing. The manufacturing process comprises knitting, basting, ironing, cutting, sewing, finishing, and packaging (see Figure 1). In the area of knitting with knitting machines and different types of fibers, canvases are woven that will be transformed into garments; therefore, during the operations of this department, the occurrence of faults have a detrimental effect on the quality of the product, in the machine-hours and the process flow. Therefore, implementing simple tools with proven effectiveness is essential to eliminate or mitigate risks, prevent damages, and improve system performance. This paper presents a case study in a textile sector company in the southern state of Guanajuato to prioritize the most common failure modes in the initial area of the production process.

Figure 1. Manufacturing process

2. Methodology

The stages of the methodology, objectives, and procedures used to carry out the implementation of the FMEA in the knitting area are described in Figure 2.

Stages	Objectives	Procedures
1. Identification of the problem	Improve the performance of the system to identify risks and plan corrective or preventive actions in the machinery.	Manufacturing process analysis
2. Theoretical basis	Review the state of the art of the current implementation of the FMEA.	Scientific articles.
	Study the techniques for the correct implementation of the FMEA.	Bibliography
3. Analysis	Establish the scope of the FMEA to identify failure modes and comprehensively understand the system.	Functional Block Diagram, Subsystem Diagram, Brainstorming.
4. Determination	Establish the scope of the FMEA to identify failure modes and comprehensively understand the system.	Sessions and meetings of experts
5. Evaluation	Determine the level of severity, occurrence, and detection of failures during machinery operations.	Criteria table
6. Prioritization	Hierarchize failure modes to focus efforts on those with the most significant impact on knitting area operations.	Número de prioridad de riesgo NPR
7. Results and conclusions	Suggest controls to reduce or eliminate the risk associated with failures and recommend corrective actions.	FMEA report

Figure 2. Methodology

3. Literature Review

Next, part of the consulted literature is presented and with which the importance and broad applicability of the FMEA technique in various sectors can be highlighted. Scheu *et al*. (2019) develop criticality analysis and FMEA to determine the most critical failure modes of next-generation offshore wind turbine systems. Colli (2015) applies an FMEA for a photovoltaic system by identifying the components and subcomponents of the system from the design of the photovoltaic research matrix of the Northeast Solar Energy Research Center of Brookhaven. Mutlu and Altuntas (2019) develop an FMEA for the ring-spinning yarn production process in the textile industry to classify all possible risks concerning occupational health and safety. Beyene *et al*. (2018) applied an FMEA to reduce the high downtime in loom machines. Ahn *et al*. (2017), through an FMEA, analyzed the risks of a hybrid system that has a fuel cell and a gas turbine for marine propulsion. Subriadi and Najwa (2020) propose an FMEA to assess information technology risks applying two sets of action research cycles. Anjalee *et al*. (2021) used an FMEA to identify the dispensing process of a tertiary care hospital. Aichele *et al*. (2020) examine the FMEA technique and show a new approach for an improved representation of the time course of risks. In their study, Saulino *et al*. (2017) use FMEA to transform clinical knowledge into a risk mitigation plan for intrathecal drug administration in pain management. When studying the previous applications, it is possible to conclude that this case study contributes to the literature in the way of studying and analyzing machinery as a system and not as a single component with individual failures, since it is essential to establish the relationship between subsystems to find sources of error effectively. In this paper, only the carriage subsystem is discussed in detail to explain the steps of the method.

4. Results

From the systematic observation of the process, the failure mode and effect analysis were carried out in a company in the textile sector dedicated to the manufacture of children's clothing. The steps and results are described below.

4.1 Analysis

The scope of the FMEA was defined to identify and prioritize failures that put machinery and operations carried out in the principal area of the manufacturing process at risk and, consequently, the quality of the product. Qin and Pedrycz (2020) point out that in general, a team of experts who have good mastery and experience in specific fields is required to examine and quantify failure modes, impacts, reasons, and to propose current countermeasures comprehensively, therefore, to carry out the analysis, a team of experts with knowledge and experience in the knitting department was formed (see Table 1).

Table 1. Multidisciplinary team

Expert	Area	Experience
E_1	Mechanics / Programming	40 years
E_2	Operational	20 years
E_3	Electronics	26 years
E_4	Production	10 years

Based on its experience, the team determined to classify the machinery into eight parts (subsystems), considering that they are the most important and where faults compromise the process flow. Figure 3 shows the location of each subsystem of the knitting machine.

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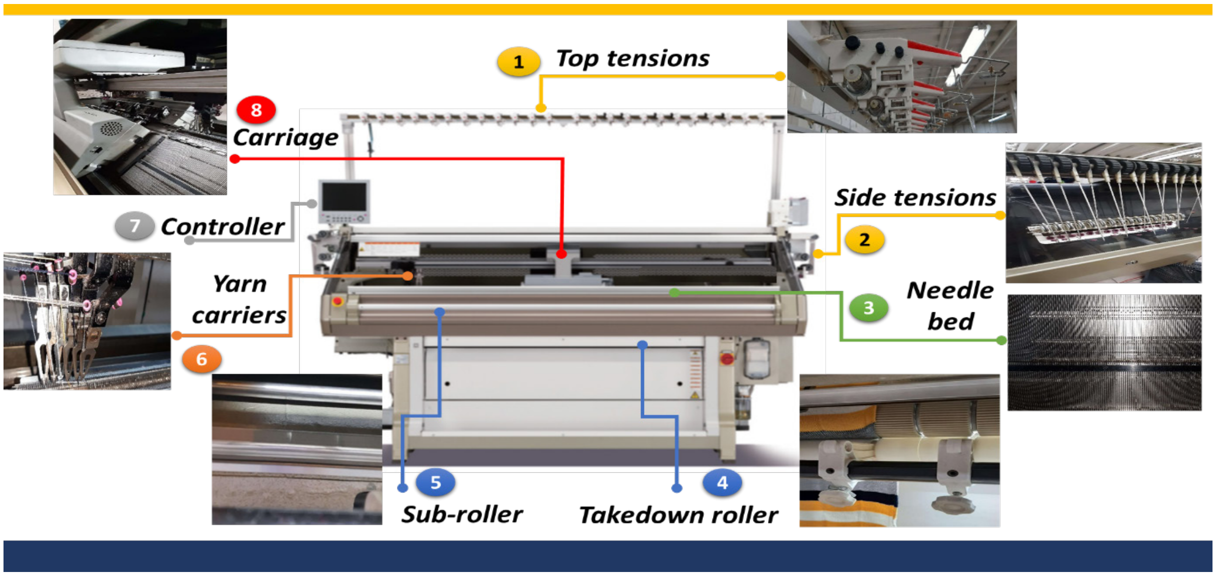


Figure 3. Knitting machine subsystems

A scheme is used to determine the relationship between subsystems, and the failure modes are classified according to two types: electronic and mechanical. The scheme is presented in Figure 4; for example, the carriage (8) is bi-directionally related in electronic form with the controller, as the controller sends the information of the times, speed, and work parameters to the carriage, in the same way, the carriage sends stop and error signals to the controller using sensors. The preceding makes it possible to analyze possible sources of error and their effects specifically.

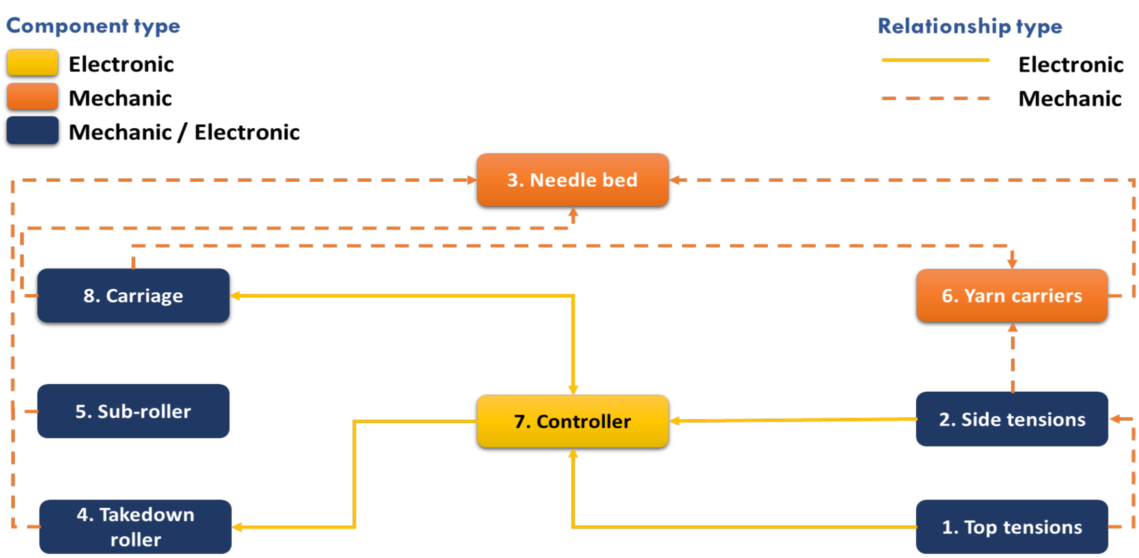


Figure 4. Relationship between subsystems

Derived from the analysis of the subsystems, the experts identified 33 failure modes or ways the system could fail. Figure 5 shows a functional block diagram with the modes of each subsystem.

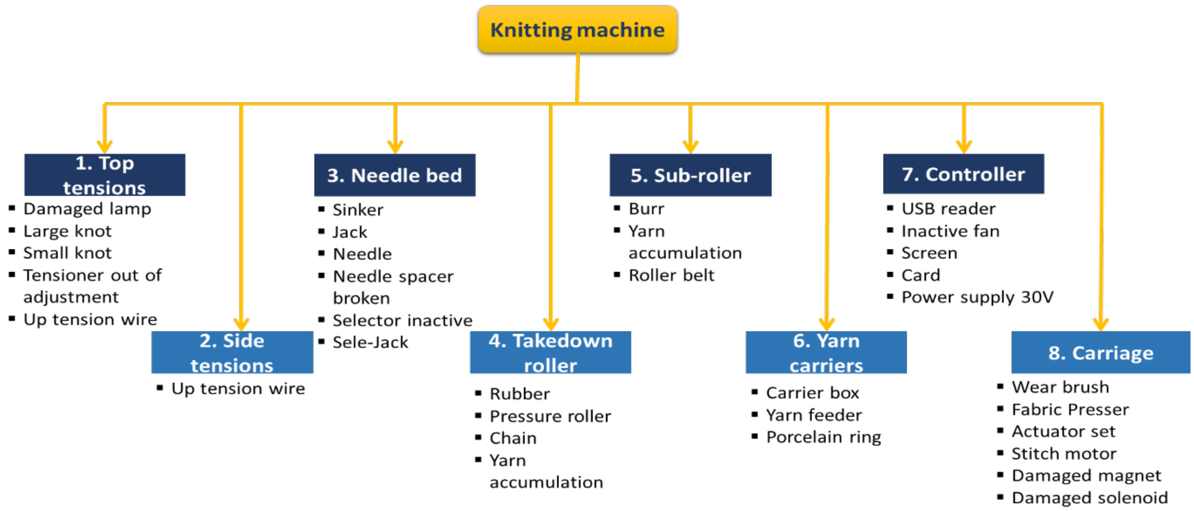


Figure 5. Block diagram

4.2 Determination

Once the multidisciplinary team had a better understanding of the system, work meetings were held, and through the brainstorming tool, the effects that are the impact of each failure were determined. Below, to explain in more detail, only the results of the carriage analysis are presented (8). This subsystem has the electronic cards that receive the information of the work parameters, fabric presser, motors, sensors, and activates the needle system to form the loops of the knitted fabric; in addition, this subsystem controls the cams that adjust the stitch density, the most crucial parameter of tissues. Table 2 describes the effects for the six modes and the classification of the mechanism where the failures occur. Also, Figure 6 shows the components where the carriage subsystem failure modes occur.

Table 2. Classification and effects of failures

Subsystem	ID	Failure mode	Component classification	Effect
8. Carriage	F_{28}	Wear brush	Mechanical	-Does not adjust the tabs of the needles
	F_{29}	Fabric presser	Electronic/ Mechanical	-Loops do not go down properly
	F_{30}	Actuator set	Electronic	-The loops are not formed according to the programmed instructions
	F_{31}	Stitch motor	Electronic/ Mechanical	-Knit fabric with loose or tight loops depending on the system
	F_{32}	Damaged magnet	Mechanical	-The carriage operates out of time
	F_{33}	Damaged solenoid	Electronic	-The yarn carriers do not activate

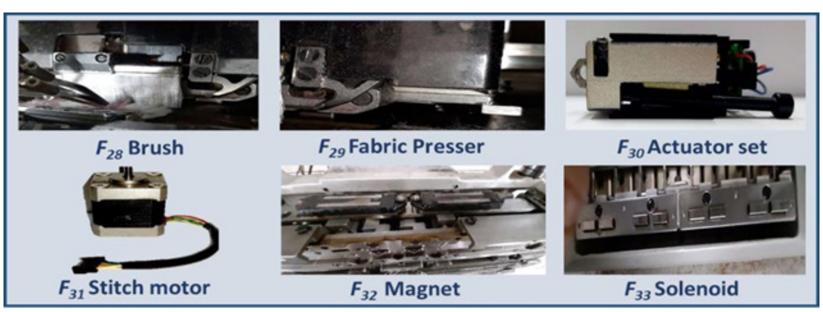


Figure 6. Faulty components

For each failure mode and its effects, secondary effects, causes that cause them, and the current controls for the detection of these failures were established.

Table 3. Causes and controls of subsystem 8

Subsystem	ID	Secondary effect	Causes	Controls
8. Carriage	F_{28}	Loops not forming properly	1. Wear on the brush fiber	Daily inspection
	F_{29}	Inconsistencies in the knit fabric	1. Failure in fabric presser motor	Inspection / season
			2. Fabric presser misaligned	Inspection / manual
			3. Bent fabric presser	Inspection
			4. Broken fabric presser	Inspection
	F_{30}	Inconsistencies in the knit fabric	1. Coil failure	-
			2. Loose cables	Inspection
			3. Broken actuator	-
			4. Damaged connection	Inspection / season
	F_{31}	Inconsistencies in the knit fabric	1. Swivel tension	-
			2. Damaged winding	-
			3. Wear	-
			4. Loose wire	Inspection
			5. Damaged connection	-
	F_{32}	The machine cannot be operated properly	1. Tires with wear	Inspection
	F_{33}	Fabric drops	1. Cable disconnected	Inspection
			2. Worn coil	Inspection / season

4.3 Evaluation

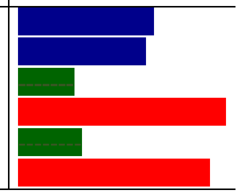
This step is critical in decision-making due to the need to evaluate the factors with which the RPN is determined; at this stage, the experts carried out a qualitative analysis, considering their experience and opinion regarding each of the failure modes of knitting machines. It was decided to use Table 4, proposed by Chang *et al.* (2019), to standardize criteria and rating scales. Detection estimates how well the control detects machinery failures and prevents further damage. The occurrence estimates the frequency of possible risks, and finally, the severity defines the severity of the consequences both in the machinery itself and in the manufacturing process flow; therefore, these are the critical aspects that the team considered.

Table 4. Evaluation criteria

Level	Severity (*S*)	Occurrence (*O*)	Detection (*D*)
1	No	Almost never	Almost certain
2	Very slight	Remote	Very high
3	Slight	Very slight	High
4	Minor	Slight	Moderately high
5	Moderate	Low	Medium
6	Significant	Medium	Low
7	Major	Moderately high	Slight
8	Extreme	High	Very slight
9	Serious	Very high	Remote
10	Hazardous	Almost certain	Almost impossible

As a result of the evaluation carried out by the experts, Table 5 presents the level assigned to the factors for each failure mode. According to the criteria selected to evaluate the factors, the corresponding level was selected on the defined scale [1-10]. The evaluations of the four experts (E_1, E_2, E_3 y E_4) are averaged and a single team value was formed for each of the three factors.

Table 5. Factor evaluation

ID	*E₁*			*E₂*			*E₃*			*E₄*			***Team***			**Metrics**		**Graphic**
	O	**D**	**S**	**O**	**D**	**S**	**O**	**D**	**S**	**O**	**D**	**S**	**O**	**D**	**S**	**RPN**	**Priority**	
$\boldsymbol{F_{28}}$	8	1	7	10	3	9	10	4	5	9	3	5	9.25	2.75	6.50	165.3	3	
$\boldsymbol{F_{29}}$	7	4	8	2	6	5	6	3	8	6	5	6	5.25	4.50	6.75	159.5	4	
$\boldsymbol{F_{30}}$	3	4	5	2	7	9	5	4	8	3	5	6	3.25	5.00	7.00	113.8	6	
$\boldsymbol{F_{31}}$	6	5	8	3	7	9	5	6	9	7	7	8	5.25	6.25	8.50	278.9	1	
$\boldsymbol{F_{32}}$	1	8	8	3	5	6	3	6	9	2	9	6	2.25	7.00	7.25	114.2	5	
$\boldsymbol{F_{33}}$	8	6	10	2	7	5	4	5	10	8	5	9	5.50	5.75	8.50	268.8	2	

4.4 Prioritization

Prioritizing failure modes in a system and planning corrective actions are essential components of risk management in any organization (Ghoushchi *et al*., 2019). The risk priority number (RPN) allows evaluating how dangerous a failure mode can be. The value is obtained with the product of the three factors (see Equation 1) of the evaluation carried out by the team. The results of the RPN indicator are shown in Table 5; the higher the RPN value, the greater the risk for the component; likewise, the last column shows the priority assigned to each failure mode according to its level of failure risk.

$$RPN = Severity\ (S)\ x\ Occurrence\ (O)\ x\ Detection\ (D) \tag{1}$$

According to the expert assessment, the high priority failure modes in this subsystem are: F_{31} Stitch motor y F_{33} damaged coils, at the next risk level are F_{28} brush with wear and F_{29} fabric presser and finally, in the third level of risk are the modes F_{30} selection block and F_{32} magnets. The previous phases demonstrate that the FMEA technique is a support base for experts to find the sources of error and risk in each subsystem and improve the entire system's performance. The previous analysis allows generating a report to strengthen the preventive action plan in the weaving machinery, establish corrective actions for the high priority modes and initiate a mitigation plan, and, where appropriate, eliminate the risk.

5. Conclusions

The application of the FMEA allowed to creation of a work structure with which the experts in knitting machinery could identify and classify the failure modes that affect the operation of the process and the causes that cause them, and the detrimental effects on the garment manufacturing process. The results are consistent with the operations of the machinery since the effects of these failures are machine stoppages, defective canvases, and alteration in the structural parameter of the knitted fabric that is most important for the quality of the product. One of the fundamental aspects of this case study is that the machinery was analyzed as a system and not just as a component with individual failures since it is crucial to establish the relationship between the subsystems to find the sources of error more effectively. It is necessary to focus on economic and human resources that correct or reduce the level of occurrence and risk so that each subsystem operates appropriately. Subsequently, the team must seek the necessary mechanisms to establish the controls that reduce the occurrence, especially since the current controls are only by inspection, so timely detection methods must be incorporated. The seven-step method outlined in this case study encourages textile companies to use this technique to improve their operations and competitiveness.

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