An integrated Approach to Determine the Interrelationship among Faults in Production Process with Extended FMEA Model using DEMATEL and Cloud Model Theory

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THESIS ACCEPTANCE CERTIFICATE

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Dedication

Dedicated to my parents and siblings, whose unwavering love and support have been the canvas on which I painted this remarkable achievement

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ABSTRACT

Although Failure Mode and Effect Analysis (FMEA) is a common method for identifying and mitigating potential problems in various manufacturing processes, its usefulness can be enhanced if it is extended to cope with complex problems. Moreover, it is also widely accepted that the faults plaguing manufacturing processes are intertwined in such a way that they cannot be considered as independent of each other. Instead, they have intermingling impacts and by not paying due heed to such interrelationships, a research may tarnish the authenticity of its outcomes. Therefore, it is pertinent to identify not only the prominence but also the nature of these faults. In order to cater to such needs of industry and to overcome the limitations of traditional methods, the proposed approach integrates the applications of cloud model theory and DEMATEL method. The three contributions of this approach are: First, the cloud model theory is applied to handle the problem of processing random and uncertain judgements. The DEMATEL approach is expanded to take into account the cloud model setting in order to allow for unveiling the crucial faults. Third, a case study is offered which demonstrates the benefits and usefulness of the approach. The combination of Cloud model theory and DEMATEL to expand traditional FMEA and to realize its applicability in production processes underscore the novelty of this research. The approach not only ranks the faults but also categorize them into cause and effect groups. The findings show that among the faults, Turn Drum Jam in Max is the most vulnerable one in terms of effect while Tobacco Rod Break in SE is the most prominent cause. This is how this approach makes managers cognizant of the most vulnerable areas, allowing them to come up with pre-emptive measure. Consequently, the manufacturing process witnesses efficiency and effectiveness owing to significant reduction in the losses it incurs due to interrelated faults.

Keywords: Production process, Manufacturing industry, Faults, DEMATEL, Cloud Model

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LIST OF ABBREVIATIONS

FMEA	Failure Mode and Effect Analysis
RPN	Risk Priority Number
DEMATEL	Decision Making Trial and Evaluation Laboratory
CMT	Cloud Model Theory
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
FMECA	Failure Mode, Effect and Criticality Analysis
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
TODIM	An Acronym in Portuguese for Interactive Multi-Criteria Decision Making
ANP	Analytical Network Process
AHP	Analytical Hierarchy Process
SWARA	Stepwise Weight Assessment Ratio Analysis
DST	Dempster Shafer Theory
MCDM	Multicriteria Decision-Making

CHAPTER 1. INTRODUCTION

The following topics are covered in this chapter: research background and purpose of this study, industry setting, research rationale and objective of the research. It also encompasses research problem and problem statement. Thesis structure has also been provided at the end of this section.

1.1 BACKGROUND

As a result of the exceptional rate at which manufacturing industries are expanding today, quality assurance and output that is free of defects are more important than they have ever been. Because there is a lot of rivalry in the market, acquiring new customers and keeping the ones you have requires a lot of work. In this setting, the production of products that are competitive, of high quality, and free of defects is of the utmost importance. It is important for businesses to find faults in production lines that lower product quality so that they may eliminate those flaws, address the problem at hand, and enhance their production processes. One effective approach to do this is to detect the defects (Ostadi & Masouleh, 2019). Therefore, manufacturing companies are being compelled by rising levels of competitiveness to implement a variety of quality control instruments and approaches (Vinodh & Santhosh, 2012).

Methods of reliability assessment can be broadly arranged into one of three basic categories: qualitative, quantitative, or hybrid. However, in the end, using quantitative methods results in a deeper grasp of the system than using qualitative ways that are based on analytical estimation. This is because quantitative methods require the application of additional resources and skill. On the other hand, hybrid approaches, which either combine qualitative and quantitative research methods or contain other indicators, have a lot of appeal because they combine these two types of research methodologies (Tazi et al., 2017).

Incorporating a criticality analysis into a qualitative FMEA (failure mode and effects analysis) allows for the FMEA to be developed into a quantitative FMECA (failure mode, effects, and criticality analysis), which is a more comprehensive analysis. Failure mode effects analysis (FMEA) and fault tree analysis (FTA) are two methods of failure evaluation that are utilized often. The FMEA is a bottom-up approach that, in comparison to the FTA, which is a top-down method, is less organized and requires for more in-depth information from the user. The FTA method was developed by the Food and Drug Administration (FDA) (Peeters et al., 2018). The FMECA method is frequently utilized in order to enhance product dependability. It achieves this objective by conducting an analysis of the potential failure modes that may exist within a system and its equipment throughout the design and manufacturing processes, identifying any weak links, and recommending solutions (Chen et al., 2012).

The reliability theory underpins the FMEA methodology. The FMEA is an approach to failure risk assessment that takes a bottom-up approach, beginning its analysis with the smallest parts and working its way up to the impact that a failure would have on the entire system. The result of one degree of failure becomes the failure mode for the following higher level of failure for the component. In addition, Failure Mode and Effects Analysis (FMEA) can collaborate with Failure Trend Analysis (FTA) to reveal even more potential failure scenarios and root causes (Sulaman et al., 2019). As a preventative method of finding and fixing problems, FMEA includes the following five stages: first, deciding which process is going to be analyzed; second, forming an interdisciplinary group of experts; third, gathering data about the process that is being investigated; fourth, conducting a risk assessment; and fifth, putting plans into motion and tracking the results of those plans (Chiozza & C, 2009). Depending on the goal of deployment, there are three primary categories of FMEA: concept FMEA (CFMEA), design FMEA (DFMEA), and process FMEA (PFMEA). Two types of FMEA that fall under the umbrella of PFMEA are Manufacturing FMEA and Assembly FMEA (Sharma & Srivastava, 2018).

When conducting an FMEA, the risk priority numbers, also known as RPNs, are determined by multiplying the incidence, severity, and detection scores. The factors of risk are ranked from 1 to 10. The risk of the system goes up with each additional failure mode RPN. After determining the risk priority posed by each of the discovered failure modes based on the RPN values associated with them, corrective actions are done in order to protect the system. Although the RPN technique has various limits when it comes to its applicability, FMEA is still an important pre-emptive activity that should be performed. The following are the most significant restrictions: Failure modes are evaluated using the three risk variables, which may not reflect the actual process or system in use. The three risk factors are difficult to rate accurately; RPN analysis overlooks relative occurrence, severity, and detection weights. In addition to this, the computation formula for RPN is also up for debate. For instance, it is possible to obtain the same values for the RPN even while using different values for the occurrence, severity, and detection of the problem (Liu et al., 2019).

The RPN technique suffers from the following three significant drawbacks: a high rate of duplication in RPN values; an inability to take into account the ordered weights of severity, incidence, and detection; and an inefficiency in calculating the effectiveness of the reciprocal interaction between faults (Chang et al., 2014). In addition, the fuzziness and ambiguity that are present in the assessment process may lead the precise values that are used to express RPNs in a standard FMEA to be erroneous or inadequate (Zhang & Chu, 2011). In a similar vein, the FMEA, in its more traditional version, focuses solely on analyzing how the system responds to the consequences of a single failure. It is unrealistic to analyze numerous failure modes with all of the possible combination permutations and persuasions in a complex system because there are many failure modes that can occur in such a system (Xiao et al., 2011).

For the purpose of conducting a comprehensive analysis of potential failures and risks, MCDM-based FMEA methods have proven to be useful. The industrial sector places a significant amount of emphasis on being able to efficiently identify severe failures connected with components or processes in order to guarantee ongoing development. Failure mode rankings, however, can differ depending on whatever MCDM method is used to create them (Lo et al., 2020). To put it another way, selecting a Multiple Attribute Decision Making (MADM) technique to address a problem that requires rigorous decision-making is a challenging and time-consuming undertaking. In addition, the difficulty gets significantly more difficult for MADM situations when there are a number of MADM algorithms that are suitable (Chakraborty, 2021). The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, on the other hand, stands out as a practical and prospective alternative to existing multi-criteria decision making (MCDM) techniques because of the emphasis it places on the causal linkages between variables. In addition to this, it makes use of previously acquired information to investigate the relationships between different types of failure and investigates the relative significance of each component. A cause-and-effect diagram is used to illustrate the relationships that may be deduced from the evidence (Gao et al., 2021a).

1.2 INDUSTRY SETTING

It has been discovered that the tobacco industry provides a significant amount to the economies of countries all over the world, even though smoking tobacco is associated with several health risks. Additionally, it creates employment opportunities for many individuals, making it a potential source of income for the masses while also adding to the gross national product of governments all over the world. Additionally, the manufacturing line of the tobacco industry is comparable to the production lines of other industries. Therefore, the tobacco sector, just like other industries, may overcome the intermingling defect that it faces in its production line with the assistance of an efficient approach that can provide preventative measures.

1.3 RESEARCH RATIONALE

This study aims to discover the interplay between pre-identified faults that occur in the production process of manufacturing industry, to categorize these faults into their respective groups of cause and effect, and to figure out the level of impact through which they influence each other. The purpose of this research is to discover the interplay between pre-identified faults that occur in the production process of manufacturing industry. The goal of this research is to gain a better understanding of the interplay that exists between previously documented flaws that can occur in the manufacturing business. The research will provide the industry with a set of preventative measures in this manner so that the industry may avoid problems in the manufacturing process and ensure that it is both competent and efficient.

1.4 RESEARCH OBJECTIVES

Following are the research objectives of this study.

- To identify and enlist significant faults in the production line
- To determine the inter-relationship among these identified faults
- To classify these faults into cause and effect and groups

- To determine the level of influence of these faults on each other.
- To come up with a set of preventive measures to circumvent interruption in the manufacturing process.

1.5 RESEARCH PROBLEM

Companies frequently suffer significant losses because they ignore the implications of numerous risk variables, even though manufacturing processes have a high propensity for a variety of errors. These losses include, but are not limited to, losses in manufacturing volume, as well as losses in both time and energy use. These losses are also detrimental to the net productivity of organizations, as well as their reputations and the efforts they make to retain customers. When it comes to defects, companies frequently have a tough time determining both the severity of each issue and the interconnections between each of these faults. Because it has been noticed time and again that these flaws are inextricably linked to one another, this is the reason. In addition to this, they struggle to differentiate between the causes of problems and the consequences of those problems. In other words, it is quite possible that a specific defect may lead to several intertwining effects by activating a variety of other faults and by being the root-cause of additional faults. This is because faults tend to trigger one another. Under these conditions, it is not possible to proceed by only considering the unique characteristics of each of these flaws and ranking them according to the degree of severity they present. However, there is potential to explore the interrelationship among these flaws in order to identify the areas that are most prone to failure. As a result, the purpose of this research is to determine the interaction among these faults in order to assist industries in eliminating these faults by taking preventative measures and reducing their susceptibility to the repercussions that stem from the intricate interrelationship of these faults.

1.5.1 Problem statement

The problem statement of this research study is to seek a comprehensive analysis of faults hindering the performance of the production process and their mutual relationship. A prevalent problem that is important to address is to obtain a deep and profound understanding of actual nature of faults within the process. In other words, the problem that demands attention is to unveil the intricate nexuses of interdependencies that prevail among the faults. It is because it is often found that one fault can trigger or influence another one.

Therefore, this research endeavors to categorize the faults into distinct cause-and-effect groups to construct a structured framework that can elucidates the relations among them. By grouping the faults in this way and determining their ranking subsequently, it would be easy to come up with pragmatic measure to mitigate the severity of a fault.

1.6 THESIS STRUCTURE

The first chapter of the study provides an introduction to the topic of the study by focusing on areas such as the background of the study and its aim, the rationale behind the study and its goals, as well as the research problem. In addition to this, it places an emphasis on the context of the industry and the contribution that the study makes.

A review of the relevant previous work will form the basis of the second chapter. The theoretical framework, the study that has already been conducted on the topic by the researchers, as well as the applicability or relevance of this research to the industry will all be included in the scope of the research's work.

The study methodology as well as the mathematical models will be discussed in the third chapter. The research paradigm, the research setting, and the research design are going to be the primary focuses of this discussion. In addition to that, it will present the rationale for using this study methodology. In addition to that, it will bring to light the constraints that were placed on the research design.

The results and their analysis, as well as interpretations and arguments based on these results, will be covered in detail in the fourth chapter of this dissertation.

The conclusion can be found in the fifth and final chapter. It will provide a concise summary of the inquiry that was conducted during the study process. Additionally, it will describe the theoretical underpinnings as well as the practical contributions that the research has made. In addition, it will give some light on the limitations of the research as well as the future path that other researchers should be heading in.

The last section will center on the references, appendices, and questionnaires that were collected.

CHAPTER 2. LITERATURE REVIEW

2.1 GENERAL

This chapter deals with the evaluation of the existing body of knowledge on the topic of this study. Moreover, it also discusses the research gap that needs abridgment, theoretical framework the study seeking assistance from and the questions that this study is going to address.

2.2 EVALUATION OF THE EXISTING BODY OF KNOWLEDGE ON THE TOPIC

2.2.1 Applications and Evolution of FMEA

The FMEA tool is used in manufacturing processes to detect probable failures in the product, the process, and the system. The use of FMEA helps reduce the risk of failure during the design and production of innovative products (Moreira et al., 2020). FMEA typically consists of the following five stages: preparation, recognition, ranking, risk reduction, and reassessment. Calculating RPN by multiplying Severity, Occurrence, and Detection provides RPN, which is used by FMEA to evaluate the risks associated with failure modes. The probability of FM rises as RPN value increases (Kumar & Parameshwaran, 2020). In conventional RPN, severity, occurrence, and detection are all weighed as equally important contributors. Because risk factor combinations with distinct risks have the same RPN values, this limitation has resulted in practical settings producing outcomes that are unrealistically optimistic. Because of potential knowledge and experience gaps, as well as language barriers, FMEA analysis could be considered subjective. RPN modification tools are just one example of the many risk assessment approaches that can be used to remedy the shortcomings of FMEA (Fabis-Domagala et al., 2021).

It has been suggested that the RPN approach be replaced with one of several alternative risk priority models in order to improve FMEA (Liu et al., 2013). Failure mode severity ordering and variable risk ratings from FMEA teams are examples of challenges related to FMEA. Therefore, in order to address such problems, a robust and adaptable decision-making framework that incorporates a cloud model for fuzziness and a technique known as preference ranking organization method for enrichment evaluation (PROMETHEE) has been developed (Liu et al., 2017). A significant number of aircraft disasters are brought on by malfunctioning parts. The FMEA is a helpful approach for evaluating potential outcomes and generating mitigation plans; nevertheless, crisp RPN values could cause complications. As a result, research on fuzzy group decision-making was conducted to enhance FMEA. The fuzzy FMEA, also known as the FDFMEA, is more reliable than traditional FMEA when it comes to engineering (Yazdi et al., 2017).

Despite these limitations, FMEA is constantly revised to consider any new developments that have occurred in the industry in which it is active. Since its inception, FMEA has undergone a variety of iterations during which it has been improved and modified. The first phase of FMEA creation and its subsequent iterations are the two most important aspects of this methodology to investigate. The following is a list of the most important objectives that will be attained as a direct result of the development and enhancement of FME: finding Solutions to Difficult Problems, enhancing applicability, representing Causes and Effects, and analyzing Risks (Spreafico et al., 2017). Aside from this, the FMECA is regularly integrated with other multi-criteria decision-making (MCDM) approaches in order to raise its utility and application in addressing the many sides of engineering difficulties. This is done in order to improve the FMECA's ability to answer these challenges. This is done in order to make it more helpful and applicable in a variety of contexts (Dabous et al., 2021).

In the health, safety, and environment (HSE) management system, an integrated robust data envelopment analysis (RDEA)-failure mode and effects analysis (FMEA) strategy ranks the hazards. The inputs that are considered for this study include severity, occurrence, and detection. The outputs that are considered include cost and treatment time. Both the attractiveness of the parameter and its uncertainty are taken into consideration. An auto parts maker used the way that was suggested, and the results were compared to those of the DEA model and the RPN numbers. Because of this extension, risk prioritization is rendered more credible and persuasive in comparison to basic FMEA (Yousefi et al., 2018). An additional technique for determining the order of risk priority during product development is provided by MCDM when combined with the grey theory of FMEA. The prioritized failure modes can be maintained using probability-based interval analysis (Lo & Liou, 2018).

Failure modes are typically not differentiated by FMEA. As a result, it is recommended that a fuzzy hybrid FMEA model be used to evaluate improved failure modes. This model would replace RPNs with FWRPNs, which are fuzzy weighted risk priority numbers, and would use extended fuzzy AHP and fuzzy MULTIMOORA to generate weights (Fattahi & Khalilzadeh, 2018). The conventional FMEA method can be improved with an extended FMEA framework. In this method, the Failure Mode and Effects Analysis (FMEA) is used to establish failure modes and to assign values to RPNs. The Fuzzy Best-Worst Method (FBWM), on the other hand, is used to determine factor weights. Z-MOORA provides a ranking of the failures (Ghoushchi et al., 2019). The psychological behavior of FMEA team members, as well as uncertainty and risk interplay, can be modelled with the help of a hybrid FMEA framework that makes use of the TODIM (Portuguese for Interactive and Multi-Criteria Decision Making) and Choquet integral approach. The uncertainty associated with risk assessment is represented by generalized trapezoidal fuzzy numbers (Wang et al., 2019).

Faults in the warehouse can be identified using design FMEA and fuzzy-AHP analysis. Design FMEA focuses on the failure mode that leads to inefficiency in the design, whereas fuzzy-AHP strives to make weighting criteria less subjective (Hassan et al., 2019). The shortcomings in the FMEA's RPN calculation can be solved by using prospect theory. While Fuzzy AHP determines occurrence and detection weights, Fuzzy TODIM arranges failure modes according to RPN scores (Sagnak et al., 2020). An MCDM approach that integrates the Fuzzy Analytical Hierarchy Process (FAHP) with modified Fuzzy Multi-Attribute Ideal Real Comparative Analysis (modified FMAIRCA) is offered to improve FMEA risk estimate. This method offers a framework for dealing with fuzziness and risk ranking. This MCDM method that integrates the Fuzzy Analytical Hierarchy Process (FAHP) with modified Fuzzy Multi-Attribute Ideal Real Comparative Analysis provide more realistic results (Boral, Howard, et al., 2020). In order to assess the flaws in the plastic manufacturing process, a Fuzzy Bayesian Network (FBN) and a Fuzzy Best-Worst Method (FBWM) are utilized. It corrects the computations for the traditional FMEA risk priority number (RPN) (Gul et al., 2020).

The AHP method is used to calculate the relative significance of risk factors, which are then incorporated into the modified FMARCOS (Fuzzy Measurement of Alternatives and Ranking according to Compromise Solution) method, which is used to rank failure modes. This is done to address a drawback of the conventional FMEA approach (Boral et al., 2020). The RPN technique used in traditional FMEA disregards the interdependencies between failure modes in complex systems such as construction projects. In addition to that, it disregards haziness. On the other hand, a hybrid framework that makes use of fuzzy FMEA, fuzzy DEMATEL, and the Analytical Network Process may determine RPN values, locate interrelationships, and prioritize failure modes (Karamoozian & Wu, 2020). With the evidential reasoning (ER) method and interval type-2 fuzzy sets (IT2FSs), it is possible to overcome some of the flaws of the conventional FMEA approach and better handle uncertainty. (Qin et al., 2020).

Coal-to-methanol plants are required to undergo risk analysis because of the uncertainty associated with risk analysis. In the process of evaluation, the FMEA-CM technique helps to reduce a number of different types of uncertainty, including unpredictability and fuzziness (Wang et al., 2021). The risks associated with the landfill in Tehran are evaluated using FMEA and AHP. Pairwise comparison is the method that the AHP employs to rate risks according to the gravity of their consequences (Sadeghi et al., 2021). Methods such as FMEA, Stepwise Weight Assessment Ratio Analysis (SWARA), and Weighted Aggregated Sum Product Assessment (WASPAS) are offered for use in a fuzzy environment in order to identify and assess the risks associated with building projects, as well as to solve the limitations associated with FMEA (Alvand et al., 2021).

To get beyond the limitations of FMEA, an AHP-FMEA analysis is used when failures of floating offshore wind turbines are investigated. Calculating a failure risk index (RPN) requires the use of a suggested normalization algorithm and the AHP methodology. The RPN is based on two data sets, including the relative importance of severity, occurrence, and detection (determined by the proposed normalization algorithm), as well as their weights (established by the AHP methodology) (Li et al., 2021). Fuzzy Rule Base (FRB) and Grey Relations Theory (GRT) are introduced to the FMEA framework in order to incorporate the diverse perspectives of experts and assign each assessment factor a relative weight in the risk assessment. Both of these additions are made in order to ensure that the FMEA framework is comprehensive (Hassan et al., 2022). At PT. XZY, FMEA is utilized for the purpose of identifying and evaluating risks associated with logistical operations (Nurcahyanie & Cahyono, 2023).

2.2.2 Applications of Cloud Model Theory

The use of linguistic descriptors by decision-makers in the process of developing their evaluations of the green performance of alternative suppliers frequently results in ambiguity regarding the conclusions. This is due to the absence of knowledge as well as the hazy nature of the expertise provided by the specialists. Combining cloud model theory with qualitative flexible multiple criteria (QUALIFLEX) results in the production of a structure that may be utilized for an MCDM model. This makes it possible to assess the possibilities of various suppliers (Wang et al., 2017). Liu et al. (2019c) developed a new integrated FMEA model by making use of cloud model theory and the hierarchical TOPSIS technique in order to analyze and rank the various failure possibilities. By utilizing the benefits offered by the cloud model, this strategy can solve the issue of the inherent unpredictability that is present in language evaluations. This is accomplished by utilizing cloud computing.

Li et al. (2019) developed a failure mode and effects analysis that may be used in precarious circumstances. It was developed by combining the merits of cloud model theory in reconciling the unpredictability of specialists' risk appraisals with the adaptability and objectivity of rough set theory, giving rise to the failure mode and effects analysis. This analysis was developed by combining the merits of cloud model theory in reconciling the unpredictability of specialists' risk appraisals with the merits of rough set theory. Qin et al. (2021) utilized a cloud model for the evaluation of the regional energy internet in order to demonstrate the level of fuzziness and inconsistency that was there. In addition, the fuzzy AHP is designed to determine the relative significance of the parameters that are being targeted. Song et al. (2021) suggested using Cloud modelling in conjunction with a nonlinear fuzzy analytic hierarchy process as a means to carry out risk assessments in the manufacturing operations of chemical plants. This was presented as a potential way for doing risk assessments.

The fuzzy DEMATEL-CM cloud model (CM) derivative is necessary in order to carry out risk assessment in process industries. This is because it offers significantly higher levels of system reliability. The fuzzy DEMATEL algorithm, which is used in the computation of evaluation index risks, is used to identify the relevance of assessment indices (Li & Xu, 2021). Gong et al. (2021) utilized cloud model theory in a multi-objective portfolio selection model with shifting risk appetite because it is more successful at managing uncertainty and randomization of knowledge. This was done in order to describe the earnings patterns and liquidity of assets. Xie et al. (2021) devised a quantitative risk evaluation approach by utilizing a Bow-tie (BT) model and cloud model theory in order to conduct an investigation into the potential for fire and explosion accidents to take place in oil depots. This investigation was carried out for the purpose of analyzing the risk.

2.2.3 Applications of DEMATEL

DEMATEL is employed for the purpose of managing the interrelationships that exist between the various criteria as well as describing the causal relationship that exists between the various criteria. Because of this, it is employed in the management of municipal solid waste for the purposes of evaluations that are qualitative and subjective. This is because, when confronted with ambiguity, professionals are unable to define preferences using precise numerical values, which is the root cause of the problem (Tseng & Lin, 2009). In a similar fashion, the use of fuzzy DEMATEL, fuzzy TOPSIS, and fuzzy ANP constitutes a one-of-a-kind evaluation instrument for the environmentally conscientious provider. In this instance, the DEMATEL methodology is applied in order to conduct an analysis of the interdependencies that exist between the criteria. The intrinsic fuzziness of human life, on the other hand, makes MCDM analysis particularly challenging. It is essential to develop a theory that can quantify the fuzziness of such notions because of the subjectivity that humans possess. As a result of this, fuzzy logic considers bias while determining evaluation criteria. (Büyüközkan & Çifçi, 2012). According to Lin (2013), green supply chain management is a proactive approach to environmental sustainability that makes use of fuzzy set theory and DEMATEL to establish a conceptual framework that deals with the imprecision of human perceptions and discovers a causal relationship among a number of elements. This strategy was developed by using fuzzy set theory and DEMATEL to develop a conceptual framework that deals with the imprecision of human perceptions.

DEMATEL is conducting in-depth study to investigate the potential linkages between the causes of the problem. One benefit is that only a limited number of specimens are needed, and another is that the degree of correlation that exists between the various components may also be established (Zhou & Chen, 2018). DEMATEL was established at the end of 1971 as a part of the Science and Human Program at the

Geneva Research Centre of the Battelle Institute. Initially, DEMATEL focused on issues relating to ethnicity, starvation, energy, and the preservation of the environment. Nevertheless, the method may construct and assess complex models that illustrate interdependencies between the constituent parts. DEMATEL detects problems with the delivery of healthcare as well (Dikmen & Taş, 2018). The benefits of business intelligence (BI) are organized into categories using the fuzzy DEMATEL technique, which considers the cause and effect interactions between those benefits. This is done in order to help in the comprehension and discovery of intricate relationships, as well as to solve the fuzziness that exists about expertise. Managers are able to raise their level of competitiveness by isolating essential areas of BI implementation with the help of the approach, which can be employed by managers (Saen & Standing, 2018).

Professionals place a lot of faith in the DEMATEL when it comes to dissecting intricate systems in order to understand the factors that contribute to them and the effects they have. There have been multiple papers and versions written about the usefulness of DEMATEL that have been published. These articles and versions may be found here. In a study that was conducted between the years 2006 and 2016, 346 publications that were published in international journals were analyzed. Based on the methodologies that were utilized, it categorized DEMATEL into different domains, such as Classical, fuzzy, grey, analytical network process (ANP), and others. (Shengyun et al., 2018). By Han and Deng (2018) the Dempster-Shafer evidence theory was incorporated into the DEMATEL approach, which resulted in the development of an expanded version of the fuzzy DEMATEL method for finding CSFs. Professionals make use of intuitionistic fuzzy numbers, which are more commonly referred to as IFNs, in order to undertake an examination of direct factor linkages. Once IFNs have been converted into BPAs and merged in line with the Dempster combination rule, the DEMATEL approach is able to classify variables in accordance with their respective causes and effects. Dinçer and Yüksel (2018b) presented an Integrated Decision-Making Approach to evaluate the G20 economies utilizing inputs from the banking industry. This approach would use DEMATEL and TOPSIS. TOPSIS assigns ratings to the economies that make up the G20, while DEMATEL assigns weights to the criteria that are used.

DEMATEL has applications in many different areas of study. For example, it makes it easier for readers to appreciate the dynamic interrelationships that make up the quality of library services and provides suggestions for how those services might be improved. In addition, the book contains a wealth of information about libraries (Chen, 2016). Despite significant DEMATEL advancements, the results are, by their very nature, subjective. The Dempster-Shafer theory of evidence is utilized in the process of devising a method for enhancing DEMATEL by fusing together subjective and objective data (Du & Zhou, 2019). According to Behl et al. (2019), in order to identify the most important components in the management of humanitarian supply chains, Grey-DEMATEL simulates and organizes these parameters according to cause and effect. When it comes to the management of ambiguous judgements and the classification of components into causes and effects, grey-DEMATEL performs significantly better than fuzzy DEMATEL. Pandey et al. (2019) conducted an analysis of important mobile issues (CMIs) and arranged the issues into categories based on their respective causes and effects using the Fuzzy-DEMATEL method. In comparison to G-DEMATEL and E-DEMATEL, fuzzy-DEMATEL is the most effective method for researching the various problems that arise throughout the process of developing mobile apps.

The utilization of an amalgamation between the 2-tuple linguistic technique and DEMATEL serves as a potent tool for ascertaining the weights of participant attributes while providing insights into their interconnections. This dynamic approach not only aids in quantifying the significance of various attributes but also elucidates the intricate relationships among them. Furthermore, the application of fuzzy DEMATEL and TOPSIS enables the estimation of participant numbers in knowledge-intensive crowdsourcing endeavors. By harnessing the power of these advanced methodologies, it becomes feasible to navigate the complexities of crowd-driven knowledge-intensive projects, ensuring a more comprehensive understanding of the participant attributes and their collective impact on the overall success of such endeavors (Zhang & Su, 2019). Fuzzy DEMATEL with TOPSIS is used to assess the risk of a hydrogen-producing unit. TOPSIS ranks defects and assigns risk values, while fuzzy DEMATEL determines risk weights and interrelationships (Li et al., 2020). Shang et al. (2020) states that improving the evidential DEMATEL technique results in more accurate CSF determination even when the conditions are ambiguous. In the field of emergency management, the DEMATEL methodology combined with belief entropy is utilized to locate CSFs. The improved evidential DEMATEL does a better job than both the evidential DEMATEL and the D-DEMATEL at addressing the uncertain character of the information.

To effectively address the hesitance of experts when assessing the influence of criteria, an innovative approach was devised through the creation of DEMATEL's spherical fuzzy form. This novel methodology combines the robustness of DEMATEL with the versatility of spherical fuzzy theory, offering a comprehensive means to validate the concerns raised by experts regarding the practicality of DEMATEL. By seamlessly integrating these two frameworks, organizations can gain a deeper understanding of the intricacies surrounding decision-making processes. Furthermore, this approach helps to substantiate the opinions of experts, ensuring that their valuable insights and reservations are not only acknowledged but also incorporated into the evaluation and validation processes. This research exemplifies the commitment to enhancing the credibility and effectiveness of expert-driven evaluations.

In response to the understandable hesitance exhibited by experts during the evaluation of criteria, a pioneering solution emerged in the form of DEMATEL's spherical fuzzy variant. This cutting-edge approach harmoniously melds the robustness of DEMATEL with the flexibility of spherical fuzzy theory, presenting a comprehensive strategy for addressing the concerns of experts regarding the practicality of DEMATEL. The fusion of these two methodologies creates a powerful toolkit, enabling organizations to gain deeper insights into the nuances of decision-making processes. Moreover, it serves to validate the perspectives of experts, ensuring that their valuable opinions and reservations are not only considered but also integrated into the evaluation and validation procedures. This research signifies a commitment to fortifying the credibility and effectiveness of expert-driven evaluations, ultimately contributing to more informed decision-making (Gül, 2020). Abikova (2020) employed an integrated strategy to establish the most significant criteria and sub-criteria for refugee camp sites. This approach was based on fuzzy approaches, DEMATEL, and the Analytical Network Process (ANP). In this instance, the two parts of the inquiry consist of utilizing DEMATEL to categorize each criterion as either a cause or an effect and afterwards utilizing ANP to rate the criteria's relevance. Yazdi et al. (2020) utilized the DEMATEL method, the Best-Worst Method (BWM), and the Bayesian Network (BN) in order to establish a solid decision-making framework for effective safety management. This framework considers risk factors as well as the interdependencies among information sources.

The DEMATEL-ISM method is utilized in order to ascertain the causal linkages of an IoT-based agri-food supply chain coordination system. The ISM approach is utilized to structure allowing interactions in order to promote coordination, and the DEMATEL methodology is utilized to establish linkage amongst them (Yadav et al., 2020). Li et al. (2020) contends that a strategy that identifies the most significant component and its interrelationships enables managers to choose suppliers based on leagile (lean and agile) characteristics, which in turn provides global supply chains with agility and resilience. DEMATEL is responsible for identifying the most relevant factor as well as its relationships. Li et al. (2020) suggested that companies should do an analysis of the interdependencies between essential success variables in order to decide which drivers are the most significant and to design successful strategies for growth and competitiveness. In this context, the fuzzy DEMATEL technique finds and ranks the most important components of an aftermarket improvement strategy for automobile lighting.

An AHP-TOPSIS-DEMATEL triangulation of methods could be beneficial for improving e-service quality in the banking industry by following the steps such as determining and prioritizing the e-service quality factors through the use of AHP, comparing banks based on factors affecting quality through the use of TOPSIS, and establishing the causal relationship between the factors that affect quality through the use of DEMATEL (Agrawal et al., 2020). Uyanik et al. (2020) presented an MCDM framework for the selection of a suitable location for logistic centers by using DEMATEL and the Intuitive Fuzzy (IF) Technique for the TOPSIS technique. DEMATEL is used to evaluate the selection standards, whereas IF-TOPSIS is used to evaluate prospective locations for logistic centers based on uncertainty. Both models are used in conjunction with each other to enhance the efficacy of the approach. Li et al. (2020b) discovered that a fuzzy DEMATEL and TOPSIS technique for evaluating the dangers posed by hydrogen power plants may take into account the complex web of interdependencies and rank the risks involved in order to facilitate decision-making. The TOPSIS model sorts dangers in descending order and calculates risk levels, whereas the DEMATEL model analyses the significance of risk relationships.

AHP-DEMATEL is the methodology that is utilized while selecting functional logistics providers. It is possible for local potential logistics subcontractors and integrated logistics service providers to strengthen their offerings with the assistance of the AHP-DEMATEL analysis. With the help of this method, decision-makers are able to concentrate on essential criteria and identify interrelationships (Ly et al., 2021). Using the DEMATEL technique in conjunction with Ordered Weighted Geometric Average (OWGA) operators and Grey Relation Theory (GRT) to depict the safety limits of important failure modes in the yacht bilge system is one more practical risk assessment extension in FMEA. This extension was made possible by the Grey Relation Theory (Mentes & Helvacioglu, 2021). Garg (2021) employed a combination of Grey theory and the DEMATEL technique to investigate the nature of the connection between the many different strategies for reducing e-waste. The Grey-DEMATEL method is utilized to determine which mitigation techniques have the greatest impact on the management of e-waste as well as the relative relevance of those techniques.

In order to determine and rank the primary and secondary elements that are important for green strategic sourcing, an innovative technique called Grey-DEMATEL-ANP (GDANP) has been created. One of the drawbacks of DEMATEL and DEMATEL-ANP is that in order to fill up the direct influence matrix, a respondent needs a greater amount of information the more components there are. It is possible that the validity and accuracy of the results will be affected if respondents become disinterested or bored with the lengthy questionnaire. Therefore, the criteria for selecting green suppliers can be defined through the integration of the Grey-DEMATEL-ANP (G-D-ANP) technique with the DANP (Mubarik et al., 2021). Mohammed et al. (2021) implemented a strategy known as the multi-attribute decision-making possibilistic bi-objective programming model (MADM-PBOPM) in order to make the supply chain more resistant to disturbances. The DEMATEL-TOPSIS methodology evaluates the responsiveness and effectiveness of service providers. This aided in the categorization of resilience pillars (RPs) according to their causes and consequences.

In a warehouse, the Fishbone Diagram and the DEMATEL approach are often used in conjunction with one another to improve efficiency. The Fishbone Diagram has a tendency to classify the causes and consequences of the issues at hand, but the DEMATEL method is used to study the interrelationships between them (Tsou & Hsu, 2022). The use of fuzzy DEMATEL contributes to the establishment of criteria for selecting suppliers by analyzing the correlation between the indexes and the degree to which these criteria can influence one another and be influenced by one another (Mirmousa & Dehnavi, 2016). In addition to it, the Z-based Decision-making Trial and Evaluation Laboratory (Z-DEMATEL) technique generates an Influential Network Relation Map (INRM), which is used to explain the interrelationship among the elements that play a key role in determining the intention to buy an electric bicycle (Lin et al., 2022). In a nutshell, when modelling multiplex causal systems, DEMATEL performs quite well. A visual systemic model analyses the connections between the previously defined criteria and determines which are the most important (Nguyen & Chu, 2023). As a result, the DEMATEL stands out as a valuable tool for identifying risks and assessing those risks. In addition to transforming the link between the causes and effects of criteria into a model, the DEMATEL may also be used to manage the interdependencies that exist within a collection of criteria (Tseng & Lin, 2008).

2.3 RESEARCH GAP

In light of the fact that the traditional FMEA method has been called into question due to deficiencies that limit its applicability, a new integrated FMEA model has been developed by making use of cloud model theory and the hierarchical TOPSIS methodology to evaluate and rank the failure modes. This model was developed in order to evaluate and rank the potential failure modes in a product (Liu et al., 2019b). The cloud model is an uncertainty model that is used to comprehend the shift between quality and quantity, and more specifically between quality conceptions and their quantity manifestation expressed by the natural language values. This shift can be thought of as being between certain quality conceptions and their amount manifestation. One way to think about this shift is as a movement between the cloud model and the natural language values. Through the utilization of uncertainty and randomness, it is feasible to bring about a qualitative as well as quantitative shift with the Cloud model (Yan-Bin et al., 2008). The cloud model is a cognitive paradigm that, by making use of probability statistics and fuzzy set theory, has the potential to realize the bidirectional cognitive transfer between qualitative concepts and quantitative facts. This transfer could be realized through the utilization of the cloud model. Ex expectation (Ex), Entropy (En), and Hyper Entropy (He) are the three components that make up the set that cloud models employ to communicate the meaning of a thought. (Wang et al., 2014).

The findings obtained from combining Cloud Model Theory (CMT) with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as a means of addressing uncertainty, in the shape of randomness and fuzziness, in the context of the determination of risks and failures in the cigarette manufacturing industry indicate that this method is superior with regard to the classification of failures that occur throughout the manufacturing process (Ahsan et al., 2022a). The TOPSIS method is a form of MCDM that is used to select the most effective solutions from among a limited number of potential outcomes. This is accomplished through the usage of the TOPSIS approach. It starts by determining the best possible point, and then it works to align all the options with that point as best it can. Traditional TOPSIS is an unambiguous, rational, and effective instrument for multi-criteria approaches; yet, it has been criticized by academics due to several defects that distort its efficiency due to several drawbacks that distort its effectiveness. Traditional TOPSIS is an effective tool for multi-criteria approaches. One of these drawbacks is that it is unable to take into consideration the linkages or interdependencies that exist between the criteria (Xu et al., 2015).

The faults that are linked with a production process not only have a negative impact on the production process itself, but also on the items that are produced as a result. It would be insufficient to consider these faults in isolation from one another, even though it is necessary to recognize and prioritize them to make the process more effective. This is because the faults that occur during a production process frequently find themselves entwined with one another in a way that causes them to have overlapping effects on one another. In addition, not all the mistakes can be deemed to be of the same kind. There is a possibility that some of these are the causes, while others are the impacts. For this reason, it is of equal importance to explore the mutual relationship of those errors, as well as the nature of this interaction, in order to acquire a comprehensive analysis for the purpose of mitigating the effects that have resulted.

Therefore, it has been reiterated as a research gap that it is more necessary to study the interrelationship among the faults that are plaguing a production process and to categorize them based on the kind of the faults themselves than it is to rank the faults that are troubling the production process. Nevertheless, if any study is lacking in establishing how flaws interact with one another and what causes them, it is possible that the entire procedure will be insufficient and ineffectual.

2.4 THEORETICAL FRAMEWORK

The traditional FMEA, on the other hand, can only rank the importance of a single influence factor, which making it inefficient for use with systems that have many failure modes whose impacts are concurrent or interacting with one another. This limitation renders the conventional FMEA unsuitable for use with systems. That is to say, the FMEA does not accurately identify the mutual influence that exists between the various components of the system. In these kinds of situations, DEMATEL lends a hand in locating the chain of events that led to the problem, as well as in assigning a priority to the chain of events that led to the problem, so that critical issues can be addressed in a prompt and effective manner, thereby guiding the process to ensure a higher level of performance (Tsai et al., 2017). In addition to this, a novel approach to FMEA evaluation that combines fuzzy logic and the DEMATEL theory has been developed in order to increase the system's resiliency by establishing the inter-relationships between failures. This was done in order to improve the system's ability to recover from failures. The system was intended to be improved, which led to the development of this strategy. After the RPNs have been defuzzed, they are used as inputs for the DEMATEL method, which is used to examine the causative levels of failure and the factors that led to them. The DEMATEL method is used to study the causal levels of failure and the factors that led to them (Liu et al., 2019).

The United States Army was the first organization to conceptualize an FMEA as a tool for reducing risk in the year 1949. This accomplishment was accomplished by the army. After that, it was used for the same purpose in the Apollo space mission, which was the one that had developed it in the first place. Businesses employ FMEA for a broad number of purposes, some of which include engineering design, manufacturing process, product development, and product maintenance over the entirety of the product's life cycle (Parsana & Patel, 2014). The DEMATEL was conceived of by the Battelle Research Centre in the 1970s with the goal of comprehending the causality problems that evolved in the applications that were carried out in the industry at that time. It is organized around the concept that the criteria not only have links to one another but also interact with one another; this is done in order for it to be able to accomplish the goal that it has established for itself (Dinçer & Yüksel, 2018).

Therefore, this study seeks assistance from the following framework: first, the Cloud Model Theory is used to transform qualitative linguistic terms into quantitative data; second, DEMATEL Decision Making Trial and Evaluation Laboratory Method is To determine interrelationship between identified faults and to rank them.

2.5 RESEARCH QUESTIONS

This study tends to find the answers to the following questions,

- What are the faults that contribute to failures in tobacco manufacturing industry?
- What is the significance of each one of those faults?
- What is the nature of those faults?
- What is the mutual relationship between those faults?
- What is the prominence of the nature of those faults?
- What could be the contribution of this research to the industry?

CHAPTER 3. METHODOLOGY AND MATHEMATICAL MODELS

3.1 GENERAL

Methodology, mathematical models, sampling technique, techniques used in the investigation, and the overall research design of the study are all covered in this chapter.

3.2 RESEARCH PARADIGM

On the one hand, the specialists contributed their evaluations in the form of a linguistic variable. On the other hand, the research effort converted these linguist values into cloud form. As a result, the investigation makes use of a mixed hybrid strategy for the purpose of data manipulation. In order to complete this study, we collected both primary and secondary sources of information. Using an Excel-based opinion form, primary data was collected from industry professionals. On the other side, secondary data was collected from the production database of the organization as well as the manuals describing the manufacturing process. The view that was formed was graded using an 11-point linguistic scale ranging from having no influence at all to having a profound influence in order to gain the experts' judgement regarding the influence that failure modes have on each other. Because professionals are more knowledgeable and provide information that is more accurate than that provided by the general public, a linguistic scale with 11 points is utilized. As a result, this scale gives specialists greater leeway in terms of how they should evaluate anything. In addition to this, it allows for a variety of viewpoints to be expressed, enhances data analysis, makes data more reliable, and reduces the likelihood of making an error in measurement. The opinion form was developed through expert consultation and a research of the relevant literature. Those that participated in the poll included supervisors, technicians, and the servicing coordinator. The six individuals who were selected as participants were the ones that filled out the opinion forms. The FMEA frequently requires fewer people since it requires participants to have specialized expertise of the problem being investigated. This is one of the reasons why the choice of six participants was made. The number of participants required by the FMEA varies depending on the scope of the problem that is being studied. As a result, the six individuals who were selected to participate were those who possessed specialized abilities and competence in tobacco production. The following figure provides a summary of the procedures that were carried out for the research.

3.3 RESEARCH SETTING

This study is focusing on the tobacco manufacturing industry in Pakistan as its population of interest. The professionals working in the tobacco sector have been approached and asked to provide their feedback in the form of linguistic terms utilizing the opinion form. Given that the participants in this inquiry were selected on purpose, taking into mind the amount of information and expertise that they have, the strategy that was utilized in this investigation was known as purposive sampling. Additionally, weights were assigned to the participants in order to demonstrate the trustworthiness of their evaluations, which tends to make the study non-probabilistic. When determining how much weight to give to each respondent's opinion, the professional titles and years of experience of those professionals are taken into consideration.

3.4 RESEARCH METHOD

Using the secondary data, a total of thirty-one faults were found, all of which contributed to different failures in the production process. In order to give primary data that is based on these flaws, an opinion form that is built using Excel and seeks assistance from the available literature has been designed. Data manipulation is accomplished with the help of Microsoft Excel. In addition to this, the cloud model theory is implemented in order to change bidirectional cognitive transfer between qualitative linguistic evaluation and quantitative data. The DEMATEL approach is utilized in order to rate the defects and establish an understanding of the interrelationships between the problems. The figure 3-1, as shows below, depicts the steps involved in this study.

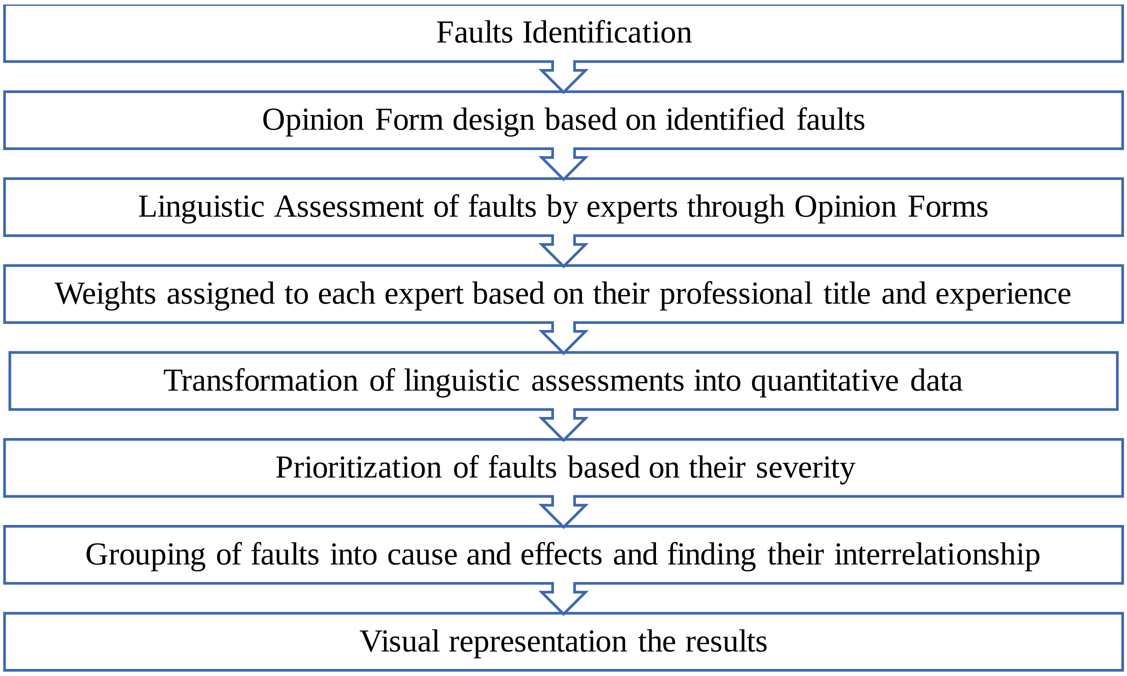

Figure 3-1: Stages of Study

3.5 MATHEMATICAL MODELS

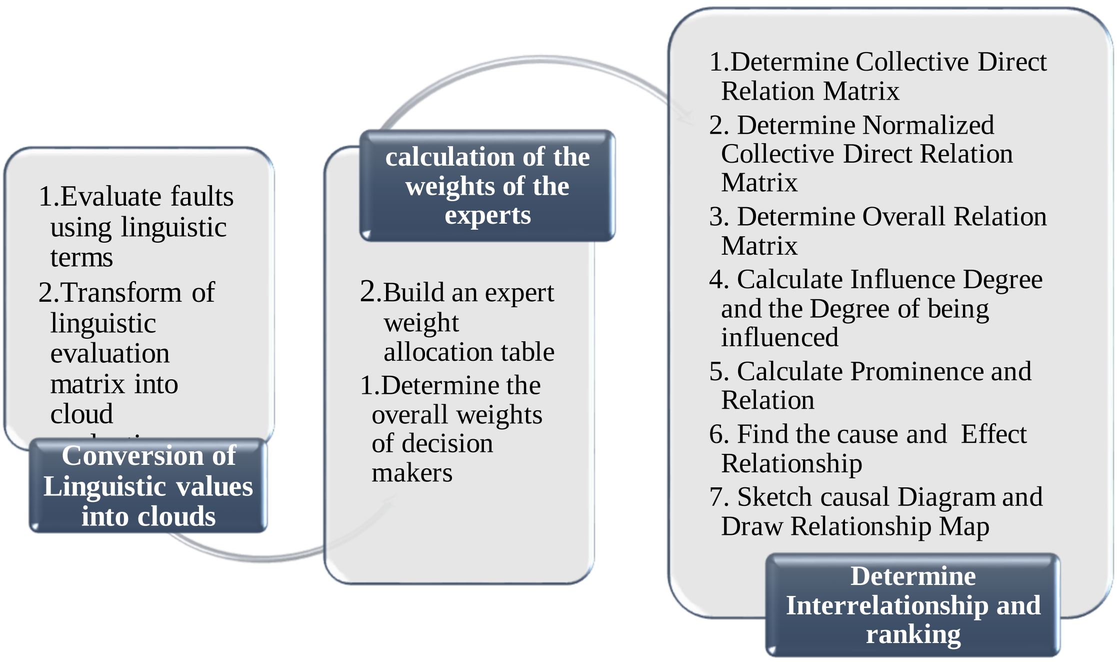

Figure 3-2: Steps of the method

Figure 3-2 provides an overview of the steps involved in the mathematical modeling.

3.5.1 Conversion of linguistic values into cloud setting

Golden segmentation method is used for the conversion of linguistic terms into clouds (Liu, Wang, Li, & Hu, 2019). According to this method a universal set having domain $U = [X_{max}, X_{min}]$ and L to be a linguistic set where $G = \{g_0, g_1, \dots, g_i\}$, $i+1$ clouds can be obtained in the following manner:

$$\tilde{y}_0 = (Ex_0, En_0, He_0), \tilde{y}_1 = (Ex_1, En_1, He_1), \dots., \tilde{y}_i = (Ex_i, En_i, He_i) \quad (1)$$

For an 11-point linguistic scale, the G_k, where $k = 11$, is represented as follows,

$$G = \{g_0 = No\ Influence\ (NI), g_1 = Extremely\ Low\ (EL), g_2 = Very\ Low\ (VL), g_3 = Low\ (L), g_4 = Medium\ Low\ (ML), g_5 = Medium\ (M), g_6 = Medium\ High\ (MH), g_7 = High(H), g_8 = Very\ High(VH), g_9 = Extremely\ High(EH), g_{10} = Profound\ Influence\ (PI)\}$$

Numerical values of clouds are calculated using equations 2 to 12.

$$\tilde{y}_0 = (Ex_0, En_0, He_0) = \left(X_{min} + 3En_0, \frac{En_1}{0.618}, \frac{He_1}{0.618}\right) \quad (2)$$

$$\tilde{y}_1 = (Ex_1, En_1, He_1) = \left(Ex_2 - 0.382 * (Ex_2 - Ex_0), \frac{En_2}{0.618}, \frac{He_2}{0.618}\right) \quad (3)$$

$$\tilde{y}_2 = (Ex_2, En_2, He_2) = \left(Ex_3 - 0.382 * (Ex_3 - Ex_0), \frac{En_3}{0.618}, \frac{He_3}{0.618}\right) \quad (4)$$

$$\tilde{y}_3 = (Ex_3, En_3, He_3) = \left(Ex_4 - 0.382 * (Ex_4 - Ex_0), \frac{En_4}{0.618}, \frac{He_4}{0.618}\right) \quad (5)$$

$$\tilde{y}_4 = (Ex_4, En_4, He_4) = \left(Ex_5 - 0.382 * (Ex_5 - Ex_0), \frac{En_5}{0.618}, \frac{He_5}{0.618}\right) \quad (6)$$

$$\tilde{y}_5 = (Ex_5, En_5, He_5) = \left(\frac{(X_{min} + X_{mzx})}{2}, 0.382 * \left(\frac{X_{max} + X_{min}}{3(g+2)}\right), He_4\right) \quad (7)$$

$$\tilde{y}_6 = (Ex_6, En_6, He_6) = \left(Ex_5 + 0.382 * (Ex_{10} - Ex_5), \frac{En_5}{0.618}, \frac{He_5}{0.618}\right) \quad (8)$$

$$\tilde{y}_7 = (Ex_7, En_7, He_7) = \left(Ex_6 + 0.382 * (Ex_{10} - Ex_6), \quad \frac{En_6}{0.618}, \quad \frac{He_6}{0.618}\right) \quad (9)$$

$$\tilde{y}_8 = (Ex_8, En_8, He_8) = \left(Ex_7 + 0.382 * (Ex_{10} - Ex_7), \quad \frac{En_7}{0.618}, \quad \frac{He_7}{0.618}\right) \quad (10)$$

$$\tilde{y}_9 = (Ex_9, En_9, H_{e_9}) = \left(Ex_8 + 0.382 * (Ex_{10} - Ex_8), \quad \frac{En_8}{0.618}, \quad \frac{He_8}{0.618}\right) \quad (11)$$

$$y_{10} = (Ex_{10}, En_{10}, He_{10}) = \left(X_{max} - 3En_{10}, \frac{En_9}{0.618}, \quad \frac{He_9}{0.618}\right) \quad (12)$$

The domain $U = [X_{min}, X_{max}]$ and H_{e_5} are adjusted before the commencement of calculating the numerical values of clouds. The values for H_{e_5} is less than $1/3$.

3.5.2 Assigning weights to the decision makers

Weights are assigned to the decision makers depending on their knowledge, professional capabilities, and duration of employment. These weights need to be determined using either a subjective or an objective method. Following the allocation of weights, the total score and corresponding weights can be determined using equation 33.

$$\omega_k = \frac{H_k}{\sum_{k=1}^{n} H_k}, k = 1,2,3, \dots, n \quad (33)$$

Table 1. as suggested by Liu et al., (2019) shows criteria for calculating weights of Decision Makers.

Table 3-1: Weights allocation table

Aspect	Classes	Score
Seniority level	Senior level	5
	Sub-senior level	4
	Intermediate level	3
	Associate level	2

	junior level	1
Experience in industry	Over 20 years	4
	Between 10 and 19 years	3
	Between 5 and 9 years	2
	Under 5 years	1

Following step are involved in the application of DEMATEL (Gao et al., 2021a).

3.5.3 Determine the collective direct relation matrix

Following the generation of cloud matrices and the assignment of weights to the decision makers, the obtained matrices are then transformed into a collective direct-relation matrix $\tilde{Z} = [\tilde{z}]_{n\times n}$ using equation 13.

$$\tilde{z}_{ij} = \sum_{k=1}^{m} w_k \tilde{z}_{ij}^k = \sum_{k=1}^{m} w_k\left(Ex_{ij}^k, En_{ij}^k, He_{ij}^k\right) = \left(\sum_{k=1}^{m} w_k Ex_{ij}^k, \sqrt{\sum_{k=1}^{m} w_k\left(En_{ij}^k\right)^2}, \sqrt{\sum_{k=1}^{m} w_k\left(He_{ij}^k\right)^2}\right) \quad (13)$$

The resultant collective direct-relation matrix is shown as,

$$\tilde{Z} = \sum_{k=1}^{m}\left(w_k \tilde{Z}^k\right) = \begin{bmatrix} Ex_{11}, En_{11}, He_{11} & \cdots & Ex_{1n}, En_{1n}, He_{1n} \\ \vdots & \ddots & \vdots \\ Ex_{n1}, En_{n1}, He_{n1} & \cdots & Ex_{nn}, En_{nn}, He_{nn} \end{bmatrix}$$

3.5.4 Determine Normalized collective direct-relation matrix

Once the collective direct-relation matrix $\tilde{Z} = [\tilde{z}]_{n\times n}$ is obtained, the next step is to calculate normalized collective direct-relation matrix $X = \left[x_{ij}\right]_{n\times n}$ using equations 14 to 17.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nn} \end{bmatrix}$$

Using

$$x_{ij} = \left(Ex_{ij}^N, En_{ij}^N, He_{ij}^N\right) = \left(\frac{Ex_{ij}}{\alpha}, \frac{En_{ij}}{\beta}, \frac{He_{ij}}{\gamma}\right) \tag{14}$$

$$\alpha = \left(max\left\{max_{1\leq i\leq n}\sum_{j=1}^{n} Ex_{ij}\,, max_{1\leq j\leq n}\sum_{i=1}^{n} Ex_{ij}\right\}\right) \tag{15}$$

$$\beta = \left(max\left\{max_{1\leq i\leq n}\sum_{j=1}^{n} En_{ij}\,, max_{1\leq j\leq n}\sum_{i=1}^{n} En_{ij}\right\}\right) \tag{16}$$

$$\gamma = \left(max\left\{max_{1\leq i\leq n}\sum_{j=1}^{n} He_{ij}\,, max_{1\leq j\leq n}\sum_{i=1}^{n} He_{ij}\right\}\right) \tag{17}$$

Here $0 \leq Ex_{ij}^N, En_{ij}^N, He_{ij}^N \leq 1$

3.5.5 Determine overall relation matrix

After calculating normalized collective direct-relation matrix $X = \left[x_{ij}\right]_{n\times n}$, the next step is to calculate overall-relation matrix $T = \left[t_{ij}\right]_{n\times n}$. To accomplish this goal, the normalized collective direct-relation matrix is subdivided into three matrices. This allows for the generation of more precise values. The reason for this is because the normalized collective direct-relation matrix is in the form of clouds, making it impossible to directly calculate its inverse. Three new matrices obtained are shown as,

$$A = \left[Ex_{ij}^N\right]_{n\times n} \tag{18}$$

$$B = \left[En_{ij}^N\right]_{n\times n} \tag{19}$$

$$C = \left[He_{ij}^N\right]_{n\times n} \tag{20}$$

Hence, the overall-relation matrix can be obtained using equations 21 to 23.

$$T_A = A + A^2 + A^3 + \cdots = \sum_{i=1}^{\infty} A^i = A(I - A)^{-1} = \left[Ex_{ij}^T\right]_{n\times n} \tag{21}$$

$$T_B = B + B^2 + B^3 + \cdots = \sum_{i=1}^{\infty} B^i = B(I - B)^{-1} = \left[En_{ij}^T\right]_{n \times n} \qquad (22)$$

$$T_C = C + C^2 + C^3 + \cdots = \sum_{i=1}^{\infty} C^i = C(I - C)^{-1} = \left[He_{ij}^T\right]_{n \times n} \qquad (23)$$

Here I indicates identity matrix. The resultant overall-relation matrix can be shown as

$$T = \left[t_{ij}\right]_{n \times n} = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nn} \end{bmatrix}$$

3.5.6 Calculate the influence degree and the degree of being influenced

Following the completion of the calculation of the overall-relation matrix, the next step is to determine the influence degree P_i and the Degree of being influenced R_j with the help of equations 24 and 25,

$$P_i = \sum_{j=1}^{n} t_{ij} = \sum_{j=1}^{n} \left(Ex_{ij}^T, En_{ij}^T, He_{ij}^T\right) = \left(\sum_{j=1}^{n} Ex_{ij}^T, \sqrt{\sum_{j=1}^{n} \left(En_{ij}^T\right)^2}, \sqrt{\sum_{j=1}^{n} \left(He_{ij}^T\right)^2} \right), i = 1,2,3, \ldots, n \; (24)$$

$$R_j = \sum_{i=1}^{n} t_{ij} = \sum_{i=1}^{n} \left(Ex_{ij}^T, En_{ij}^T, He_{ij}^T\right) = \left(\sum_{i=1}^{n} Ex_{ij}^T, \sqrt{\sum_{i=1}^{n} \left(En_{ij}^T\right)^2}, \sqrt{\sum_{i=1}^{n} \left(He_{ij}^T\right)^2} \right), j = 1,2,3, \ldots, n \; (25)$$

3.5.7 Calculate the prominence and relation

After obtaining the influence degree and the degree of being influenced, the next step is to calculate prominence p_i and relation r_i using equations 26 to 29.

$$p_i = P_i + R_j \qquad (26)$$

$$p_i = \left(\sum_{j=1}^{n} Ex_{ij}^T + \sum_{i=1}^{n} Ex_{ij}^T, \sqrt{\sum_{j=1}^{n} \left(En_{ij}^T\right)^2 + \sum_{i=1}^{n} \left(En_{ij}^T\right)^2}, \sqrt{\sum_{j=1}^{n} \left(He_{ij}^T\right)^2 + \sum_{i=1}^{n} \left(He_{ij}^T\right)^2}, i = 1,2, \ldots, n, \right) (27)$$

And

$$r_i = P_i - R_j \quad (28)$$

$$r_i = \left(\sum_{j=1}^{n} Ex_{ij}^{T} - \sum_{i=1}^{n} Ex_{ij}^{T}, \sqrt{\sum_{j=1}^{n} \left(En_{ij}^{T}\right)^2 + \sum_{i=1}^{n} \left(En_{ij}^{T}\right)^2}, \sqrt{\sum_{j=1}^{n} \left(He_{ij}^{T}\right)^2 + \sum_{i=1}^{n} \left(He_{ij}^{T}\right)^2}, i = 1,2,\ldots,n. \right) \quad (29)$$

3.5.8 Find the cause-and-effect relationship

The following stage, which follows the calculation of prominence and relation, is to determine the cause-and-effect relationship based on the values that were just determined. Finding prominence and relation can be accomplished by using the values of expectation. When utilizing the DEMATEL, the prominence of a fault shows the significance of the fault. As a result, the significance of a criterion increases in direct proportion to the extent of the magnitude of its prominence. Moreover, the relation r_i helps one in categorizing a fault into a cause group or an effect group. If the magnitude of relation r_i is greater than zero for a fault, it is considered as a cause. It shows that this fault impacts other faults more than it is being impacted by others. On the other hand, if the magnitude of relation r_i is smaller than zero for a fault, it is considered as an effect. In other words, it is considered that this fault is being impacted by other faults more than it impacts them.

3.5.9 Sketch causal diagram

Based on the values of the expectation of prominence p_i and relation r_i, causal diagram is drawn. It helps in depicting the importance of faults and categorizing these faults into cause and effect groups. The causal diagram is based on horizontal p_i and vertical axes r_i. Here, horizontal axis shows the importance of faults, whereas the vertical axis indicates the nature of fault.

3.5.10 Draw relationship map

A relationship map is drawn to visually represent the interrelationship between the faults. The purpose of the relationship map is to depict the most influential relationship from identified faults. It is drawn based on crisp values of expectation of overall-relation matrix. It can be represented as $T^* = \left[t_{ij}^*\right]_{n\times n}$ where $t_{ij}^* = Ex_{ij}^T$. The matrix obtained is shown in equation 30.

$$T^* = \left[t_{ij}^*\right]_{n\times n} \tag{30}$$

$$T^* = \begin{bmatrix} t_{11}^* & \cdots & t_{1n}^* \\ \vdots & \ddots & \vdots \\ t_{n1}^* & \cdots & t_{nn}^* \end{bmatrix}$$

When developing the map of relationships, including all the relations can make the map convoluted and difficult to understand if they are all included. A threshold value is established, which assists in the removal of relations that can be ignored. This is done with the objective of simplifying the relationship map and removing any complications that may arise as a result. However, it is important to keep in mind that if the threshold value is quite high, it will display a significant number of defects as being independent. This is something that should be taken into consideration. On the other hand, if the value of the threshold is set very low, presenting the data will become more difficult as a result. Because of this, the value of the threshold can be determined by using the equation 31.

$$\delta = \bar{t}_{ij} + \varphi \ (i, j = 1,2, \dots, n) \tag{31}$$

Here, δ indicates the threshold value, whereas $\bar{t}_{ij}$ and φ represent the mean and the standard deviation of the matrix T^*.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter the application of proposed approach in industry is illustrated. The detailed execution of the approach as well as the results obtained from the application of the theory are jotted down in this section.

4.2 APPLICATION OF THE STUDY IN INDUSTRY

This study demonstrates how cloud model theory and DEMATEL can be integrated into practical applications. Exploring the relationships among detected faults connected with the tobacco production process is one way in which successful execution can help bring about improvements in the conventional FMEA.

The purpose of this study is to investigate the correlation between the defects that tarnish the efficiency of the production process. The study will be implemented in the tobacco manufacturing business. The objective of this study is to evaluate how useful and practical the technique is. During the study, both technological and human-made mistakes will be taken into consideration and examined.

The figure given below provides additional clarity regarding the stages.

4.3 EXECUTION OF THE METHOD

The following steps are involved in the application of the method in manufacturing industry.

4.3.1 Step 1: Identification of faults

In order to properly evaluate system failures, and the faults that contribute to it, one must first have a solid understanding of how the system itself functions. It is possible for the process by which raw material is transformed into a completed product to be a confusing one. In addition to those stages, it often takes a greater amount of work and more control than the average individual would anticipate. Multiple inputs, a variety of controlled variable contributions, and many uncontrolled variable data lines all contribute to the increased assembly yields. Therefore, the organization's standards as well as its literature are utilized in order to ascertain the corresponding risk factors that are situated within their hierarchy and by which each failure mode can be evaluated. The figure shown below represents the main units of the machine and their function.

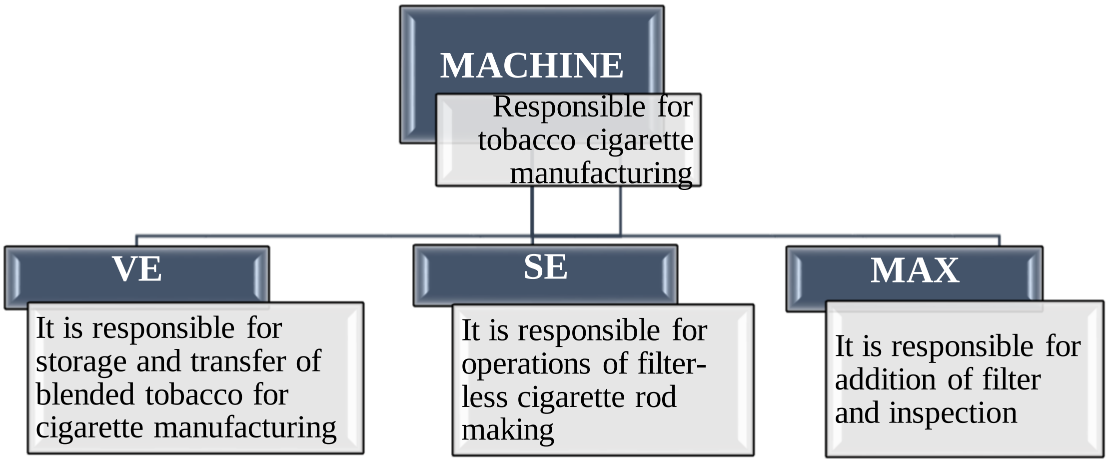

Figure 4-1: Structure and function of machine units

As shown in the figure 4-1, VE, SE, and MAX are the three primary components that make up the framework of the cigarette mechanism. VE is responsible for ensuring that the quality of the tobacco is maintained while also satisfying SE's tobacco standards. On the other hand, MAX contributes to the process of filtering cigarettes and inspecting those that have been filtered, while the responsibility of SE is to make cigarette rods.

Having done with the examination of manufacturing process, 31 Potential failure modes, shown in table 4-1, plaguing the manufacturing process are identified and outlined in the figure. The three primary components of production machinery—VE, SE, and MAX—are the most vulnerable to these modes, as seen in the table.

Table 4-1: Identified faults in production line

Assigned Names	Identified Faults
F1	No Tobacco in VE
F2	Trimmer Guard in VE
F3	Steep angle conveyer overload VE

F4	Airlock Flap in VE
F5	Magnetic Rail failure in VE
F6	Stems in VE
F7	Tobacco Rod Break in SE
F8	Tobacco Paper Break in SE
F9	No Tobacco Paper in SE
F10	Bobbin Loader in SE
F11	Ink Stock in SE
F12	Knife Advance in SE
F13	Dynamic Rod Monitoring in SE
F14	Seam heater wire break in SE
F15	No Tipping Paper in MAX
F16	Tipping Paper Break in MAX
F17	Filter Level in MAX
F18	Filter Rod Monitor Stop in MAX
F19	Filter choke up in MAX
F20	Inspection drum guard in MAX
F21	Inspection Drum Jam in MAX
F22	Feed Roller Guard in MAX
F23	Roll Block Jam in MAX
F24	Turn Drum Jam in MAX

F25	Discharge Choke Up in MAX
F26	Motor Circuit Breaker in MAX
F27	Stop on link up machine (HCF)
F28	Tray Station (HCF)
F29	Operating mod change
F30	MLP No Communication
F31	Compressed air failure

These identified faults are assigned with a particular name for the sake of simplicity in calculations. For example, the first fault, no tobacco in VE, is named as F1.

4.3.2 Step 2: Construction of opinion form

In order to build an opinion form in response to the problems that were discovered, assistance from the relevant literature was sought. The DEMATEL technique required that the opinion form be designed in such a way that it could satisfy the standards that were laid forth for it. The feedback form took the form of a matrix created in Microsoft Excel, with discovered flaws listed along its horizontal and vertical rows and columns, respectively. The participants were given a list of linguistic phrases, and they were required to fill out a cell that corresponded to each cell in the survey.

4.3.3 Step 3: Selections of Respondents

The questionnaire was given in the shape of an excel-based opinion form to six different responders to complete up. This is due to the fact that both the FMEA and DEMATEL methods rely on the judgement of experts; hence, these two methods involve fewer but more expert respondents. These professionals have an extensive knowledge base in their field. They range widely in terms of their professional titles and levels of expertise. Within the opinion form, they were obligated to provide information regarding their professional title and level of experience. They were provided with a concise description, along with the requirements of the opinion form, and instructions on how to fill out the opinion form. They are industry specialists; thus, it was not difficult for them to comprehend the nature of the dimension being asked for in the opinion form. In addition to this, students were given eleven linguistic terms to choose from so that they could keep the flexibility of their judgements.

4.3.4 Step 4: Calculation of the weight of the respondents

Respondent are assigned with weights. It is necessary to determine these weights utilizing either the subjective or objective weightage system. This phase involves two steps: first, construct a weight allocation table, second, allocation of overall weight to the respondents. The weight allocation system is based on an approach that is subject to interpretation, and it has two components: the seniority level and the experience level. The level of seniority is further subdivided into five classes, commencing with the subordinate level and working its way up to the senior level. In a similar manner, the experience level has an additional four classifications, ranging from a respondent with experience of less than five years to a respondent with more than twenty years of expertise. The formula for determining the communal weights is just the addition of these two scores.

Table 4-2: Weight allocation table

Aspect	Classes	Score
Seniority level	Senior level	5
	Sub-senior level	4
	Intermediate level	3
	Associate level	2
	Junior level	1
Experience in industry	Over 20 years	4
	Between 10 and 19 years	3

	Between 5 and 9 years	3
	Under 5 years	1

The weights are assigned to different respondents based on their understanding of a subject, their professional competencies, and their number of years of experience. Based on weights allocation table 4-2, the corresponding weights of the decision members are shown in table 4-3.

Table 4-3: Weights of team members

Sr. No. of Respondents	**Professional title-based scoring**	**Experience-based scoring**	**Cumulative scoring**	**Final weightage of decision makers (ω_k)**
1	5	3	8	0.205128205
2	4	4	8	0.205128205
3	4	4	8	0.205128205
4	3	3	6	0.153846154
5	3	3	6	0.153846154
6	1	2	3	0.076923077

Overall weights of the respondents are calculated using equation 33.

$$\omega_k = \frac{H_k}{\sum_{k=1}^{n} H_k}, k = 1,2,3, \dots, n$$

Where k indicates respondents, while n indicates the total number of respondents.

4.3.5 Step 5: Conversion of linguistic values into cloud setting

As for the sake of investigating the interrelationship between the identified faults, an opinion form is circulated among six decision makers, these decision makers, who are well-versed when it comes to knowledge and experience in the tobacco manufacturing industry, provided their judgments on presence of interrelationship as well as the potency of interrelationship between the faults. The subjective weights of these decision makers are calculated (Ahsan et al., 2022b). The decision makers used 11-point linguistic terms to indicate the presence and degree of interrelationships. These linguistic terms are shown as,

$$L = \{l_0 = No\ Influence\ (NI), l_1 = Extremely\ Low\ (EL), l_2 = Very\ Low\ (VL), l_3 = Low\ (L), l_4 = Medium\ Low\ (ML), l_5 = Medium\ (M), l_6 = Medium\ High\ (MH), l_7 = High (H), l_8 = Very\ High (VH), l_9 = Extremely\ High (EH), l_{10} = Profound\ Influence\ (PI)\}$$

The numerical clouds are obtained using equations 2-12. The clouds that correspond to linguistic values on scale are shown below.

$$\tilde{y}_0 = (3.513, 1.177, 0.554)$$

$$\tilde{y}_1 = (3.731, 0.727, 0.343)$$

$$\tilde{y}_2 = (3.864, 0.449, 0.212)$$

$$\tilde{y}_3 = (4.081, 0.278, 0.131)$$

$$\tilde{y}_4 = (4.432, 0.172, 0.081)$$

$$\tilde{y}_5 = (5.000, 0.106, 0.050)$$

$$\tilde{y}_6 = (5.561, 0.172, 0.081)$$

$$\tilde{y}_7 = (5.908, 0.278, 0.131)$$

$$\tilde{y}_8 = (6.122, 0.449, 0.212)$$

$$\tilde{y}_9 = (6.254, 0.727, 0.343)$$

$\tilde{y}_{10} = (6.468, 1.177, 0.554)$

Where the range is $X_{min}, X_{max} = 0, 10$, and $He_5 = 0.05$

Expectation (Ex), Entropy (En) and Hyper-entropy make the set of clouds is used by the cloud model theory to express a judgement. In cloud model theory, the term "expectation" refers to the center of a cloud's representation, which stands for the value within a specific cloud that is considered to be the most likely or anticipated value. It represents the predominant tendency of the data distribution in the cloud. In the theory of cloud models, entropy is used to quantify the amount of disorder or uncertainty present in a cloud. The more uncertain a situation is, the higher the entropy, while a more concentrated and predictable distribution of values is indicative of a lower entropy. The concept of hyper-entropy is an extension of the concept of entropy, and it is used to characterize uncertainty in a cloud space that has several dimensions. When dealing with various qualities or variables inside a cloud model, it provides a quantitative analysis of the total randomness and unpredictability of the situation. In other words, it determines the degree of uncertainty in entropy. The corresponding values of Expectation, Entropy and Hyper-entropy against all the linguistic terms are illustrated in the table 4-4.

Table 4-4: Conversion of linguistic values into clouds

Linguistic Terms	**Numerical Values (Ex, En, He)**
No Influence (NI)	(3.513, 1.177, 0.554)
Extremely Low Influence (EL)	(3.731, 0.727, 0.343)
Very Low Influence (VL)	(3.864, 0.449, 0.212)
Low Influence (L)	(4.081, 0.278, 0.131)
Medium Low Influence (ML)	(4.432, 0.172, 0.081)
Medium Influence (M)	(5.000, 0.106, 0.050)
Medium High Influence (MH)	(5.561, 0.172, 0.081)
High Influence (H)	(5.908, 0.278, 0.131)
Very High Influence (VH)	(6.122, 0.449, 0.212)
Extremely High Influence (EH)	(6.254, 0.727, 0.343)

Profound Influence (PI)	$(6.468, 1.177, 0.554)$

Subjective weighting scheme adopted to calculate corresponding weights of the decision makers. Weights of the decision makers are determined using equation 33.

4.3.6 Step 6: Collective direct relation matrix

After getting cloud matrices and allocating weights to the decision makers, these matrices are transformed into a collective direct-relation matrix $[\tilde{z}]_{31\times31}$ using equation 13.

Table 4-5: Calculation of collective direct relation matrix

		Effect of F20 on F21		Collective direct Relation Matrix
TMs	(wk)	Linguistic terms	Numerical Values (Ex, En, He)	$\left(\sum_{k=1}^{m} w_k Ex_{ij}^k, \sqrt{\sum_{k=1}^{m} w_k \left(En_{ij}^k\right)^2}, \sqrt{\sum_{k=1}^{m} w_k \left(He_{ij}^k\right)^2}\right)$
1	0.205	H	(5.908, 0.278, 0.131)	
2	0.205	VH	(6.254, 0.727, 0.343)	
3	0.205	VH	(6.254, 0.727, 0.343)	5.973846154,0.339904964, 0.160342182
4	0.153	H	(5.908, 0.278, 0.131)	k shows decision makers, m=6, ij represents rows and columns, respectively.

5	0.153	H	(5.908, 0.278, 0.131)	
6	0.076	H	(5.908, 0.278, 0.131)	

4.3.7 Step 7: Normalized collective direct relation matrix

The collective direct-relation matrix is the converted into normalized collective direct-relation matrix $[x_{ij}]_{31\times31}$using the equation 14-17. The first thing that must be done in order to compute the normalized collective direct relation matrix is to add up all the values in the row. In the same manner, each value from the column is added to the total. The next step is to select the maximum value from each row and the maximum value from each column. After that, the value with the greatest difference between these two maximum values is the one that is used for dividing the data for expectation, entropy, and hyper-entropy.

Table 4-6: Calculation of Normalized collective direct relation matrix

		$\frac{Ex_{ij}}{\alpha}, \frac{En_{ij}}{\beta}, \frac{He_{ij}}{\gamma}$
$\alpha = \left(max \left\{ max_{1\le i\le n} \sum_{j=1}^{n} Ex_{ij}, max_{1\le j\le n} \sum_{i=1}^{n} Ex_{ij} \right\} \right)$	125.33	For Effect of F20 on F21 0.047662798,0.009626309, 0.009647544
$\beta = \left(max \left\{ max_{1\le i\le n} \sum_{j=1}^{n} En_{ij}, max_{1\le j\le n} \sum_{i=1}^{n} En_{ij} \right\} \right)$	35.31	
$\gamma = \left(max \left\{ max_{1\le i\le n} \sum_{j=1}^{n} He_{ij}, max_{1\le j\le n} \sum_{i=1}^{n} He_{ij} \right\} \right)$	16.62	

Then, based on normalized collective direct-relation matrix, an overall-relation matrix $T = [t_{ij}]_{n \times n}$ is constructed using equations 18-23.

Table 4-7: calculation of overall relation matrix

	Calculation of overall relation matrix for Ex	Calculation of overall relation matrix for En	Calculation of overall relation matrix for He
	$A(I-A)^{-1}$	$B(I-B)^{-1}$	$C(I-C)^{-1}$
Effect of F20 on F21	0.318127	0.369573	0.369766

Overall relation matrix is calculated by taking the inverse of normalized collective direct relation matrix. For the values of Ex, En and He, overall relation matrix is calculated separately.

4.3.8 Step 8: Influence degree and degree of being influenced

Thenceforth, with the help of equation 24 and 25 the influence degree P_i and the degree of being influenced R_j are calculated.

4.3.9 Step 9: Calculate prominence and relation

Afterwards, equations 26-29 are used to calculate the prominence p_i and the relation r_i.

4.3.10 Step 10: Prominence

Prominence indicates the severity of a fault if it is cause, and vulnerability of a fault if it is an effect. In other words, the greater the magnitude of Prominence, the more important a criterion is.

Table 4-8: Calculation of prominence

Assigned Names	Actual Names	Prominence values	Rank
F21	Drum Jam in MAX	19.4647927, 16.7479144, 16.7552165,	Higher
F20	Inspection Drum guard in MAX	17.4494541, 17.6390681, 17.6457879,	Lower

Similarly, prominence vales for rest of the faults are calculated and show in the table 4-9.

Table 4-9: Ranking based on Prominence values in Descending Order

Identified Faults	Assigned Names	pi Value	RANK
Turn Drum Jam in MAX	F24	20.1258795	1
Roll Block Jam in MAX	F23	19.9464006	2
Inspection Drum Jam in MAX	F21	19.4647927	3
Discharge Choke Up in MAX	F25	19.2796197	4
Tobacco Rod Break in SE	F7	19.2512793	5
No Tipping Paper in MAX	F15	19.2355669	6
Filter Rod Monitor Stop in MAX	F18	18.9874679	7
Tipping Paper Break in MAX	F16	18.8805156	8
No Tobacco in VE	F1	18.7544951	9
Filter choke up in MAX	F19	18.6896897	10
Airlock Flap in VE	F4	18.599663	11
Steep angle conveyer overload VE	F3	18.5279708	12

Filter Level in MAX	F17	18.4328859	13
Magnetic Rail failure in VE	F5	18.3954089	14
Tobacco Paper Break in SE	F8	18.3745643	15
Bobbin Loader in SE	F10	18.2760459	16
No Tobacco Paper in SE	F9	18.2068193	17
Stems in VE	F6	17.9670742	18
Trimmer Guard in VE	F2	17.947616	19
Stop on link up machine (HCF)	F27	17.8231934	20
Compressed air failure	F31	17.7941441	21
Tray Station (HCF)	F28	17.6694477	22
Knife Advance in SE	F12	17.6212526	23
Dynamic Rod Monitoring in SE	F13	17.5271409	24
Inspection drum guard in MAX	F20	17.4494541	25
Feed Roller Guard in MAX	F22	17.4365233	26
Seam heater wire break in SE	F14	17.1212151	27
MLP No Communication	F30	17.0693418	28
Operating mod change	F29	17.0693418	28
Motor Circuit Breaker in MAX	F26	17.0693418	28
Ink Stock in SE	F11	17.0693418	28

The relation values assign faults to either a cause group or an impact group depending on their nature. It is determined to be a cause of a fault if the size of the relation r_i is bigger than zero for the fault in question. It is determined to be an effect rather than a fault if the size of the relation r_i is negative and greater than zero.

Table 4-10: Calculation of relation

Assigned names	Actual names	Relation values	Group
F21	Drum Jam in MAX	-0.04422804, 16.74791449, 16.75521656,	Effect
F20	Inspection Drum guard in MAX	0.02899341, 17.63906861, 17.64578798,	Cause

F21 gives negative value of relation, so it is considered to be an effect. However, F20 gives positive value of relation, so it is a cause.

Relationship map will further display their mutual relation. Similarly, rest of the faults can also be grouped as shown in the following tables.

Table 4-11: cause group and the ranking of faults

Assigned Names	Identified Faults	ri Values	Group Name	Pi Value	Rank
F7	Tobacco Rod Break in SE	0.40329493	Cause	19.2512793	1
F15	No Tipping Paper in MAX	0.21453214	Cause	19.2355669	2
F18	Filter Rod Monitor Stop in MAX	0.16557459	Cause	18.9874679	3
F16	Tipping Paper Break in MAX	0.10689366	Cause	18.8805156	4
F17	Filter Level in MAX	0.28267455	Cause	18.4328859	5

F10	Bobbin Loader in SE	0.00526596	Cause	18.2760459	6
F9	No Tobacco Paper in SE	0.12041181	Cause	18.2068193	7
F6	Stems in VE	0.60289859	Cause	17.9670742	8
F27	Stop on link up machine (HCF)	0.04014179	Cause	17.8231934	9
F31	Compressed air failure	0.72480230	Cause	17.7941441	10
F28	Tray Station (HCF)	0.23552603	Cause	17.6694477	11
F13	Dynamic Rod Monitoring in SE	0.35831025	Cause	17.5271409	12
F20	Inspection drum guard in MAX	0.02899341	Cause	17.4494541	13
F14	Seam heater wire break in SE	0.05187332	Cause	17.1212151	14

Table 4-12: Effect group and the ranking of faults

Assigned Name	Identified Faults	ri Values	Group Name	pi Values	Rank
F24	Turn Drum Jam in MAX	-0.218801	Effect	20.1258795	1
F23	Roll Block Jam in MAX	-0.083841	Effect	19.9464006	2

F21	Inspection Drum Jam in MAX	-0.044228	Effect	19.4647927	3
F25	Discharge Choke Up in MAX	-0.506859	Effect	19.2796197	4
F1	No Tobacco in VE	-0.234424	Effect	18.7544951	5
F19	Filter choke up in MAX	-0.210058	Effect	18.6896897	6
F4	Airlock Flap in VE	-0.220891	Effect	18.599663	7
F3	Steep angle conveyer overload VE	-0.411828	Effect	18.5279708	8
F5	Magnetic Rail failure in VE	-0.039306	Effect	18.3954089	9
F8	Tobacco Paper Break in SE	-0.064207	Effect	18.3745643	10
F2	Trimmer Guard in VE	-0.739597	Effect	17.947616	11
F12	Knife Advance in SE	-0.199967	Effect	17.6212526	12
F22	Feed Roller Guard in MAX	-0.36718	Effect	17.4365233	13

Table 4-13: Neutral group

Assigned Names	Identified Faults	ri Values	Group Name	pi Values	Rank
F30	MLP No Communication	0	Neutral	17.0693418	SAME
F29	Operating mod change	0	Neutral	17.0693418	SAME
F26	Motor Circuit Breaker in MAX	0	Neutral	17.0693418	SAME
F11	Ink Stock in SE	0	Neutral	17.0693418	SAME

4.3.11 Step 11: Construct causal diagram

Subsequently, the expected values of prominence and relation are used to construct a causal diagram as shown in figure 4-2 and 4-3. The x-axis and the y-axis, as well as their respective negative and positive values, make up a causal diagram. In the causal diagram, the horizontal axis displays the values of prominence, which indicate the significance of the faults; on the other hand, the vertical axis displays the relation, which reflects the type of the faults. Both axes are connected by the connection that represents the type of the faults. As shown in causal diagrams, figure 4-3 helps in visualizing the prominence and relation values of the faults, while figure 4-2 indicates only the assigned names of those faults.

In the causal diagram, the faults above the zero line on x-axis are causes. It is because they indicate positive values of relation. Similarly, that faults shown below the x-axis are effects because they indicate negative values of relation. In other words, the grouping of faults in cause and effect group is indicated based on the values of relation. Likewise, the causal diagram also indicates the prominence of faults. For this on x-axis from the zero line shows the significance of a fault. For example, in figure 4-2, the fault F7 is located at the farthest distance from zero, therefore, it is considered to be the most prominent cause. In the similar fashion, in order to identify the most significant cause, one can located that fault that is laying below the zero line on x-axis and also laying at farthest distance from zero on x-axis. Based on this principle of DEMATEL, it can be observed that the fault F24 is fulfilling these two rules; hence, it is considered to be the most critical effect.

Likewise, figure 4-2 also helps in identifying the faults that do not categorize themselves into cause and effect groups. In other words, these faults are considered to be neutral because they neither affect nor be affected by other faults. Therefore, according to the DEMATEL method, the faults that do not show positive or negative values of relation fall on zero line and also indicate their prominence values as the least ones among other faults. Based on this principle of DEMATEL, causal diagram shows such faults F11, F26, F29 and F30. Another important point to note here is that the faults that are falling neither in cause group nor in effect group also show the same value of prominence. It suggests that these faults have the same ranking and that raking is also the least one among other identified faults.

In this way, causal diagrams 4-2 and 4-3, provide visual representation of faults. They help identify type as well as the prominence of a fault. It not only depicts overall ranking but also shows ranking of faults after their classification into group. This characteristic of causal diagram helps in visualizing individualized ranking of causes and effects.

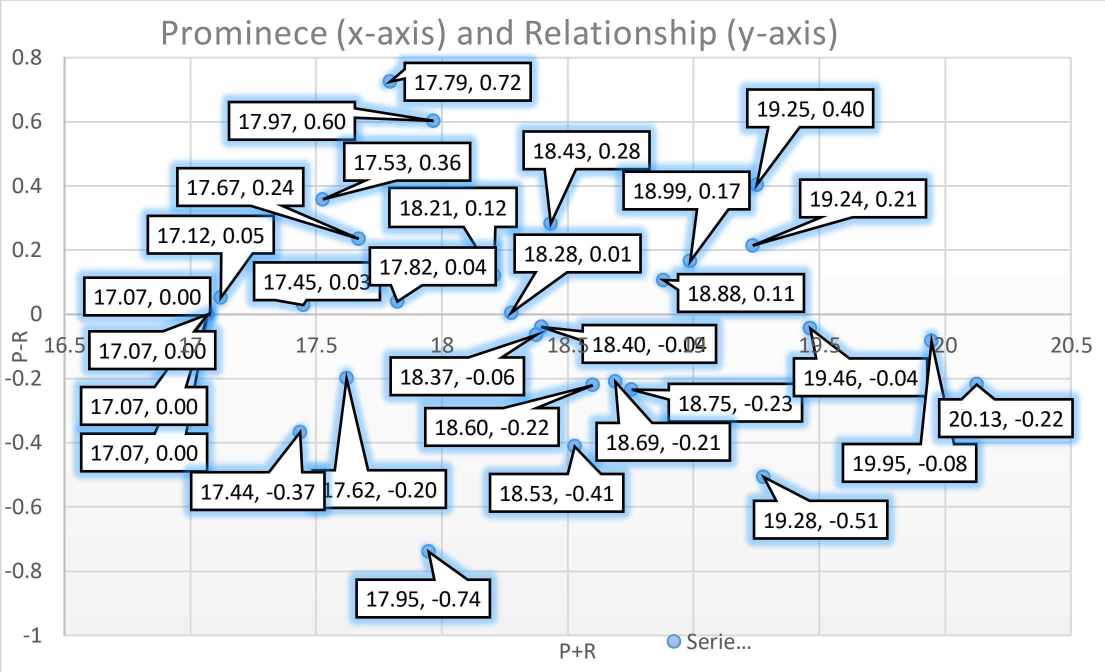

Figure 4-2: Causal diagram with values

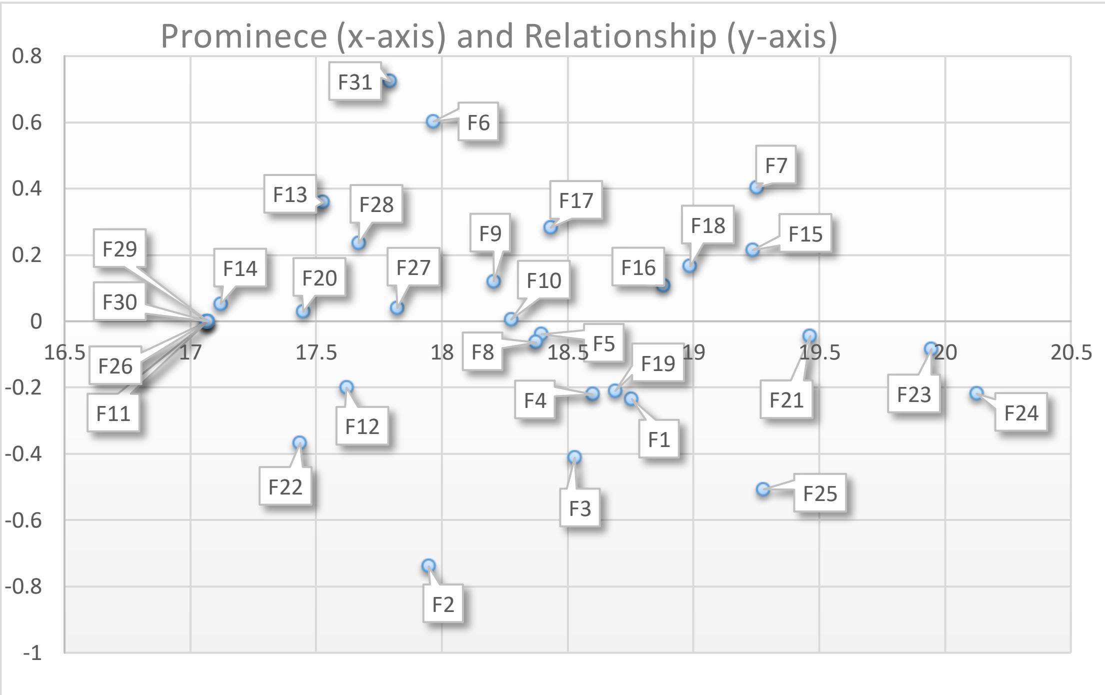

Figure 4-3: Causal diagram with fault names

4.3.12 Step 12 Construct relationship map

In order to calculate, relationship map, the first step is to calculate Effect matrix. Effect matrix is calculated by eliminating the values from the cell which are less than threshold value. In this case is the threshold value is 0.316377105. from the Effect matrix it is clear that the effect of F20 on F21 is 0.318127439, which is greater than the threshold value. It shows that F20(cause) has an effect on F21(Effect). This relation can be viewed in the relationship map given below. This is how we can determine interrelationship between rest of the faults.

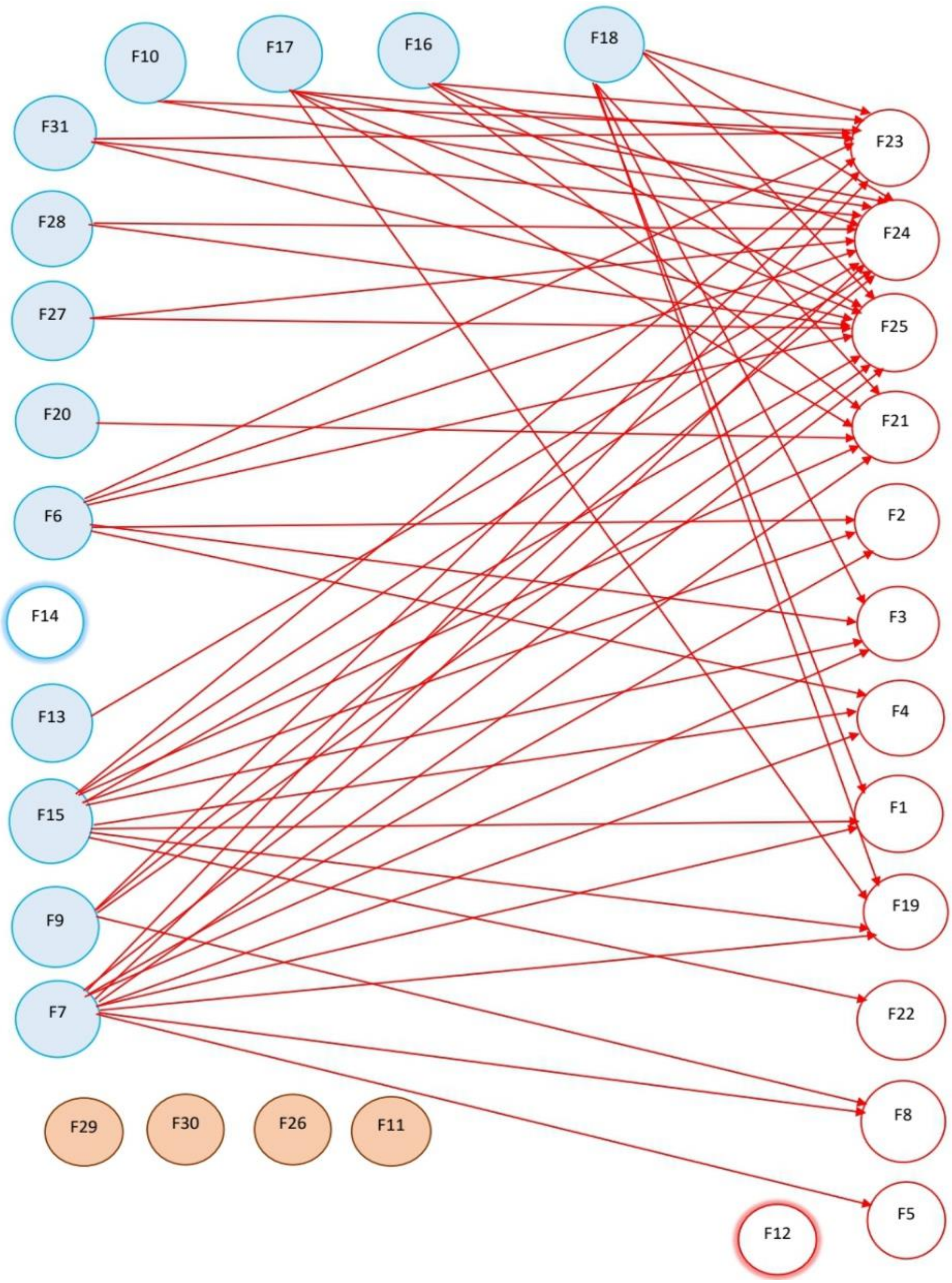

Figure 4-4: Relationship map

4.4 RESULTS

Based on the results obtained from the calculations, various meaningful conclusions can be drawn. To begin with, the results obtained from the prominence p_i indicate that the Turn Drum Jam in MAX contains the highest value of prominence when it comes to overall raking with other faults. This conclusion is based on the fact that the fault Turn Drum Jam in MAX has the highest value among all p_i values. In DEMATEL, the values of prominence suggest that the higher the value of the prominence the more a fault is higher in the ranking and vice versa. In line with this principle of DEMATEL, it can be observed in the table 4-9. that Turn Drum Jam in MAX has the highest value of prominence and is ranked at the first slot in ranking, indicating that it is the most prominent fault among others. It is, then, followed by the fault Roll Block Jam in MAX and inspection drum jam in MAX, respectively. This how, using the prominence p_i, the identified faults are ranked and shown in table 4-9.

Apart from it, based on the values obtained from relation r_i the 31 faults are categorized into effect group and cause group. These groups are shown in 4-11, 4-12 and 4-13. In DEMATEL, if the relation value of faults is less than zero, they are the effects. On the other hand, if the relation value of a fault is greater than zero, it is a cause. Based on this premise, table 4-11 and 4-12 indicate the cause and effect group. All the faults falling in effect group are indicating negative values of relation, whereas all faults indicating positive values of relation are grouped in cause group. However, faults having the relation value as zero are placed in another grouped named neutral group as shown in table 4-13. It is because they are neither showing positive nor negative value of relation. This how the relation values help in grouping of identified faults in cause and effect groups as shown in table.

Moreover, after dividing the faults into cause group and effect group relation r_i, they are further ranked in their respective groups based on the values of prominence p_i, as shown in table 4-11, 4-12 and 4-13. According to the prominence p_i and relation r_i, Turn Drum Jam in MAX fall in effect group and has the highest prominence in the effect group. Likewise, Tobacco Rod Break in SE fall in the cause group and is ranked at the top in this group because it has the highest value of prominence in cause group. In other words, the results obtained from both prominence and relation values and their subsequent grouping reveal the following information. Firstly, turn drum jam in MAX has negative value of relation and the highest value of prominence, so it is to be considered as the most vulnerable fault. Similarly, in the effect group, feed roller guard in MAX is placed at the bottom, indicating the least affected effect, because it not only shows negative value of relation, but also show minimum value of prominence among other effects. Same judgements can be made for the cause group. For instance, Tobacco Rod Break in SE is ranked highest in cause group because of two reason: first, it shows negative value of relation, second, it shows highest value of prominence among other causes. This is how one can find the group and the ranking in respective group for all identified faults. Likewise, table 4-9 shows that operating mode change and MLP no communication show, owing to the lowest values of prominence, are ranked at the lowest position in the ranking table, indicating that they are least prominent faults among the total identified faults. When it comes to relation values of these faults, it is further revealed that they neither show positive nor negative value. Therefore, they are placed in a separate group because they neither impact nor be impacted.

Causal diagram, as shown in figure 4-2 and 4-3, provides a visual representation of faults based on prominence and relation values. It consists of x-axis and y-axis. X-axis indicate prominence values, whereas y-axis indicate relation values. The faults, having negative values of relation and falling below the zero line on x-axis, are effects, while the faults above the x-axis, showing positive of relation are effects. Distance of a faults on x-axis from zero indicate the importance of that fault. For example, it can be observed from the causal diagram that the fault F24 (Turn Drum Jam in MAX) is falling below the zero line on x-axis, which shows that it is an effect. It can also be visualized from the causal diagram that this fault is residing at the farthest distance from zero, which show that it has the most prominence value as an effect. Similarly, it can be noted that the fault F7(Tobacco Rod Break in SE) is falling above the zero line and indicating the maximum distance from zero in its respective group. This indication suggest that this fault is not only the cause but also the most detrimental one. Moreover, faults falling on x-axis, including, F30 (MPL no communication) and F29 (operating mod change) are neither falling in cause group nor in effect group. Their prominence value and position on x-axis also show that they are the least prominent faults.

The relationship map provides further information on the interdependence between the faults. The relationship map helps in visualizing the most influential faults.

It also helps in visualizing the interrelationship among faults. In order to construct it, the overall relation-matrix is used in its crisp form. With the help of equation 31, the threshold value is determined as 0.316377105. Here, the mean value of matrix T^* is 0.294517947, whereas the standard deviation of matrix T^* is 0.021859158. All the relationships that have values greater than the threshold value are incorporated to construct relationship map. The relationship map is shown in figure 4-4. In relationship map, tale of arrow indicates causes, whereas the head of arrows indicate effects. In this map, the faults indicated in blue circle are causes, while the faults indicated in red circles are effects. The faults that do not show the tendency of cause or effect are shown at the bottom of the relationship map. The number of lines originating from or approaching to a fault indicate the prominence of a fault. In other words, the greater number of lines originating from or approaching to a fault, the severity this fault exhibits. The analysis of relationship map shows that maximum number of arrows are originating from F7 (Tobacco Rod Break in SE). it shows that F7 is the most severe and detrimental cause. This is how the relationship map further substantiate the results obtained from the table and causal diagram. Likewise, it can also be observed that maximum number of arrows are approaching to F24 (Turn Drum Jam in MAX), showing it as the most impacted effect. The faults having zero value of relation and least values of prominence are shown at that bottom of the map, indicating that they do not have any relationship with rest of the faults. Contrarily, F14 (Seam Heater Wire Break in SE) and F12 (Knife Advance in SE) though fall in cause and effect group respectively, yet they do not show any interdependence due to the fact that their value from overall-relation matrix is less than the threshold value. Putting it simply, these two faults, despite falling in respective group, do not show significant prominence and are, thus, discarded in the relationship map. In this way, the relation between rest of the causes and effects can also be observed in the relationship map.

4.5 DISCUSSION

Although the research methodology used in this study is not groundbreaking within the wider scope of research methodologies, its implementation within the specific context of manufacturing industry signifies a noteworthy shift from traditional approaches. The method used in the study has predominantly been employed in disciplines such as supply chain management, safety systems, energy, environment, and business intelligence. Significantly, the method was employed by Mirmousa and

Dehnavi (2016) for the evaluation of interdependencies among suppliers in supply chain management, while Gao et al. (2021) employed the same method to research the same phenomenon for green suppliers. Lin (2013) also sought assistance from this method to come up with a proactive approach to environmental sustainability that made the use of fuzzy set theory and DEMATEL to construct a conceptual framework that takes into account the imprecision of human perceptions and discovers a causal relationship among a number of elements. Nevertheless, its utilization within the realm of manufacturing industry has thus far been limited. In construction industry, Liu et al. (2019) used and integrated approach based on cloud model theory and TOPSIS for risk assessment. Likewise, an extension of traditional FMEA using cloud model theory and hierarchical TOPIS is employed by Ahsan et al. (2022) for the ranking of risk factors. Although TOPSIS is an efficient method based on structural analysis, yet it overlooks interdependencies among criteria and considers criteria as independent of each other. Therefore, through the adaptation and usage of this well-established method in my research, I have successfully overcome a disciplinary barrier and showcased its effectiveness in uncovering unexamined aspects of production processes in manufacturing industry. The adoption of a cross-disciplinary approach has revealed novel viewpoints and facilitated a more profound comprehension of manufacturing industry, hence reinforcing the adaptability of this methodology beyond its conventional confines. Although this study is not the first to utilize this method, it represents a groundbreaking instance of successfully incorporating it into the field of manufacturing and production. As such, it provides a valuable model for future research endeavors aiming to exploit its capabilities in this domain.

CHAPTER 5. CONCLUSION AND FUTURE RESEARCH

5.1 GENERAL

This chapter includes summary of the study, both theoretical and practical contribution, and limitation of the research. By providing solutions to address these limitations, it also provides future recommendation to researchers.

5.2 SUMMARY OF THE STUDY

The negative consequences of defects in a production process extend beyond the process itself and impact the resulting items. In addition to the task of finding and prioritizing problems, it is important to thoroughly examine the interconnections among them. The interconnection of flaws results in a complex interplay, where their effects become entangled and mutually influence one another. This work has the potential to provide a comprehensive analysis for effectively addressing the consequences arising from these errors. The main aim of this study is to investigate the interconnections among various defects that affect the production process in the manufacturing industry, and to establish a hierarchical ranking of these faults. This study aims to utilize the aid of two techniques. The use of the cloud model theory is utilized to address the challenge of managing unpredictability and uncertainty in decision-making processes, which arise from variations in cognitive capacities and background knowledge among decision makers. Furthermore, the DEMATEL approach is extended to incorporate the cloud model framework, enabling the identification of critical flaws and the analysis of their interdependencies. The proposed model is utilized to categorize the total number of discovered problems into distinct groups based on their causes and effects. Subsequently, the interdependence among the flaws is also discovered. Furthermore, a comprehensive rating of the flaws is determined, independent of their position within specific groups. The aforementioned results have also been visually represented through the utilization of diagrams and maps. The findings indicate that the turn drum jam in MAX is the area most significantly impacted, as it is influenced by the highest number of causes. Additionally, the tobacco rod break in SE emerges as the most prominent cause due to its capacity to elicit the greatest number of effects. The research highlights the originality of combining Cloud model theory with DEMATEL to enhance traditional FMEA and extend its applicability in manufacturing operations.

The implementation of this study has resulted in a notable increase in production efficiency within the industry. This improvement can be attributed to a substantial decrease in losses that were previously experienced as a result of interconnected defects. In a nutshell, to uncover and analyze the faults and intermingling nature of these faults that could jeopardize the efficacy of the production process in the cigarette manufacturing industry, this study used an integrated methodology that combines cloud model theory with DEMATEL method.

5.2 CONTRIBUTION

5.2.1 Practical contribution of the study

The successful application of this methodology is crucial in identifying aspects inside a system or process that require increased focus and examination. The difficulty spots that have been discovered serve as the primary areas where troubles tend to arise or collect, potentially leading to disruptions or negative outcomes. Once these crucial areas have been identified, they can undergo a thorough range of corrective actions and treatments designed to alleviate the potential consequences that may arise from them. By adopting the insights and recommendations generated from this study, the sector has the potential to achieve significant enhancements in the overall quality of its output. These enhancements go beyond simply improving the quality of the product, since they also involve substantial progress in increasing the production quantity. This objective is accomplished by strategically minimizing the time lost due to machine component failures or malfunctions during the production process. The effective implementation of this methodology not only acts as a proactive strategy to anticipate and prevent prospective problems but also as a driving force for enhancing both the quality and quantitative components of production. The study serves as a potent instrument for enhancing operational efficiency, so making a significant contribution to the industry's competitive advantage and long-term viability.

5.2.2 Theoretical contribution of the study

This study makes advances in Failure Modes and Effects Analysis (FMEA) methodology in several key areas. These advances cover these major areas. To begin with, one of the major contributions is reducing FMEA result duplication. This study reduces redundant or overlapping results by using novel methods to evaluate and examine. Duplicative efforts are reduced, improving FMEA workflow efficiency and resource allocation. Likewise, as the traditional FMEA generally struggles with real-world uncertainty and ambiguity. To make FMEA work in complicated situations, this study expands the theoretical basis. The framework is adaptable and resilient to dynamic and unexpected circumstances by including uncertainty and ambiguity management strategy. This improvement makes FMEA more useful in many facets of industry. Apart from it, understanding the complex network of reciprocal linkages between failure modes is another theoretical contribution of this study. Traditional FMEA emphasizes specific failure modes. Also, TOPSIS considers faults as independent to each other. This study improves theory by identifying and analyzing interdependencies and feedback loops between failure modes. This holistic view helps explain how failure modes interact and cascade, improving decision-making and risk management in industry. In conclusion, this study's theoretical contributions expand FMEA by addressing crucial challenges like result duplication, adaptation in uncertain environments, and reciprocal failure mode linkages. These theoretical contributions improve FMEA's effectiveness, efficiency, relevance, and applicability in a rapidly changing and complex environment, making it a valuable tool for proactive risk assessment and management in various domains in the industry.

5.3 LIMITATION OF THE STUDY

Despite the fact that it assists corporate managers in discovering and analyzing important flaws and the linkages between them more effectively, this model does not operate without restrictions. To begin, the decision makers may not be able to offer all the evaluation data due to their limited cognitive capacity. As a result, some of the evaluation matrix parts are left unfilled as a result of this. As a consequence of this, the question of how to generate appropriate instructions for filling up the associated matrix is one that is significant and important, and it calls for additional research to be conducted. In addition, the individuals that make the decisions come from a diversity of life experiences and cognitive skill sets. As a result, a tool that is designed for the display of judgements on a more general level would not be adequate. In addition, the efficiency of this method can be increased by making improvements to the weightage mechanism. In a similar vein, one of the downsides of DEMATEL is that a respondent needs a bigger amount of information the more components there are in order to fill up the direct influence matrix. It is probable that the validity and accuracy of the results will be impaired if respondents grow indifferent or bored with the lengthy questionnaire. This is because the length of the questionnaire makes it more likely that respondents will become bored.

5.4 FUTURE DIRECTIONS

Additionally, an objective method of weightage assignment, as opposed to a subjective method of weightage assignment, may bring about significant improvements to the strategy. In addition, the Grey hypothesis can be combined with DEMATEL in order to solve the problem of respondents' weariness and lack of interest in the survey. Moreover, it is advisable to give the respondent a variety of options to complete the form because they have diverse backgrounds and cognitive abilities. HFLTS, PLTS, LHFS, and ILIFTS are a few of the choices available. The abbreviation HFLTS stands for "Highly Fuzzy Linguistic Term Sets." In a highly fuzzy way, respondents may express a significant preference for specific options or traits using the HFLTS, signifying a high degree of belonging to their chosen choices. The acronym PLTS stands for "Partially Linguistic Term Sets." It recommends that respondents give more complex responses to questions about their preferences, allowing for partial membership to several options or qualities. It suggests that people favor a variety of options to some extent. LHFS is an abbreviation for "Low-High Fuzzy Sets." Respondents most likely utilize a variety of fuzzy sets in this instance to describe their preferences, suggesting variable degrees of favor from low to high across various alternatives or features. The acronym ILIFTS stands for "Interval-Valued Linguistic Fuzzy Term Sets." By using intervals rather than a single point, respondents may utilize ILIFTS to express a range of fuzzy preferences. It enables them to be flexible with their tastes. Additionally, it is advised that the total number of identified faults be whittled down to just the crucial faults. This action must be conducted in the initial stage. The expertise of professionals is also required for this. In this way the simplicity in calculations can be ensured. Lastly, it is recommended to investigate further examples in manufacturing industry in order to demonstrate that the method and to invigorate and broaden the scope of the study.

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APPENDICES

Appendix A: Linguistic Conversion

Sr. NO.	y	Linguistic Value	EX	EN	HE
1	y0	NI	3.513	1.177	0.554
2	y1	EL	3.731	0.727	0.343
3	y2	VL	3.864	0.449	0.212
4	y3	L	4.081	0.278	0.131
5	y4	ML	4.432	0.172	0.081
6	y5	M	5.000	0.106	0.05
7	y6	MH	5.561	0.172	0.081
8	y7	H	5.908	0.278	0.131
9	y8	VH	6.122	0.449	0.212
10	y9	EH	6.254	0.727	0.343
11	y10	PI	6.468	1.177	0.554

Appendix B: Weight allocation table

Professional Title	Scores by PT	Work Experience in industry	Score by WE	Hk	$\mathbf{w}k = \frac{Hk}{\sum_{k=1}^{l} Hk}$
Maintenance Supervisor & Senior E.O J15 Technical Operator	5	19 years	3	8	0.205128205
M10 J14 Technical Operator	4	35 years	4	8	0.205128205
E.O J14 Technical Operator	4	27 years	4	8	0.205128205
J12 Technical Operator II	3	12 years	3	6	0.153846154
J10 Technical Operator II	3	10 years	3	6	0.153846154
J(N) Skilled Worker	1	6 years	2	3	0.076923077
				39	1

Appendix C: Opinion Form

The following survey will be used to implement a final research thesis for Masters in Engineering Management at EME College NUST Islamabad

Name:______________________________

Professional Title:______________________________

Work Experience (Years): ____________________

Identify the impact rating for the failure modes given in below table using following nine linguistic terms.

1. No Influences as (NI)
2. Extremely Low Influence as (EL)
3. Very Low Influence as (VL)
4. Low Influence as (L)
5. Medium Low Influence as (ML)
6. Medium Influence as (M)
7. Medium High Influence as (MH)
8. High Influence as (H)
9. Very High Influence as (VH)
10. Extremely High Influence as (EH)
11. Profound Infuence as (PI)

NOTE-1: Read it as, influence of a fault mentioned in column (Vertically) on a fault mentioned correspondingly in row (Horizontally)

Note-2: The Diagonal Entries need not to be filled, as the influence of a fault on itself is not considered.

Sr. No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Failure modes	**No Tobacco in VE**	**Trimmer guards in VE**	**Steep angle conveyer overload VE**	**Airlock Flap in VE**	**Magnetic Rail failure in VE**	**Stems in VE**	**Tobacco Rod Break in SE**	**Tobacco Paper Break in SE**	**No Tobacco Paper in SE**	**Bobbin Loader in SE**	**Ink Stock in SE**	**Knife Advance in SE**	**Dynamic Rod Monitoring in SE**	**Seam heater wire break in SE**	**No Tipping Paper in MAX**	**Tipping Paper Break in MAX**	**Filter Level in MAX**	**Filter Rod Monitor Stop in MAX**	**Filter Choke Up in MAX**	**Inspection drum guard in MAX**	**Inspection Drum Jam in MAX**	**Feed Roller Guard in MAX**	**Roll Block Jam in MAX**	**Turn Drum Jam in MAX**	**Discharge Choke Up in MAX**	**Motor Circuit Breaker in MAX**	**Stop on link up machine (HCF)**	**Tray Station (HCF)**	**Operating mod change**	**MLP No Communication**	**Compressed air failure**
1	**No Tobacco in VE**																															
2	**Trimmer Guard in VE**																															
3	**angle conveyer overload**																															
4	**Airlock Flap in VE**																															
5	**Rail failure in VE**																															
6	**Stems in VE**																															
7	**Rod Break in SE**																															
8	**Tobacco Paper Break in**																															
9	**No Tobacco Paper in SE**																															
10	**Bobbin Loader in SE**																															
11	**Ink Stock in SE**																															
12	**Knife Advance in SE**																															
13	**Dynamic Rod Monitori**																															
14	**Seam heater wire**																															
15	**No Tipping Paper in**																															
16	**Tipping Paper Break in MAX**																															
17	**Filter Level in MAX**																															
18	**Rod Monitor Stop in**																															
19	**Choke Up in MAX**																															
20	**n drum guard in MAX**																															
21	**n Drum Jam in MAX**																															
22	**Roller Guard in MAX**																															
23	**Block Jam in MAX**																															
24	**Drum Jam in MAX**																															
25	**e Choke Up in MAX**																															
26	**Circuit Breaker in MAX**																															
27	**Stop on link up machine (HCF)**																															
28	**Tray Station (HCF)**																															
29	**Operating mod change**																															
30	**MLP No Communication**																															
31	**Compressed air failure**																															

Signature:____________________

Date:____________________

Appendix D: Weighted Collective Direct Relation Matrices

weight(expectation)
w1(Ex1)

Sr. No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Failure modes	No Tobacco in VE	Trimmer guards in VE	Steep angle conveyer overload VE	Airlock Flap in VE	Magnetic Rail failure in VE	Stems in VE	Tobacco Rod Break in SE	Tobacco Paper Break in SE	No Tobacco Paper in SE	Bobbin Loader in SE	Ink Stock in SE	Knife Advance in SE	Dynamic Rod Monitoring in SE	Seam heater wire break in SE	No Tipping Paper in MAX	Tipping Paper Break in MAX	Filter Level in MAX	Filter Rod Monitor Stop in MAX	Filter Choke Up in MAX	Inspection drum guard in MAX	Inspection Drum Jam in MAX	Feed Roller Guard in MAX	Roll Block Jam in MAX	Turn Drum Jam in MAX	Discharge Choke Up in MAX	Motor Circuit Breaker in MAX	Stop on link up machine (HCF)	Tray Station (HCF)	Operating mod change	MLP No Communication	Compressed air failure
1	No Tobacco in VE	0	1.140717949	1.255794872	1.255794872	0.909128205	0.837128205	0.765333333	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
2	Trimmer Guard in VE	0.837128205	0	0.765333333	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
3	Steep angle conveyer overload VE	1.282871795	0.837128205	0	1.025641026	0.909128205	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
4	Airlock Flap in VE	1.211897436	0.909128205	1.211897436	0	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
5	Magnetic Rail failure in VE	1.211897436	0.909128205	1.140717949	1.211897436	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
6	Stems in VE	0.837128205	1.140717949	0.909128205	1.025641026	1.025641026	0	0.837128205	0.909128205	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
7	Tobacco Rod Break in SE	1.211897436	1.140717949	1.211897436	1.140717949	1.211897436	0.909128205	0	1.211897436	0.909128205	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
8	Tobacco Paper Break in SE	0.837128205	0.765333333	0.765333333	0.720615385	0.720615385	0.720615385	0.909128205	0	1.282871795	1.255794872	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
9	No Tobacco Paper in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	1.282871795	0	1.255794872	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
10	Bobbin Loader in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.140717949	1.211897436	1.255794872	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
11	Ink Stock in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
12	Knife Advance in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
13	Dynamic Rod Monitoring in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
14	Seam heater wire break in SE	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.837128205	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
15	No Tipping Paper in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	1.255794872	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	1.211897436	1.140717949	1.211897436	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
16	Tipping Paper Break in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	0	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	0.720615385	1.211897436	1.211897436	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
17	Filter Level in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	1.255794872	1.255794872	0.720615385	0.720615385	0.720615385	1.211897436	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
18	Filter Rod Monitor Stop in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	0	1.282871795	0.720615385	0.720615385	0.720615385	1.255794872	1.255794872	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
19	Filter choke up in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	1.255794872	0	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
20	Inspection drum guard in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	1.211897436	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
21	Inspection Drum Jam in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	1.255794872	0.720615385	0.720615385	0.720615385	1.211897436	0	0.720615385	1.211897436	1.255794872	1.211897436	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
22	Feed Roller Guard in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
23	Roll Block Jam in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	1.140717949	1.025641026	1.211897436	1.255794872	0.720615385	1.211897436	0.720615385	0	1.255794872	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
24	Turn Drum Jam in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	1.211897436	0.720615385	1.140717949	1.140717949	0.720615385	1.211897436	0.720615385	1.255794872	0	1.211897436	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
25	Discharge Choke Up in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.837128205	0.909128205	0.720615385	1.211897436	0.720615385	1.140717949	1.255794872	0	0.720615385	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385
26	Motor Circuit Breaker in MAX	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385
27	Stop on link up machine (HCF)	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	0.720615385	0	1.211897436	0.720615385	0.720615385	0.720615385
28	Tray Station (HCF)	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.255794872	0.720615385	1.255794872	0	0.720615385	0.720615385	0.720615385
29	Operating mod change	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385	0.720615385
30	MLP No Communication	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0	0.720615385
31	Compressed air failure	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.211897436	0.720615385	1.211897436	0.720615385	0.720615385	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	1.140717949	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0.720615385	0

Appendix E: Normalized Collective Direct Relation Matrix

Normalized Collective Direct Relation Matrix (SECOND STEP) For EX

DIVIDE ALL CELLS WITH THE HIGHEST VALUE FROM PREVIOUS STEP

HIGHEST VALUE FROM PREVIOUS STEP IS 125.335615384615

Sr. No.	Failure modes	1 No Tobacco in VE	2 Trimmer guards in VE	3 Steep angle conveyer overload VE	4 Airlock Flap in VE	5 Magnetic Rail failure in VE	6 Stems in VE	7 Tobacco Rod Break in SE	8 Tobacco Paper Break in SE	9 No Tobacco Paper in SE	10 Bobbin Loader in SE	11 Ink Stock in SE	12 Knife Advance in SE	13 Dynamic Rod Monitoring in SE	14 Seam heater wire break in SE	15 No Tipping Paper in MAX
1	No Tobacco in VE	0	0.046001617	0.049141904	0.04930393	0.034847974	0.032728946	0.0304483	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
2	Trimmer Guard in VE	0.032817733	0	0.030230628	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
3	Steep angle conveyer overload VE	0.049898028	0.0346704	0	0.042624838	0.037969644	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
4	Airlock Flap in VE	0.047400119	0.037969644	0.047881698	0	0.04563133	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
5	Magnetic Rail failure in VE	0.047400119	0.036557027	0.046569529	0.047094887	0	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
6	Stems in VE	0.034089396	0.046569529	0.037568874	0.042073497	0.042073497	0	0.033658552	0.036707188	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
7	Tobacco Rod Break in SE	0.047400119	0.045454983	0.047881698	0.046569529	0.047881698	0.037835236	0	0.046781268	0.035976023	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
8	Tobacco Paper Break in SE	0.032725059	0.030149001	0.030149001	0.028028745	0.028028745	0.028028745	0.037835236	0	0.049898028	0.049681992	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
9	No Tobacco Paper in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.04723216	0.049898028	0	0.049384944	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
10	Bobbin Loader in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.046569529	0.048231937	0.049384944	0	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
11	Ink Stock in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745	0.028028745	0.028028745	0.028028745
12	Knife Advance in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.04473691	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745	0.028028745	0.028028745
13	Dynamic Rod Monitoring in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.047619018	0.028028745	0.028028745	0.028028745	0.028028745	0.049384944	0	0.028028745	0.028028745
14	Seam heater wire break in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.033392191	0	0.028028745
15	No Tipping Paper in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0
16	Tipping Paper Break in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.049384944
17	Filter Level in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
18	Filter Rod Monitor Stop in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
19	Filter choke up in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
20	Inspection drum guard in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
21	Inspection Drum Jam in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.043743066
22	Feed Roller Guard in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
23	Roll Block Jam in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.047662798
24	Turn Drum Jam in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.048144377
25	Discharge Choke Up in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
26	Motor Circuit Breaker in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
27	Stop on link up machine (HCF)	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
28	Tray Station (HCF)	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
29	Operating mod change	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
30	MLP No Communication	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
31	Compressed air failure	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.047094887	0.028028745	0.047094887	0.028028745	0.028028745	0.046001617

Sr. No.	Failure modes	16 Tipping Paper Break in MAX	17 Filter Level in MAX	18 Filter Rod Monitor Stop in MAX	19 Filter Choke Up in MAX	20 Inspection drum guard in MAX	21 Inspection Drum Jam in MAX	22 Feed Roller Guard in MAX	23 Roll Block Jam in MAX	24 Turn Drum Jam in MAX	25 Discharge Choke Up in MAX	26 Motor Circuit Breaker in MAX	27 Stop on link up machine (HCF)	28 Tray Station (HCF)	29 Operating mod change	30 MLP No Communication	31 Compressed air failure
1	No Tobacco in VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
2	Trimmer Guard in VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
3	Steep angle conveyer overload VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
4	Airlock Flap in VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
5	Magnetic Rail failure in VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
6	Stems in VE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
7	Tobacco Rod Break in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
8	Tobacco Paper Break in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
9	No Tobacco Paper in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
10	Bobbin Loader in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
11	Ink Stock in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
12	Knife Advance in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
13	Dynamic Rod Monitoring in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
14	Seam heater wire break in SE	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
15	No Tipping Paper in MAX	0.049222917	0.028028745	0.028028745	0.028028745	0.028028745	0.049384944	0.047400119	0.045788651	0.04713744	0.045788651	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
16	Tipping Paper Break in MAX	0	0.028028745	0.028028745	0.028028745	0.028028745	0.046711506	0.028028745	0.043771707	0.046711506	0.045362717	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
17	Filter Level in MAX	0.028028745	0	0.049384944	0.049384944	0.028028745	0.028028745	0.028028745	0.047400119	0.045362717	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
18	Filter Rod Monitor Stop in MAX	0.028028745	0.046881921	0	0.049898028	0.028028745	0.028028745	0.028028745	0.049384944	0.049384944	0.045788651	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
19	Filter choke up in MAX	0.028028745	0.046881921	0.048818669	0	0.028028745	0.028028745	0.028028745	0.037522844	0.046832208	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
20	Inspection drum guard in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0	0.047662798	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
21	Inspection Drum Jam in MAX	0.049384944	0.028028745	0.028028745	0.028028745	0.044810559	0	0.028028745	0.047662798	0.049384944	0.047662798	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
22	Feed Roller Guard in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
23	Roll Block Jam in MAX	0.046569529	0.04276211	0.048013037	0.049384944	0.028028745	0.048013037	0.028028745	0	0.049384944	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
24	Turn Drum Jam in MAX	0.047662798	0.028028745	0.046569529	0.046569529	0.028028745	0.047662798	0.028028745	0.049681992	0	0.047662798	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
25	Discharge Choke Up in MAX	0.028028745	0.028028745	0.031805886	0.033135035	0.028028745	0.046881921	0.028028745	0.046569529	0.049168908	0	0.028028745	0.042848852	0.028028745	0.028028745	0.028028745	0.028028745
26	Motor Circuit Breaker in MAX	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745
27	Stop on link up machine (HCF)	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.049168908	0.028028745	0	0.046974186	0.028028745	0.028028745	0.028028745
28	Tray Station (HCF)	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.049168908	0.028028745	0.049168908	0	0.028028745	0.028028745	0.028028745
29	Operating mod change	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745	0.028028745
30	MLP No Communication	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0	0.028028745
31	Compressed air failure	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.046264297	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0.028028745	0

HIGHEST VALUE FROM SUM OF ROWS AND SUM OF COLU	125.3356154

Appendix F: Overall Relation Matrices

MULTIPLICATION OF MATRICS

T=A(I-A)^-1

Sr. No.	Failure modes	1 No Tobacco in VE	2 Trimmer guards in VE	3 Steep angle conveyer overload VE	4 Airlock Flap in VE	5 Magnetic Rail failure in VE	6 Stems in VE	7 Tobacco Rod Break in SE	8 Tobacco Paper Break in SE	9 No Tobacco Paper in SE	10 Bobbin Loader in SE	11 Ink Stock in SE	12 Knife Advance in SE	13 Dynamic Rod Monitoring in SE	14 Seam heater wire break in SE	15 No Tipping Paper in MAX	16 Tipping Paper Break in MAX
1	No Tobacco in VE	0.281745	0.321007	0.327826	0.326107	0.306884	0.288535	0.308145	0.299904	0.294675	0.297362	0.279735	0.290765	0.281195	0.279735	0.308365	0.304736
2	Trimmer Guard in VE	0.29279	0.256897	0.289715	0.286023	0.280652	0.265919	0.286283	0.280654	0.275815	0.278346	0.261849	0.272173	0.263215	0.261849	0.288649	0.285251
3	Steep angle conveyer overload VE	0.323036	0.304379	0.274771	0.313859	0.303669	0.278566	0.299857	0.293924	0.288855	0.291506	0.274229	0.285041	0.27566	0.274229	0.302295	0.298737
4	Airlock Flap in VE	0.324906	0.311399	0.324585	0.277047	0.314691	0.282192	0.303767	0.297761	0.292626	0.295312	0.277809	0.288763	0.279258	0.277809	0.306242	0.302638
5	Magnetic Rail failure in VE	0.32456	0.309754	0.323049	0.321694	0.270731	0.281878	0.303429	0.29743	0.292301	0.294984	0.2775	0.288441	0.278948	0.2775	0.305901	0.302301
6	Stems in VE	0.315334	0.32229	0.317764	0.320089	0.314267	0.257569	0.312001	0.308873	0.295594	0.298263	0.280416	0.291472	0.281879	0.280416	0.309115	0.305477
7	Tobacco Rod Break in SE	0.344622	0.337767	0.344231	0.341046	0.335905	0.309139	0.295898	0.33441	0.318863	0.314344	0.295201	0.306841	0.296741	0.295201	0.325414	0.321584
8	Tobacco Paper Break in SE	0.309457	0.302651	0.306351	0.302621	0.296956	0.281275	0.312777	0.270543	0.312872	0.315272	0.276876	0.287793	0.278321	0.276876	0.305214	0.301622
9	No Tobacco Paper in SE	0.305479	0.301	0.30472	0.302918	0.297326	0.281572	0.321722	0.318472	0.265653	0.315246	0.277106	0.288032	0.278552	0.277106	0.305467	0.301872
10	Bobbin Loader in SE	0.30477	0.300306	0.304016	0.302222	0.296642	0.28093	0.320408	0.316243	0.312016	0.267486	0.27648	0.287382	0.277923	0.27648	0.304777	0.30119
11	Ink Stock in SE	0.286127	0.282014	0.285457	0.283832	0.278572	0.263978	0.284205	0.278627	0.273823	0.276337	0.232694	0.270208	0.261315	0.259959	0.286565	0.283192
12	Knife Advance in SE	0.291728	0.287503	0.291052	0.289374	0.284031	0.269002	0.305267	0.284062	0.279006	0.281446	0.264756	0.247931	0.266138	0.264756	0.291853	0.288418
13	Dynamic Rod Monitoring in SE	0.298754	0.294423	0.298063	0.296342	0.290873	0.275457	0.315242	0.290901	0.285696	0.288174	0.271084	0.30198	0.245234	0.271084	0.298829	0.295312
14	Seam heater wire break in SE	0.287685	0.28355	0.287012	0.285378	0.280089	0.265415	0.28585	0.280145	0.275314	0.27784	0.261373	0.271784	0.267811	0.234108	0.288124	0.284732
15	No Tipping Paper in MAX	0.321849	0.317223	0.321096	0.319267	0.313351	0.296935	0.319688	0.313413	0.30801	0.310837	0.292414	0.303943	0.293939	0.292414	0.296586	0.339791
16	Tipping Paper Break in MAX	0.314906	0.31038	0.31417	0.31238	0.306592	0.29053	0.312792	0.306652	0.301366	0.304132	0.286106	0.297387	0.287599	0.286106	0.336609	0.28591
17	Filter Level in MAX	0.310828	0.30636	0.3101	0.308334	0.30262	0.286766	0.30874	0.30268	0.297462	0.300193	0.2824	0.293535	0.283874	0.2824	0.312047	0.308359
18	Filter Rod Monitor Stop in MAX	0.317392	0.312829	0.316649	0.314846	0.309011	0.292823	0.315261	0.309072	0.303744	0.306532	0.288364	0.299734	0.289869	0.288364	0.318753	0.314985
19	Filter choke up in MAX	0.307288	0.30287	0.306568	0.304823	0.299174	0.283501	0.305224	0.299233	0.294074	0.296774	0.279184	0.290192	0.280641	0.279184	0.308342	0.304703
20	Inspection drum guard in MAX	0.292265	0.288064	0.291581	0.289921	0.284548	0.269641	0.290303	0.284605	0.279698	0.282265	0.265536	0.276005	0.266921	0.265536	0.293021	0.289675
21	Inspection Drum Jam in MAX	0.321406	0.316786	0.320654	0.318828	0.312919	0.296526	0.319248	0.312981	0.307586	0.310409	0.292011	0.303525	0.293535	0.292011	0.338054	0.339474
22	Feed Roller Guard in MAX	0.286127	0.282014	0.285457	0.283832	0.278572	0.263978	0.284205	0.278627	0.273823	0.276337	0.259959	0.270208	0.261315	0.259959	0.286565	0.283192
23	Roll Block Jam in MAX	0.328038	0.323322	0.32727	0.325406	0.319376	0.302644	0.325835	0.319439	0.313932	0.316814	0.298036	0.309788	0.299591	0.298036	0.348304	0.343516
24	Turn Drum Jam in MAX	0.328706	0.323981	0.327936	0.326069	0.320026	0.303261	0.326499	0.32009	0.314572	0.317459	0.298643	0.310418	0.300201	0.298643	0.349449	0.345209
25	Discharge Choke Up in MAX	0.311686	0.307205	0.310956	0.309186	0.303456	0.287558	0.309593	0.303516	0.298283	0.301021	0.28318	0.294345	0.284657	0.28318	0.313238	0.309635
26	Motor Circuit Breaker in MAX	0.286127	0.282014	0.285457	0.283832	0.278572	0.263978	0.284205	0.278627	0.273823	0.276337	0.259959	0.270208	0.261315	0.259959	0.286565	0.283192
27	Stop on link up machine (HCF)	0.29804	0.293756	0.297343	0.29565	0.290171	0.274969	0.296039	0.290228	0.285225	0.287843	0.270782	0.281459	0.272195	0.270782	0.298519	0.295007
28	Tray Station (HCF)	0.298665	0.294372	0.297966	0.296269	0.290779	0.275545	0.29666	0.290837	0.285823	0.288446	0.27135	0.282049	0.272766	0.27135	0.299145	0.295626
29	Operating mod change	0.286127	0.282014	0.285457	0.283832	0.278572	0.263978	0.284205	0.278627	0.273823	0.276337	0.259959	0.270208	0.261315	0.259959	0.286565	0.283192
30	MLP No Communication	0.286127	0.282014	0.285457	0.283832	0.278572	0.263978	0.284205	0.278627	0.273823	0.276337	0.259959	0.270208	0.261315	0.259959	0.286565	0.283192
31	Compressed air failure	0.307892	0.303464	0.307171	0.30542	0.299761	0.284051	0.30644	0.300182	0.295027	0.3154	0.27972	0.30879	0.281179	0.27972	0.325381	0.305091

Sr. No.	Failure modes	17 Filter Level in MAX	18 Filter Rod Monitor Stop in MAX	19 Filter Choke Up in MAX	20 Inspection drum guard in MAX	21 Inspection Drum Jam in MAX	22 Feed Roller Guard in MAX	23 Roll Block Jam in MAX	24 Turn Drum Jam in MAX	25 Discharge Choke Up in MAX	26 Motor Circuit Breaker in MAX	27 Stop on link up machine (HCF)	28 Tray Station (HCF)	29 Operating mod change	30 MLP No Communication	31 Compressed air failure
1	No Tobacco in VE	0.295591	0.305444	0.306586	0.284886	0.315524	0.290508	0.32317	0.327782	0.319594	0.279735	0.290205	0.285083	0.279735	0.279735	0.279735
2	Trimmer Guard in VE	0.276691	0.285914	0.286983	0.26667	0.295349	0.271933	0.302506	0.306824	0.299159	0.261849	0.271649	0.266855	0.261849	0.261849	0.261849
3	Steep angle conveyer overload VE	0.289772	0.299432	0.300551	0.279278	0.309313	0.284789	0.316808	0.32133	0.313303	0.274229	0.284492	0.279472	0.274229	0.274229	0.274229
4	Airlock Flap in VE	0.293556	0.303341	0.304475	0.282924	0.313351	0.288508	0.320945	0.325525	0.317393	0.277809	0.288207	0.28312	0.277809	0.277809	0.277809
5	Magnetic Rail failure in VE	0.293229	0.303003	0.304136	0.28261	0.313003	0.288187	0.320588	0.325163	0.31704	0.2775	0.287886	0.282805	0.2775	0.2775	0.2775
6	Stems in VE	0.29631	0.306187	0.307332	0.285579	0.316291	0.291214	0.323956	0.32858	0.320371	0.280416	0.290911	0.285777	0.280416	0.280416	0.280416
7	Tobacco Rod Break in SE	0.311933	0.322331	0.323537	0.300637	0.332968	0.306569	0.341037	0.345905	0.337264	0.295201	0.30625	0.300845	0.295201	0.295201	0.295201
8	Tobacco Paper Break in SE	0.29257	0.302323	0.303453	0.281974	0.312299	0.287539	0.319867	0.324433	0.316328	0.276876	0.287239	0.28217	0.276876	0.276876	0.276876
9	No Tobacco Paper in SE	0.292813	0.302574	0.303705	0.282209	0.312559	0.287778	0.320133	0.324702	0.316591	0.277106	0.287478	0.282404	0.277106	0.277106	0.277106
10	Bobbin Loader in SE	0.292152	0.30189	0.303019	0.281571	0.311853	0.287128	0.31941	0.323969	0.315875	0.27648	0.286828	0.281766	0.27648	0.27648	0.27648
11	Ink Stock in SE	0.274693	0.28385	0.284911	0.264745	0.293217	0.26997	0.300322	0.304609	0.296999	0.259959	0.269688	0.264929	0.259959	0.259959	0.259959
12	Knife Advance in SE	0.279763	0.289089	0.290169	0.269631	0.298629	0.274952	0.305865	0.310231	0.302481	0.264756	0.274665	0.269818	0.264756	0.264756	0.264756
13	Dynamic Rod Monitoring in SE	0.286449	0.295998	0.297104	0.276075	0.305766	0.281523	0.313175	0.317645	0.30971	0.271084	0.28123	0.276267	0.271084	0.271084	0.271084
14	Seam heater wire break in SE	0.276188	0.285394	0.286461	0.266185	0.294812	0.271438	0.301956	0.306266	0.298615	0.261373	0.271155	0.26637	0.261373	0.261373	0.261373
15	No Tipping Paper in MAX	0.309281	0.32009	0.321331	0.298152	0.35152	0.322032	0.356158	0.362373	0.352078	0.292414	0.303617	0.298009	0.292414	0.292414	0.292414
16	Tipping Paper Break in MAX	0.302586	0.313152	0.314365	0.291687	0.34187	0.297524	0.346931	0.354481	0.344418	0.286106	0.297067	0.291581	0.286106	0.286106	0.286106
17	Filter Level in MAX	0.272205	0.329716	0.330918	0.287612	0.319288	0.29329	0.345665	0.348622	0.323386	0.2824	0.29298	0.2878	0.2824	0.2824	0.2824
18	Filter Rod Monitor Stop in MAX	0.323294	0.289311	0.338087	0.293693	0.326445	0.299486	0.354758	0.359714	0.346761	0.288364	0.299406	0.293882	0.288364	0.288364	0.288364
19	Filter choke up in MAX	0.313397	0.325464	0.280093	0.284334	0.315496	0.289946	0.332744	0.345953	0.319711	0.279184	0.289644	0.284522	0.279184	0.279184	0.279184
20	Inspection drum guard in MAX	0.280593	0.289956	0.291041	0.243464	0.318127	0.275767	0.307149	0.31156	0.303747	0.265536	0.275479	0.270612	0.265536	0.265536	0.265536
21	Inspection Drum Jam in MAX	0.308884	0.319729	0.320974	0.313303	0.304301	0.303561	0.357425	0.363971	0.353316	0.292011	0.303224	0.297599	0.292011	0.292011	0.292011
22	Feed Roller Guard in MAX	0.274693	0.28385	0.284911	0.264745	0.293217	0.242705	0.300322	0.304609	0.296999	0.259959	0.269688	0.264929	0.259959	0.259959	0.259959
23	Roll Block Jam in MAX	0.329666	0.345535	0.34805	0.303854	0.356345	0.309886	0.319463	0.371709	0.342325	0.298036	0.309217	0.303735	0.298036	0.298036	0.298036
24	Turn Drum Jam in MAX	0.316574	0.344591	0.345885	0.304472	0.357075	0.310526	0.367537	0.325452	0.361224	0.298643	0.31011	0.304358	0.298643	0.298643	0.298643
25	Discharge Choke Up in MAX	0.299683	0.313649	0.316068	0.288699	0.338081	0.294106	0.345704	0.352864	0.297432	0.28318	0.307824	0.288853	0.28318	0.28318	0.28318
26	Motor Circuit Breaker in MAX	0.274693	0.28385	0.284911	0.264745	0.293217	0.26997	0.300322	0.304609	0.296999	0.232694	0.269688	0.264929	0.259959	0.259959	0.259959
27	Stop on link up machine (HCF)	0.28614	0.295762	0.296894	0.275775	0.305817	0.281211	0.313216	0.317733	0.329769	0.270782	0.254316	0.293898	0.270782	0.270782	0.270782
28	Tray Station (HCF)	0.28674	0.296382	0.297516	0.276353	0.306458	0.2818	0.313872	0.318399	0.330461	0.27135	0.301812	0.249648	0.27135	0.27135	0.27135
29	Operating mod change	0.274693	0.28385	0.284911	0.264745	0.293217	0.26997	0.300322	0.304609	0.296999	0.259959	0.269688	0.264929	0.232694	0.259959	0.259959
30	MLP No Communication	0.274693	0.28385	0.284911	0.264745	0.293217	0.26997	0.300322	0.304609	0.296999	0.259959	0.269688	0.264929	0.259959	0.232694	0.259959
31	Compressed air failure	0.29558	0.305441	0.306584	0.284877	0.315886	0.308068	0.323473	0.32811	0.319891	0.27972	0.290194	0.285068	0.27972	0.27972	0.252455

MULTIPLICATION OF MATRICES

T=B(I-B)^-1

Sr. No.	Failure modes	1 No Tobacco in VE	2 Trimmer guards in VE	3 Steep angle conveyer overload VE	4 Airlock Flap in VE	5 Magnetic Rail failure in VE	6 Stems in VE	7 Tobacco Rod Break in SE	8 Tobacco Paper Break in SE	9 No Tobacco Paper in SE	10 Bobbin Loader in SE	11 Ink Stock in SE	12 Knife Advance in SE	13 Dynamic Rod Monitoring in SE	14 Seam heater wire break in SE	15 No Tipping Paper in MAX	16 Tipping Paper Break in MAX	17 Filter Level in MAX	18 Filter Rod Monitor Stop in MAX	19 Filter Choke Up in MAX	20 Inspection drum guard in MAX	21 Inspection Drum Jam in MAX	22 Feed Roller Guard in MAX	23 Roll Block Jam in MAX	24 Turn Drum Jam in MAX	25 Discharge Choke Up in MAX	26 Motor Circuit Breaker in MAX	27 Stop on link up machine (HCF)	28 Tray Station (HCF)	29 Operating mod change	30 MLP No Communication	31 Compressed air failure
1	No Tobacco in VE	0.31767332	0.319946	0.33706	0.346555	0.336031	0.363714	0.329546	0.373723	0.384922	0.383	0.403524	0.387957	0.393933	0.403524	0.366467	0.375199	0.376281	0.367074	0.369836	0.397592	0.355667	0.38487	0.347797	0.343617	0.345124	0.403524	0.390395	0.394124	0.403524	0.403524	0.403524
2	Trimmer Guard in VE	0.35459964	0.34055	0.367556	0.391916	0.390017	0.419412	0.375288	0.404719	0.417497	0.415861	0.438125	0.421223	0.427711	0.438125	0.39789	0.407371	0.408547	0.39855	0.401483	0.431684	0.386164	0.417871	0.37762	0.373082	0.374717	0.438125	0.423869	0.427919	0.438125	0.438125	0.438125
3	Steep angle conveyer overload VE	0.34919124	0.331722	0.332509	0.346105	0.344761	0.398384	0.356523	0.384707	0.396845	0.395286	0.416447	0.400382	0.406549	0.416447	0.378203	0.387215	0.388332	0.37883	0.381686	0.410326	0.367057	0.397196	0.358935	0.354622	0.356177	0.416447	0.402897	0.406746	0.416447	0.416447	0.416447
4	Airlock Flap in VE	0.33450083	0.326907	0.340311	0.338515	0.345678	0.396026	0.354362	0.382146	0.394211	0.392667	0.413688	0.397729	0.403856	0.413688	0.375697	0.38465	0.385759	0.37632	0.379149	0.407607	0.364625	0.394564	0.356557	0.352272	0.353817	0.413688	0.400228	0.404051	0.413688	0.413688	0.413688
5	Magnetic Rail failure in VE	0.33231676	0.324037	0.335269	0.345404	0.334498	0.393555	0.35215	0.379759	0.391749	0.390214	0.411105	0.395245	0.401334	0.411105	0.373349	0.382246	0.383408	0.374012	0.374216	0.405061	0.362347	0.3921	0.354351	0.350132	0.351605	0.411105	0.397728	0.401528	0.411105	0.411105	0.411105
6	Stems in VE	0.30410163	0.299923	0.306604	0.312103	0.310412	0.330217	0.300382	0.323359	0.361011	0.359057	0.377924	0.363344	0.368941	0.377924	0.343218	0.351396	0.352409	0.343786	0.346384	0.372368	0.333103	0.360453	0.325732	0.321817	0.323229	0.377924	0.365627	0.36912	0.377924	0.377924	0.377924
7	Tobacco Rod Break in SE	0.3015253	0.295294	0.306718	0.311229	0.312414	0.330571	0.289522	0.324507	0.331663	0.355245	0.373568	0.359156	0.364689	0.373568	0.339261	0.347346	0.348347	0.339823	0.342377	0.368076	0.329263	0.356298	0.321978	0.318108	0.319503	0.373568	0.361413	0.364865	0.373568	0.373568	0.373568
8	Tobacco Paper Break in SE	0.33106214	0.335667	0.344674	0.367782	0.365937	0.393666	0.325087	0.347844	0.380877	0.376521	0.410431	0.394597	0.400676	0.410431	0.372739	0.381621	0.382723	0.373358	0.376104	0.404398	0.361755	0.391458	0.35375	0.3495	0.351031	0.410431	0.397077	0.40087	0.410431	0.410431	0.410431
9	No Tobacco Paper in SE	0.37453612	0.369201	0.379081	0.388138	0.385999	0.415677	0.350401	0.39075	0.382355	0.397123	0.434158	0.417409	0.423839	0.434158	0.394288	0.403683	0.404849	0.394942	0.39785	0.427776	0.382668	0.414088	0.374201	0.369705	0.371325	0.434158	0.420032	0.424045	0.434158	0.434158	0.434158
10	Bobbin Loader in SE	0.37037672	0.365012	0.37477	0.383581	0.381458	0.410807	0.343623	0.376264	0.394529	0.375441	0.429002	0.412452	0.418806	0.429002	0.389605	0.398889	0.400041	0.390252	0.393125	0.422696	0.378123	0.40917	0.369757	0.365314	0.366915	0.429002	0.415044	0.419009	0.429002	0.429002	0.429002
11	Ink Stock in SE	0.39088504	0.385379	0.395771	0.405332	0.403165	0.434027	0.388463	0.419362	0.432587	0.430883	0.421692	0.436438	0.443161	0.453951	0.412262	0.422086	0.423304	0.412946	0.415988	0.447277	0.400113	0.432965	0.39126	0.386559	0.388252	0.453951	0.43918	0.443376	0.453951	0.453951	0.453951
12	Knife Advance in SE	0.38697091	0.381546	0.39179	0.401291	0.39911	0.429736	0.371724	0.415149	0.428282	0.426271	0.449101	0.399518	0.438427	0.449101	0.407858	0.417577	0.418783	0.408535	0.411543	0.442499	0.395838	0.42834	0.38708	0.382429	0.384105	0.449101	0.434489	0.438639	0.449101	0.449101	0.449101
13	Dynamic Rod Monitoring in SE	0.37789013	0.372613	0.382581	0.391889	0.38973	0.419695	0.352911	0.405397	0.418252	0.416035	0.438324	0.406314	0.395648	0.438324	0.398071	0.407556	0.408733	0.398731	0.401667	0.431881	0.386339	0.418061	0.377791	0.373252	0.374887	0.438324	0.424062	0.428113	0.438324	0.438324	0.438324
14	Seam heater wire break in SE	0.38190342	0.376523	0.386678	0.396017	0.393902	0.424052	0.380075	0.409726	0.422646	0.420994	0.443533	0.426781	0.40999	0.411274	0.402801	0.412399	0.41359	0.403469	0.406441	0.437013	0.39093	0.423029	0.382281	0.377687	0.379342	0.443533	0.429101	0.4332	0.443533	0.443533	0.443533
15	No Tipping Paper in MAX	0.34423889	0.33939	0.348542	0.356961	0.355054	0.382233	0.342106	0.369317	0.380964	0.379463	0.399778	0.384356	0.390277	0.399778	0.332273	0.356772	0.373392	0.365253	0.367857	0.394121	0.339211	0.358281	0.320907	0.317831	0.317996	0.399778	0.387211	0.390455	0.399778	0.399778	0.399778
16	Tipping Paper Break in MAX	0.35314191	0.348168	0.357556	0.366194	0.364236	0.392118	0.350954	0.378869	0.390817	0.389277	0.410118	0.394296	0.40037	0.410118	0.358532	0.350579	0.382812	0.374503	0.377228	0.404466	0.338885	0.39149	0.337803	0.326282	0.326599	0.410118	0.397219	0.400553	0.410118	0.410118	0.410118
17	Filter Level in MAX	0.36272398	0.357615	0.367258	0.37613	0.374119	0.402758	0.360476	0.389149	0.401422	0.39984	0.421246	0.404995	0.411234	0.421246	0.383577	0.392775	0.361843	0.36942	0.372005	0.415037	0.372283	0.401748	0.340646	0.334011	0.361126	0.421246	0.407524	0.411433	0.421246	0.421246	0.421246
18	Filter Rod Monitor Stop in MAX	0.35875498	0.353702	0.363239	0.372014	0.370026	0.398351	0.356532	0.384891	0.397029	0.395465	0.416637	0.400563	0.406734	0.416637	0.378959	0.388024	0.366344	0.348463	0.372212	0.410492	0.3684	0.397362	0.345342	0.341066	0.331491	0.416637	0.403538	0.40692	0.416637	0.416637	0.416637
19	Filter choke up in MAX	0.36480345	0.359665	0.369363	0.378286	0.376264	0.405067	0.362543	0.39138	0.403723	0.402132	0.423661	0.407317	0.413591	0.423661	0.385397	0.394611	0.372888	0.369166	0.357169	0.417422	0.374053	0.404061	0.357512	0.338224	0.363235	0.423661	0.40986	0.413792	0.423661	0.423661	0.423661
20	Inspection drum guard in MAX	0.38278994	0.377398	0.387575	0.396937	0.394816	0.425039	0.380418	0.410677	0.423628	0.421959	0.444549	0.427399	0.433983	0.444549	0.404042	0.413667	0.414526	0.404366	0.407346	0.406127	0.369573	0.423991	0.383638	0.37887	0.380699	0.444549	0.430076	0.434194	0.444549	0.444549	0.444549
21	Inspection Drum Jam in MAX	0.35284632	0.347876	0.357257	0.365887	0.363931	0.39179	0.35066	0.378552	0.39049	0.388952	0.409775	0.393966	0.400035	0.409775	0.358323	0.366952	0.382652	0.374013	0.376692	0.387574	0.331133	0.39116	0.332222	0.335128	0.329223	0.409775	0.396833	0.400219	0.409775	0.409775	0.409775
22	Feed Roller Guard in MAX	0.39088504	0.385379	0.395771	0.405332	0.403165	0.434027	0.388463	0.419362	0.432587	0.430883	0.453951	0.436438	0.443161	0.453951	0.412262	0.422086	0.423304	0.412946	0.415988	0.447277	0.400113	0.400707	0.39126	0.386559	0.388252	0.453951	0.43918	0.443376	0.453951	0.453951	0.453951
23	Roll Block Jam in MAX	0.33718517	0.332436	0.3414	0.349647	0.347778	0.3744	0.335096	0.36175	0.373158	0.371688	0.391587	0.37648	0.38228	0.391587	0.334305	0.340664	0.338274	0.335831	0.344601	0.386167	0.324968	0.373991	0.307878	0.321066	0.337359	0.391587	0.3788	0.382466	0.391587	0.391587	0.391587
24	Turn Drum Jam in MAX	0.33655965	0.331819	0.340767	0.348998	0.347133	0.373706	0.334474	0.361078	0.372466	0.370998	0.39086	0.375782	0.38157	0.39086	0.334879	0.342091	0.365882	0.332242	0.334697	0.38546	0.323788	0.373269	0.326069	0.303337	0.314182	0.39086	0.378513	0.381746	0.39086	0.39086	0.39086
25	Discharge Choke Up in MAX	0.34423306	0.339385	0.348536	0.356955	0.355048	0.382226	0.3421	0.369311	0.380958	0.379457	0.399772	0.384349	0.39027	0.399772	0.364236	0.372965	0.374475	0.343308	0.342923	0.394262	0.330378	0.381263	0.321341	0.325243	0.311272	0.399772	0.36891	0.390889	0.399772	0.399772	0.399772
26	Motor Circuit Breaker in MAX	0.39088504	0.385379	0.395771	0.405332	0.403165	0.434027	0.388463	0.419362	0.432587	0.430883	0.453951	0.436438	0.443161	0.453951	0.412262	0.422086	0.423304	0.412946	0.415988	0.447277	0.400113	0.432965	0.39126	0.386559	0.388252	0.421692	0.43918	0.443376	0.453951	0.453951	0.453951
27	Stop on link up machine (HCF)	0.37585321	0.370559	0.380551	0.389744	0.387661	0.417336	0.373524	0.403235	0.415951	0.414313	0.436493	0.419654	0.426119	0.436493	0.396389	0.405833	0.406998	0.397408	0.400384	0.430071	0.385095	0.416316	0.376603	0.371948	0.357051	0.436493	0.390733	0.403007	0.436493	0.436493	0.436493
28	Tray Station (HCF)	0.37850545	0.373174	0.383237	0.392494	0.390397	0.420281	0.37616	0.40608	0.418887	0.417236	0.439574	0.422616	0.429126	0.439574	0.399186	0.408697	0.40987	0.400212	0.403209	0.433106	0.387812	0.419253	0.379261	0.374573	0.359571	0.439574	0.408929	0.397469	0.439574	0.439574	0.439574
29	Operating mod change	0.39088504	0.385379	0.395771	0.405332	0.403165	0.434027	0.388463	0.419362	0.432587	0.430883	0.453951	0.436438	0.443161	0.453951	0.412262	0.422086	0.423304	0.412946	0.415988	0.447277	0.400113	0.432965	0.39126	0.386559	0.388252	0.453951	0.43918	0.443376	0.421692	0.453951	0.453951
30	MLP No Communication	0.39088504	0.385379	0.395771	0.405332	0.403165	0.434027	0.388463	0.419362	0.432587	0.430883	0.453951	0.436438	0.443161	0.453951	0.412262	0.422086	0.423304	0.412946	0.415988	0.447277	0.400113	0.432965	0.39126	0.386559	0.388252	0.453951	0.43918	0.443376	0.453951	0.421692	0.453951
31	Compressed air failure	0.35472693	0.349733	0.359167	0.367848	0.365884	0.393887	0.3534	0.381062	0.392929	0.368453	0.411992	0.373506	0.4022	0.411992	0.349274	0.383456	0.384163	0.374737	0.3775	0.40593	0.363468	0.369672	0.355703	0.35141	0.352981	0.411992	0.398576	0.402395	0.411992	0.411992	0.379734

MULTIPLICATION OF MATRICES

T=C(I-C)^-1

Sr. No.	Failure modes	1 No Tobacco in VE	2 Trimmer guards in VE	3 Steep angle conveyer overload VE	4 Airlock Flap in VE	5 Magnetic Rail failure in VE	6 Stems in VE	7 Tobacco Rod Break in SE	8 Tobacco Paper Break in SE	9 No Tobacco Paper in SE	10 Bobbin Loader in SE	11 Ink Stock in SE	12 Knife Advance in SE	13 Dynamic Rod Monitoring in SE	14 Seam heater wire break in SE	15 No Tipping Paper in MAX	16 Tipping Paper Break in MAX	17 Filter Level in MAX	18 Filter Rod Monitor Stop in MAX	19 Filter Choke Up in MAX	20 Inspection drum guard in MAX	21 Inspection Drum Jam in MAX	22 Feed Roller Guard in MAX	23 Roll Block Jam in MAX	24 Turn Drum Jam in MAX	25 Discharge Choke Up in MAX	26 Motor Circuit Breaker in MAX	27 Stop on link up machine (HCF)	28 Tray Station (HCF)	29 Operating mod change	30 MLP No Communication	31 Compressed air failure
1	No Tobacco in VE	0.317582	0.3201417	0.337328	0.34678	0.336231	0.36392	0.32981	0.373592	0.384808	0.383221	0.403704	0.388156	0.394051	0.403704	0.366652	0.375387	0.376582	0.367257	0.370588	0.397774	0.355857	0.385053	0.348663	0.343813	0.345343	0.403704	0.389696	0.394327	0.403704	0.403704	0.403704
2	Trimmer Guard in VE	0.354508	0.340743	0.367834	0.392102	0.390204	0.419596	0.375515	0.404563	0.417358	0.416085	0.438303	0.421422	0.427822	0.438303	0.398075	0.407559	0.408856	0.398732	0.402349	0.431864	0.386355	0.418052	0.378544	0.373278	0.374939	0.438303	0.423093	0.428122	0.438303	0.438303	0.438303
3	Steep angle conveyer overload	0.347946	0.3316235	0.332414	0.345962	0.344627	0.398215	0.356428	0.384207	0.396352	0.395138	0.416238	0.400207	0.406285	0.416238	0.378035	0.387041	0.388273	0.378659	0.382093	0.410123	0.366905	0.397007	0.359487	0.354486	0.356064	0.416238	0.401794	0.406569	0.416238	0.416238	0.416238
4	Airlock Flap in VE	0.334397	0.3270767	0.340538	0.338672	0.34586	0.39618	0.354559	0.381979	0.394061	0.392858	0.413836	0.397897	0.40394	0.413836	0.375854	0.384808	0.386033	0.376474	0.379889	0.407757	0.364787	0.394716	0.357413	0.352441	0.354009	0.413836	0.399475	0.404223	0.413836	0.413836	0.413836
5	Magnetic Rail failure in VE	0.333175	0.3251505	0.33645	0.346575	0.335644	0.394773	0.353299	0.380621	0.39266	0.391462	0.412365	0.396483	0.402505	0.412365	0.374518	0.38344	0.384661	0.375136	0.378539	0.406307	0.363491	0.393313	0.356142	0.351188	0.352751	0.412365	0.398056	0.402786	0.412365	0.412365	0.412365
6	Stems in VE	0.304009	0.3000798	0.306802	0.31225	0.310559	0.330357	0.300574	0.323211	0.360895	0.359231	0.378059	0.363498	0.369019	0.378059	0.34336	0.351541	0.35266	0.343927	0.347047	0.372505	0.333251	0.360592	0.326514	0.321972	0.323405	0.378059	0.36494	0.369277	0.378059	0.378059	0.378059
7	Tobacco Rod Break in SE	0.301463	0.2954792	0.306956	0.311411	0.312613	0.330751	0.289728	0.324428	0.331596	0.35545	0.373738	0.359344	0.364801	0.373738	0.339436	0.347523	0.348629	0.339997	0.34308	0.368248	0.329442	0.356471	0.322782	0.318292	0.319708	0.373738	0.360769	0.365057	0.373738	0.373738	0.373738
8	Tobacco Paper Break in SE	0.330698	0.335622	0.34466	0.367674	0.365831	0.393536	0.325051	0.347422	0.379647	0.376487	0.410282	0.394481	0.400472	0.410282	0.372626	0.381504	0.382718	0.373241	0.376627	0.404255	0.361655	0.391327	0.354344	0.349415	0.350969	0.410282	0.396045	0.400752	0.410282	0.410282	0.410282
9	No Tobacco Paper in SE	0.374141	0.369117	0.379031	0.388021	0.385883	0.415535	0.350384	0.389481	0.381911	0.397075	0.433997	0.417282	0.423619	0.433997	0.394164	0.403555	0.404839	0.394815	0.398396	0.427621	0.382559	0.413945	0.374825	0.369611	0.371255	0.433997	0.418937	0.423915	0.433997	0.433997	0.433997
10	Bobbin Loader in SE	0.370266	0.3652135	0.375013	0.383778	0.381655	0.411001	0.343864	0.376163	0.394464	0.37567	0.429191	0.412661	0.418928	0.429191	0.389799	0.399086	0.400356	0.390443	0.393984	0.422886	0.378322	0.409361	0.370674	0.365518	0.367144	0.429191	0.414297	0.419221	0.429191	0.429191	0.429191
11	Ink Stock in SE	0.390731	0.3855547	0.39599	0.405499	0.403333	0.434189	0.388673	0.41917	0.432414	0.431084	0.421845	0.436614	0.443245	0.454104	0.412425	0.422251	0.423595	0.413106	0.416853	0.447433	0.400283	0.433123	0.39219	0.386735	0.388456	0.454104	0.438346	0.443555	0.454104	0.454104	0.454104
12	Knife Advance in SE	0.386824	0.3817259	0.392013	0.401464	0.399282	0.429903	0.371961	0.414966	0.428117	0.426478	0.449261	0.3997	0.438518	0.449261	0.408027	0.417748	0.419078	0.408701	0.412408	0.442661	0.396014	0.428504	0.388008	0.38261	0.384313	0.449261	0.433671	0.438825	0.449261	0.449261	0.449261
13	Dynamic Rod Monitoring in SE	0.377762	0.3728033	0.382814	0.392073	0.389913	0.419874	0.353154	0.405234	0.418108	0.416254	0.438497	0.40655	0.395754	0.438497	0.398251	0.40774	0.409037	0.398909	0.402527	0.432056	0.386526	0.418238	0.378712	0.373444	0.375105	0.438497	0.423281	0.428311	0.438497	0.438497	0.438497
14	Seam heater wire break in SE	0.381698	0.3766403	0.386836	0.396124	0.394009	0.424149	0.380228	0.40948	0.422416	0.421131	0.443618	0.426893	0.40987	0.41136	0.402903	0.412501	0.413814	0.403568	0.407228	0.437101	0.39104	0.423122	0.383135	0.377805	0.379486	0.443618	0.428224	0.433314	0.443618	0.443618	0.443618
15	No Tipping Paper in MAX	0.344778	0.3402106	0.349419	0.357809	0.355898	0.383125	0.342962	0.369872	0.381558	0.380385	0.400698	0.385265	0.391116	0.400698	0.333086	0.357642	0.374321	0.366069	0.369311	0.39503	0.340054	0.359183	0.324186	0.318636	0.318853	0.400698	0.387292	0.391378	0.400698	0.400698	0.400698
16	Tipping Paper Break in MAX	0.353032	0.3483554	0.357784	0.366375	0.364418	0.392297	0.351172	0.378727	0.390693	0.389492	0.41029	0.394488	0.40048	0.41029	0.358751	0.350758	0.3831	0.374678	0.378039	0.40464	0.339075	0.391664	0.338648	0.326475	0.326814	0.41029	0.396557	0.400748	0.41029	0.41029	0.41029
17	Filter Level in MAX	0.362641	0.3578373	0.367522	0.376348	0.374337	0.402975	0.360731	0.389036	0.401327	0.400094	0.421458	0.405226	0.41138	0.421458	0.383791	0.392992	0.362165	0.369671	0.372924	0.41525	0.372502	0.401962	0.341584	0.334236	0.361372	0.421458	0.406881	0.411667	0.421458	0.421458	0.421458
18	Filter Rod Monitor Stop in MAX	0.358359	0.3536119	0.363183	0.371904	0.369917	0.398216	0.356472	0.384442	0.396589	0.395369	0.416482	0.400441	0.406523	0.416482	0.378838	0.387898	0.366365	0.34835	0.371932	0.410344	0.368293	0.397226	0.345988	0.341033	0.331429	0.416482	0.402522	0.406795	0.416482	0.416482	0.416482
19	Filter choke up in MAX	0.36471	0.3598786	0.369619	0.378495	0.376473	0.405274	0.362789	0.391255	0.403617	0.402376	0.423862	0.407538	0.413727	0.423862	0.385601	0.394819	0.373228	0.369403	0.358041	0.417625	0.374262	0.404264	0.358433	0.33845	0.363472	0.423862	0.409196	0.414016	0.423862	0.423862	0.423862
20	Inspection drum guard in MAX	0.382645	0.377576	0.387795	0.397108	0.394986	0.425203	0.380629	0.410496	0.423465	0.422163	0.444706	0.427579	0.434073	0.444706	0.404207	0.413834	0.414817	0.404529	0.4082	0.406286	0.369766	0.424153	0.384555	0.379047	0.380903	0.444706	0.429265	0.434377	0.444706	0.444706	0.444706
21	Inspection Drum Jam in MAX	0.352757	0.3480837	0.357505	0.36609	0.364134	0.391991	0.350899	0.378432	0.390388	0.389188	0.40997	0.394181	0.400167	0.40997	0.358531	0.367194	0.382959	0.374208	0.377523	0.387783	0.331332	0.391357	0.333104	0.335375	0.329472	0.40997	0.396171	0.400437	0.40997	0.40997	0.40997
22	Feed Roller Guard in MAX	0.390731	0.3855547	0.39599	0.405499	0.403333	0.434189	0.388673	0.41917	0.432414	0.431084	0.454104	0.436614	0.443245	0.454104	0.412425	0.422251	0.423595	0.413106	0.416853	0.447433	0.400283	0.400865	0.39219	0.386735	0.388456	0.454104	0.438346	0.443555	0.454104	0.454104	0.454104
23	Roll Block Jam in MAX	0.33727	0.3328019	0.341809	0.350017	0.348147	0.374782	0.335493	0.361818	0.373249	0.372102	0.391972	0.376875	0.382599	0.391972	0.334694	0.341047	0.339184	0.336217	0.34563	0.386549	0.325363	0.374367	0.308845	0.32146	0.337747	0.391972	0.378357	0.382867	0.391972	0.391972	0.391972
24	Turn Drum Jam in MAX	0.335492	0.3310482	0.340008	0.348173	0.346313	0.372807	0.333725	0.359911	0.371283	0.370141	0.389906	0.374889	0.380583	0.389906	0.334059	0.341241	0.365112	0.331396	0.33447	0.384523	0.322994	0.372368	0.325935	0.302557	0.313487	0.389906	0.374236	0.380901	0.389906	0.389906	0.389906
25	Discharge Choke Up in MAX	0.344146	0.3395876	0.348779	0.357154	0.355246	0.382423	0.342334	0.369195	0.38086	0.379689	0.399964	0.384559	0.3904	0.399964	0.36443	0.373162	0.374772	0.343522	0.34376	0.394454	0.330596	0.381457	0.322216	0.325482	0.311496	0.399964	0.368272	0.391102	0.399964	0.399964	0.399964
26	Motor Circuit Breaker in MAX	0.390731	0.3855547	0.39599	0.405499	0.403333	0.434189	0.388673	0.41917	0.432414	0.431084	0.454104	0.436614	0.443245	0.454104	0.412425	0.422251	0.423595	0.413106	0.416853	0.447433	0.400283	0.433123	0.39219	0.386735	0.388456	0.421845	0.438346	0.443555	0.454104	0.454104	0.454104
27	Stop on link up machine (HCF)	0.375723	0.3707457	0.38078	0.389924	0.387841	0.417512	0.373744	0.40307	0.415805	0.414526	0.436662	0.419844	0.42622	0.436662	0.396565	0.406012	0.407297	0.39758	0.401234	0.430241	0.385276	0.416488	0.377515	0.372134	0.357303	0.436662	0.389949	0.403214	0.436662	0.436662	0.436662
28	Tray Station (HCF)	0.378384	0.3733719	0.383477	0.392686	0.390588	0.420469	0.376391	0.405925	0.41875	0.417463	0.439755	0.422818	0.429239	0.439755	0.399374	0.408888	0.410182	0.400396	0.404076	0.433288	0.388005	0.419438	0.380189	0.37477	0.359834	0.439755	0.408191	0.397674	0.439755	0.439755	0.439755
29	Operating mod change	0.390731	0.3855547	0.39599	0.405499	0.403333	0.434189	0.388673	0.41917	0.432414	0.431084	0.454104	0.436614	0.443245	0.454104	0.412425	0.422251	0.423595	0.413106	0.416853	0.447433	0.400283	0.433123	0.39219	0.386735	0.388456	0.454104	0.438346	0.443555	0.421845	0.454104	0.454104
30	MLP No Communication	0.390731	0.3855547	0.39599	0.405499	0.403333	0.434189	0.388673	0.41917	0.432414	0.431084	0.454104	0.436614	0.443245	0.454104	0.412425	0.422251	0.423595	0.413106	0.416853	0.447433	0.400283	0.433123	0.39219	0.386735	0.388456	0.454104	0.438346	0.443555	0.454104	0.421845	0.454104
31	Compressed air failure	0.354592	0.3498972	0.359371	0.368005	0.366041	0.394039	0.353593	0.380892	0.392775	0.36866	0.412136	0.373691	0.402281	0.412136	0.349434	0.383611	0.384433	0.374888	0.378291	0.406076	0.363627	0.369834	0.356507	0.35174	0.353169	0.412136	0.397822	0.402563	0.412136	0.412136	0.379878

Appendix G: Influence Degree and the Degree of being Influenced

Influence Degree (FI) and the Degree of Being Influenced (FJ)

[illegible]	[illegible]

Prominence (pI) and Relation (rI)

Appendix H: Calculation of Prominence and Relation

Results Deduced From Prominence (pi) and Relation (ri) Values														
		P			R			p=P+R			r=P-R			
No.	Critieria	Ex	En	He	Ex	En	He	Ex	En	He	Ex	En	He	Cause or Effect
1	No Tobacco in VE	9.26003538	11.82024193	11.82534915	9.494459693	11.61870722	11.61848317	18.75449507	16.57445254	16.57793816	-0.234424317	16.57445254	16.57793816	Effect
2	Trimmer Guard in VE	8.6040093	12.35528377	12.36037436	9.343606671	11.53003356	11.53511447	17.94761597	16.89954765	16.90673594	-0.739597369	16.89954765	16.90673594	Effect
3	Steep angle conveyer	9.05807097	12.02158838	12.02061223	9.469899862	11.69710844	11.70287733	18.52797083	16.77322071	16.77654483	-0.411828891	16.77322071	16.77654483	Effect
4	Airlock Flap in VE	9.18938593	11.97850715	11.98310486	9.410277055	11.84909397	11.85402465	18.59966299	16.84890683	16.85564305	-0.220891122	16.84890683	16.85564305	Effect
5	Magnetic Rail failure in VE	9.17805122	11.93791239	11.9600189	9.217357713	11.81487827	11.81981509	18.39540893	16.79598466	16.81517412	-0.039306491	16.79598466	16.81517412	Effect
6	Stems in VE	9.28498642	11.40730929	11.41170982	8.682087828	12.29435518	12.29919094	17.96707425	16.77134087	16.77787885	0.602898591	16.77134087	16.77787885	Cause
7	Tobacco Rod Break in SE	9.8272871	11.33478996	11.33978995	9.423992165	11.57535809	11.58101447	19.25127927	16.20081412	16.20835378	0.403294936	16.20081412	16.20835378	Cause
8	Tobacco Paper Break in SE	9.15517862	11.92862181	11.92857812	9.219385684	12.06670835	12.0660442	18.3745643	16.96754162	16.9670386	-0.064207065	16.96754162	16.9670386	Effect
9	No Tobacco Paper in SE	9.16361557	12.29564085	12.29555701	9.043203754	12.27132851	12.27104685	18.20681932	17.37147913	17.37122083	0.120411813	17.37147913	17.37122083	Cause
10	Bobbin Loader in SE	9.1406555	12.21694595	12.22220292	9.135390405	12.24322117	12.24868022	18.27604591	17.29596002	17.30353754	0.005265096	17.29596002	17.30353754	Cause
11	Ink Stock in SE	8.53467089	12.59260361	12.59730982	8.534670888	12.59260361	12.59730982	17.06934178	17.80863081	17.81528639	0	17.80863081	17.81528639	NIL
12	Knife Advance in SE	8.71064272	12.52091806	12.52571872	8.910609859	12.32778959	12.33285112	17.62125258	17.57122037	17.57819235	-0.199967136	17.57122037	17.57819235	Effect
13	Dynamic Rod Monitoring in	8.94272556	12.35852317	12.36353266	8.584415304	12.4299961	12.43365353	17.52714086	17.52820293	17.53432862	0.358310254	17.52820293	17.53432862	Cause
14	Seam heater wire break in	8.58654421	12.43602681	12.43971334	8.534670888	12.59260361	12.59730982	17.1212151	17.69826061	17.70419957	0.051873325	17.69826061	17.70419957	Cause
15	No Tipping Paper in MAX	9.7250495	11.76037064	11.77724062	9.510517356	11.95682846	11.9616698	19.23556686	16.77116765	16.78645112	0.214532147	16.77116765	16.78645112	Cause
16	Tipping Paper Break in MAX	9.49370461	11.92510028	11.93012303	9.386810954	12.11128028	12.1161488	18.88051557	16.99679755	17.00379067	0.10689366	16.99679755	17.00379067	Cause
17	Filter Level in MAX	9.35778024	12.09767366	12.10332851	9.07510569	12.12902758	12.13579628	18.43288593	17.13087908	17.13966489	0.28267455	17.13087908	17.13966489	Cause
18	Monitor Stop in MAX	9.57652127	12.02592706	12.02583269	9.410946671	11.96930101	11.97407553	18.98746794	16.96723573	16.97053731	0.165574598	16.96723573	16.97053731	Cause
19	Filter choke up in MAX	9.23981579	12.13447896	12.13996572	9.449873894	12.01680871	12.03255557	18.68968969	17.07774198	17.09272247	-0.2100581	17.07774198	17.09272247	Effect
20	Inspection drum guard in	8.73922378	12.45212575	12.45688825	8.710230368	12.4932504	12.49799058	17.44945415	17.63906861	17.64578798	0.028993413	17.63906861	17.64578798	Cause
21	Inspection Drum Jam in	9.71028235	11.91881342	11.92418683	9.754510393	11.76582026	11.77077102	19.46479274	16.74791449	16.75521656	-0.044228044	16.74791449	16.75521656	Effect
22	Feed Roller Guard in MAX	8.53467089	12.59260361	12.59730982	8.901852398	12.27545443	12.28023458	17.43652329	17.58580243	17.59250909	-0.36718151	17.58580243	17.59250909	Effect
23	Roll Block Jam in MAX	9.93127956	11.6288301	11.63727856	10.015121	11.62433557	11.64154021	19.94640056	16.44247144	16.46061088	-0.083841443	16.44247144	16.46061088	Effect
24	Turn Drum Jam in MAX	9.9535388	11.61761385	11.60436849	10.17234073	11.54774357	11.55277887	20.12587954	16.38045583	16.37461657	-0.218801929	16.38045583	16.37461657	Effect
25	Discharge Choke Up in	9.38638031	11.75982204	11.76517094	9.893239416	11.57430282	11.57984657	19.27961973	16.5002394	16.50794033	-0.506859103	16.5002394	16.50794033	Effect
26	Motor Circuit Breaker in	8.53467089	12.59260361	12.59730982	8.534670888	12.59260361	12.59730982	17.06934178	17.80863081	17.81528639	0	17.80863081	17.81528639	NIL
27	Stop on link up machine (HCF)	8.93166759	12.32985112	12.33478337	8.891525801	12.37101549	12.36084723	17.8231934	17.46617453	17.46245759	0.040141793	17.46617453	17.46245759	Cause
28	Tray Station (HCF)	8.95248688	12.37681845	12.38194604	8.716960844	12.43364303	12.43877455	17.66944773	17.54369157	17.55094585	0.235526038	17.54369157	17.55094585	Cause
29	Operating mod change	8.53467089	12.59260361	12.59730982	8.534670888	12.59260361	12.59730982	17.06934178	17.80863081	17.81528639	0	17.80863081	17.81528639	NIL
30	MLP No Communicatio	8.53467089	12.59260361	12.59730982	8.534670888	12.59260361	12.59730982	17.06934178	17.80863081	17.81528639	0	17.80863081	17.81528639	NIL
31	Compressed air failure	9.25947319	11.95015402	11.95469854	8.534670888	12.59260361	12.59730982	17.79414408	17.36029513	17.36683712	0.724802307	17.36029513	17.36683712	Cause

Appendix I: Grouping of Faults

Results based on Relation (ri) values					
Based on Relation values (r=P-R), Negative Values indicate Effects, While Positive Values Indicate Causes					
Sr No.	CAUSE GROUP	Sr No.	EFFECT GROUP		Nil
1	Stems in VE	1	No Tobacco in VE	1	Ink Stock in SE
2	Tobacco Rod Break in SE	2	Trimmer Guard in VE	2	Motor Circuit Breaker in MAX
3	No Tobacco Paper in SE	3	Steep angle conveyer overload VE	3	Operating mod change
4	Bobbin Loader in SE	4	Airlock Flap in VE	4	MLP No Communication
5	Dynamic Rod Monitoring in SE	5	Magnetic Rail failure in VE		
6	Seam heater wire break in SE	6	Tobacco Paper Break in SE		
7	No Tipping Paper in MAX	7	Knife Advance in SE		
8	Tipping Paper Break in MAX	8	Filter choke up in MAX		
9	Filter Level in MAX	9	Inspection Drum Jam in MAX		
10	Filter Rod Monitor Stop in MAX	10	Feed Roller Guard in MAX		
11	Inspection drum guard in MAX	11	Roll Block Jam in MAX		
12	Stop on link up machine (HCF)	12	Turn Drum Jam in MAX		
13	Tray Station (HCF)	13	Discharge Choke Up in MAX		
14	Compressed air failure				

Appendix J: Ranking of grouped faults

Ranking based on Prominence values in Descending Order

RANK	FAILURE MODE	Pi Value	Cause Effect Group	
1	Turn Drum Jam in	20.1258795	Effect	Highest Pominence Value
2	Roll Block Jam in I	19.9464006	Effect	
3	Inspection Drum J	19.4647927	Effect	
4	Discharge Choke U	19.2796197	Effect	
5	Tobacco Rod Brea	19.2512793	Cause	
6	No Tipping Paper	19.2355669	cause	
7	Filter Rod Monito	18.9874679	cause	
8	Tipping Paper Bre	18.8805156	cause	
9	No Tobacco in VE	18.7544951	effect	
10	Filter choke up in	18.6896897	effect	
11	Airlock Flap in VE	18.599663	Effect	
12	Steep angle conve	18.5279708	Effect	
13	Filter Level in MA	18.4328859	cause	
14	Magnetic Rail failu	18.3954089	Effect	
15	Tobacco Paper Bre	18.3745643	Effect	
16	Bobbin Loader in S	18.2760459	Cause	
17	No Tobacco Paper	18.2068193	cause	
18	Stems in VE	17.9670742	Cause	
19	Trimmer Guard in	17.947616	Effect	
20	Stop on link up ma	17.8231934	Cause	
21	Compressed air fa	17.7941441	Cause	
22	Tray Station (HCF)	17.6694477	Cause	
23	Knife Advance in S	17.6212526	Effect	
24	Dynamic Rod Mon	17.5271409	Cause	
25	Inspection drum g	17.4494541	Cause	
26	Feed Roller Guard	17.4365233	Effect	
27	Seam heater wire	17.1212151	Cause	
28	MLP No Communi	17.0693418	Nil	
29	Operating mod ch	17.0693418	Nil	
30	Motor Circuit Brea	17.0693418	Nil	
31	Ink Stock in SE	17.0693418	Nil	

Ranking Cause Group Based on Prominence Values

RANK	FAILURE MODES	Pi Value	
1	Tobacco Rod Brea	19.2512793	Highest Among Causes
2	No Tipping Paper	19.2355669	
3	Filter Rod Monito	18.9874679	
4	Tipping Paper Bre	18.8805156	
5	Filter Level in MA	18.4328859	
6	Bobbin Loader in S	18.2760459	
7	No Tobacco Paper	18.2068193	
8	Stems in VE	17.9670742	
9	Stop on link up ma	17.8231934	
10	Compressed air fa	17.7941441	
11	Tray Station (HCF)	17.6694477	
12	Dynamic Rod Mon	17.5271409	
13	Inspection drum g	17.4494541	
14	Seam heater wire	17.1212151	Lowest Among Causes

Ranking Effect Group based on Prominence Values

RANK	FAILURE MODE	pi Value	
1	Turn Drum Jam in	20.1258795	Highest Among Effects
2	Roll Block Jam in I	19.9464006	
3	Inspection Drum J	19.4647927	
4	Discharge Choke U	19.2796197	
5	No Tobacco in VE	18.7544951	
6	Filter choke up in	18.6896897	
7	Airlock Flap in VE	18.599663	
8	Steep angle conve	18.5279708	
9	Magnetic Rail failu	18.3954089	
10	Tobacco Paper Bre	18.3745643	
11	Trimmer Guard in	17.947616	
12	Knife Advance in S	17.6212526	
13	Feed Roller Guard	17.4365233	Lowest among Effects

No Cause No Effect Group

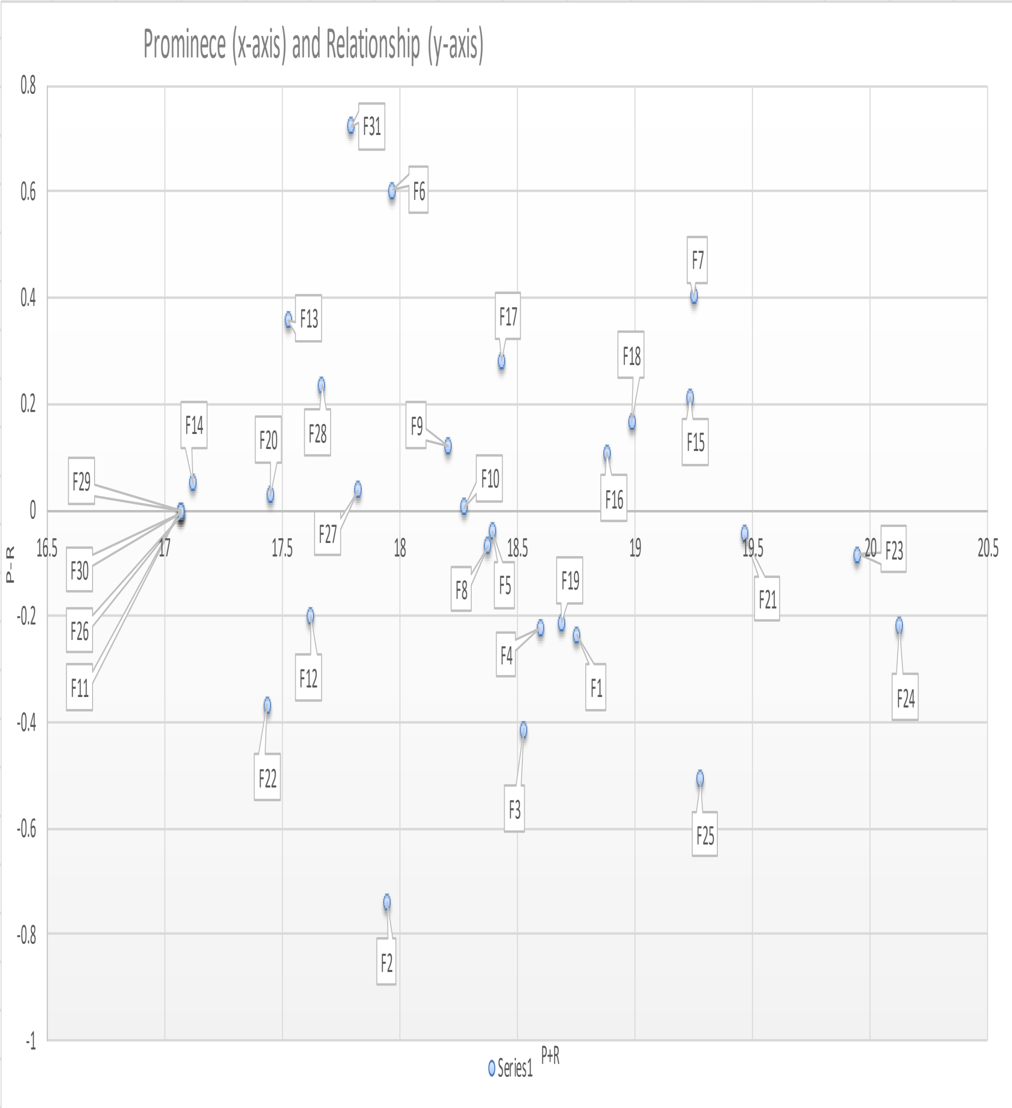
RANK	FAILURE MODES	pi Valuues	
SAME	MLP No Communi	17.0693418	These four failure modes have a relation values of Zero, which Neither falls in cause group nor in Effect Group
SAME	Operating mod ch	17.0693418	Moreover, they also show the same values of Prominence, indicating correctness of calculations
SAME	Motor Circuit Brea	17.0693418	
SAME	Ink Stock in SE	17.0693418	

No.	Critieria	Pi	Rj	pi=Pi+Rj	ri=Pi-Rj	Cause or Effect
1	No Tobacco in VE	9.260035376	9.494459693	18.7544951	-0.2344243	Effect
2	Trimmer Guard in VE	8.604009302	9.343606671	17.947616	-0.7395974	Effect
3	Steep angle conveyer	9.058070971	9.469899862	18.5279708	-0.4118289	Effect
4	Airlock Flap in VE	9.189385932	9.410277055	18.599663	-0.2208911	Effect
5	Magnetic Rail failure in VE	9.178051221	9.217357713	18.3954089	-0.0393065	Effect
6	Stems in VE	9.284986418	8.682087828	17.9670742	0.60289859	Cause
7	Tobacco Rod Break in SE	9.827287101	9.423992165	19.2512793	0.40329494	Cause
8	Tobacco Paper Break in SE	9.155178619	9.219385684	18.3745643	-0.0642071	Effect
9	No Tobacco Paper in SE	9.163615567	9.043203754	18.2068193	0.12041181	Cause
10	Bobbin Loader in SE	9.140655502	9.135390405	18.2760459	0.0052651	Cause
11	Ink Stock in SE	8.534670888	8.534670888	17.0693418	0	NIL
12	Knife Advance in SE	8.710642723	8.910609859	17.6212526	-0.1999671	Effect
13	Dynamic Rod Monitoring	8.942725558	8.584415304	17.5271409	0.35831025	Cause
14	Seam heater wire break	8.586544212	8.534670888	17.1212151	0.05187332	Cause
15	No Tipping Paper in MAX	9.725049504	9.510517356	19.2355669	0.21453215	Cause
16	Tipping Paper Break in	9.493704614	9.386810954	18.8805156	0.10689366	Cause
17	Filter Level in MAX	9.35778024	9.07510569	18.4328859	0.28267455	Cause
18	Filter Rod Monitor Stop in	9.57652127	9.410946671	18.9874679	0.1655746	Cause
19	Filter choke up in MAX	9.239815795	9.449873894	18.6896897	-0.2100581	Effect
20	Inspection drum guard in MAX	8.739223781	8.710230368	17.4494541	0.02899341	Cause
21	Inspection Drum Jam in MAX	9.710282349	9.754510393	19.4647927	-0.044228	Effect
22	Feed Roller Guard in MAX	8.534670888	8.901852398	17.4365233	-0.3671815	Effect
23	Roll Block Jam in MAX	9.931279558	10.015121	19.9464006	-0.0838414	Effect
24	Turn Drum Jam in MAX	9.953538805	10.17234073	20.1258795	-0.2188019	Effect
25	Discharge Choke Up in MAX	9.386380313	9.893239416	19.2796197	-0.5068591	Effect
26	Motor Circuit Breaker in	8.534670888	8.534670888	17.0693418	0	NIL
27	Stop on link up machine	8.931667594	8.891525801	17.8231934	0.04014179	Cause
28	Tray Station (HCF)	8.952486882	8.716960844	17.6694477	0.23552604	Cause
29	Operating mod change	8.534670888	8.534670888	17.0693418	0	NIL
30	MLP No Communication	8.534670888	8.534670888	17.0693418	0	NIL
31	Compressed air failure	9.259473195	8.534670888	17.7941441	0.72480231	Cause

Appendix K: Scatter Diagram

Drawing Scatter Diagram based on the Values of Prominence (p=P+R) and Relationship (r=P-R)

Sr. No.	Modes	p=P+R	r=P-R
F1	No Tobacco i	18.7545	-0.2344243
F2	Trimmer Gua	17.94762	-0.7395974
F3	Steep angle c	18.52797	-0.4118289
F4	Airlock Flap i	18.59966	-0.2208911
F5	Magnetic Rail	18.39541	-0.0393065
F6	Stems in VE	17.96707	0.6028986
F7	Tobacco Rod	19.25128	0.4032949
F8	Tobacco Pape	18.37456	-0.0642071
F9	No Tobacco P	18.20682	0.1204118
F10	Bobbin Loade	18.27605	0.0052651
F11	Ink Stock in S	17.06934	0
F12	Knife Advanc	17.62125	-0.1999671
F13	Dynamic Rod	17.52714	0.3583103
F14	Seam heater	17.12122	0.0518733
F15	No Tipping Pa	19.23557	0.2145321
F16	Tipping Pape	18.88052	0.1068937
F17	Filter Level ir	18.43289	0.2826746
F18	Filter Rod Mo	18.98747	0.1655746
F19	Filter choke	18.68969	-0.2100581
F20	Inspection dr	17.44945	0.0289934
F21	Inspection Dr	19.46479	-0.044228
F22	Feed Roller G	17.43652	-0.3671815
F23	Roll Block Jan	19.9464	-0.0838414
F24	Turn Drum Ja	20.12588	-0.2188019
F25	Discharge Ch	19.27962	-0.5068591
F26	Motor Circuit	17.06934	0
F27	Stop on link	17.82319	0.0401418
F28	Tray Station (	17.66945	0.235526
F29	Operating m	17.06934	0
F30	MLP No Comi	17.06934	0
F31	Compressed	17.79414	0.7248023



Horizontal axis indicates Prominence (P+R)

Vertical axis indicates Relationship (P-R)

Values above zero on x-axis are positive, indicating causes

values below x-axis are negative, indicating Effects

Appendix L: Relationship Map