Performance Analysis and Optimization of Jaw Crushers in Cement Manufacturing Plant: A Case Study in Cement Plant

Suresh Kumar Sahani[*1], Sai Kiran Oruganti[2], K. Satish Kumar[3]

[*1]Lincoln University College Malaysia
Pdf.Suresh@lincoln.edu.my
sureshsahani54@gmail.com
(Recent working to R.J.U.,Janakpurdham, Nepal)
[2]Lincoln University College Malaysia
saisharma@lincoln.edu.my
[3]Lincoln University College Malaysia
And PG and Research Department of Computer Science Erode Arts and Science College, Erode Tamilnadu, India
sathishmscgasc@gmail.com

Abstract:

Jaw crushers play a critical rule in the cement manufacturing process by reducing the size of raw materials such as limestone clay and shale this study investigates the performance of jaw crushers in cement plant focusing on factors such as crushers efficiency energy consumption and wear mechanisms a case study of cement plant using jaw crushers is presented highlighting operational challenges and solutions. The results show the optimizing crushers setting and using advanced wear-resistant materials can significantly improve performance and reduce maintenance costs recommendation for future research include the development of energy efficient designs and automation systems for jaw crushers in cement plant The failure of crusher components significantly affects the productivity of crushing plants. To enhance performance and operational reliability, it is essential to identify critical components for timely replacement before any catastrophic failure occurs through conventional maintenance practices. In crushing facilities, a systematic investigation of failure trends is essential to enhance the operational dependability of this vital equipment. This work addresses the failure analysis of a rock crusher and its important components utilizing total time on test and several statistical methodologies. Total time on the test plot has shown to be an invaluable instrument in reliability analysis.

Key-words: Jaw crusher, sub-systems, Laplace transforms, Runga-Kutta forth order, failure rates etc.

Introduction:

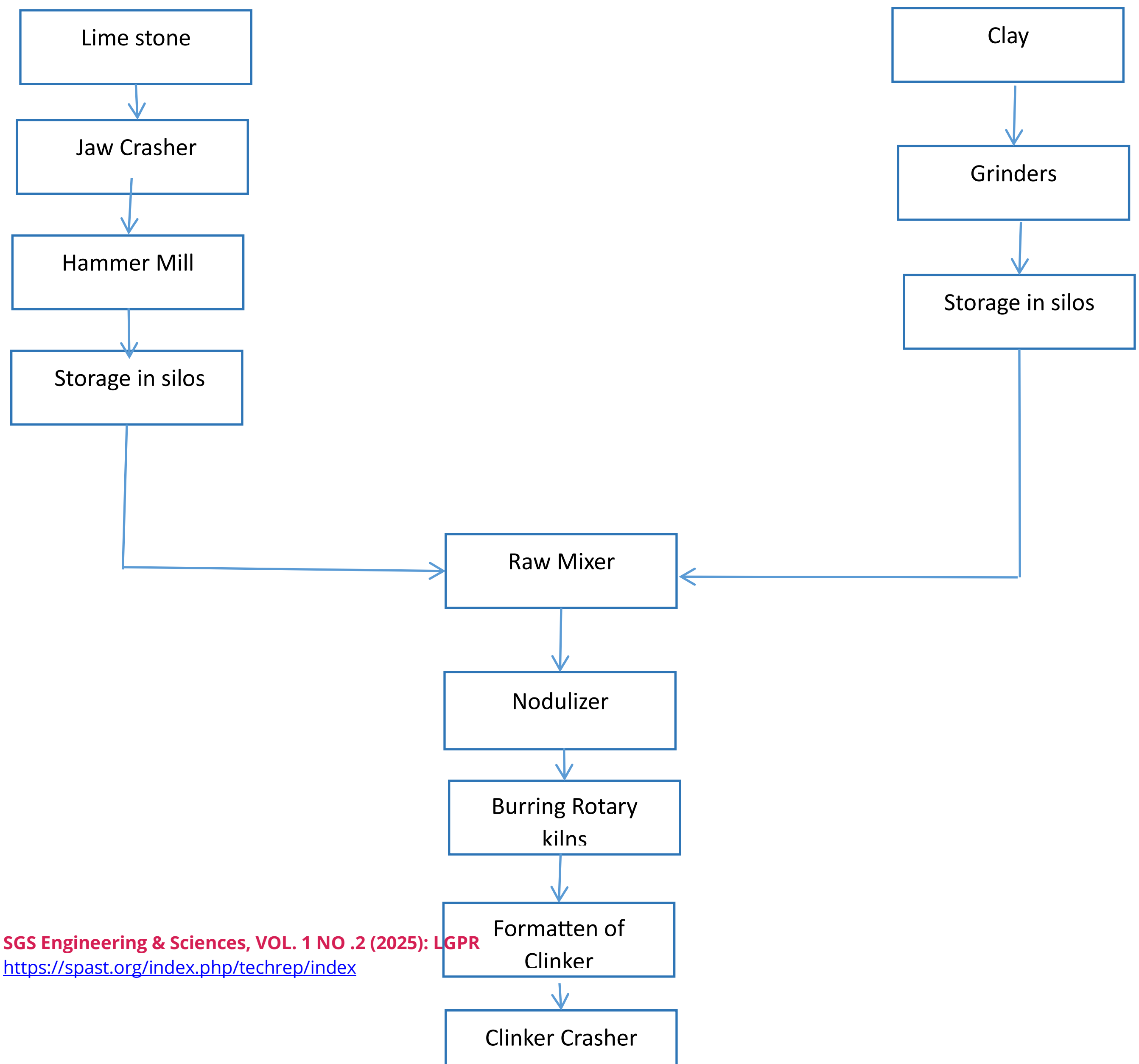
The advancement of scientific and technological growth in industry is significantly contingent upon the sophistication of equipment development. The enhancement of mining equipment quality is a multifaceted issue involving the resolution of frequently conflicting objectives, which cannot be addressed through a singular criterion for optimization. This requires more progress in the fundamental sciences related to deformations and stresses, emphasizing a careful replication of the real circumstances of manufacturing and machinery operation. The quality of technological machines, characterized by the integration of attributes derived from scientific research, technological progress, and engineering innovations, is established during manufacturing and evaluated during operation; therefore, it is susceptible to deterioration from physical and moral obsolescence [1-4].

In modern contexts, quality indicators should include both quantitative metrics and a critical assessment of the expenses involved in attaining them, while ensuring the stability of their numerical values over a defined period. A variety of indicators related to the quality of technical machinery, which are dynamic and time-dependent variables, are classified into two interrelated categories. The first category includes metrics related to the accuracy of the manufactured objects and the uniformity of this accuracy across a certain period or manufacturing timeline. This indication depends on both the chosen technical approach and the effectiveness of the processing equipment utilized (crusher, separator, etc.). The relationship between the accuracy specifications of the finished product and the machine's design issue ninth stiffness coefficient of its power system. However, an unlimited increase in stiffness does not inherently correspond to a commensurate improvement in product accuracy or a decrease in energy consumption during elastic deformation. Rather, it is associated with an increase in a vital machine parameter: material consumption, since it requires an expansion of the cross-section of power system components and dynamic effects on the processed material and the adjacent environment (foundation, building) where persons work. The second set includes characteristics of equipment quality that delineate performance, reliability, longevity, energy use, material intensity, labor comfort affected by ergonomics, aesthetics, safety engineering, and environmental factors. Machines employed for materials processing are categorized as process equipment, which presents significant opportunities for almost infinite improvements in worker productivity. However, these possibilities do not suggest that a qualitative productivity indicator may be assessed only on the theoretically attainable speed of the machine's components and the minimum processing time. The limitations on the performance indicator's value are reliably achievable metrics of machine dependability and durability, requiring an assessment of the economic costs related to production, operation, and maintenance to guarantee consistent reliability and durability. Thus, the performance indicator should be assessed not just by the quantity of products manufactured per time unit, but largely by the quantity of products produced per time unit relative to the material costs paid in obtaining this quantity of products. The formulation of energy intensity indicators for technological processes and processing equipment must account for the velocity of the operational components and the elastic properties of both the material being processed and the machine's power elements as a cohesive system. Elastic deformations of the system, combined with the velocity of the working body, act as a source of dynamic effects on the processed material and are the primary determinants of the working body's movement speed during technological operations; this speed is essential for the machine's energy and process in tensity. The quality metric of material consumption is associated with the quality of the technical process, as shown by material utilization, and the quality of the machine, which dictates its weight. The importance of the value limit of this quality indicator pertains not only to its influence on production capital costs and machine expenses but also to the machine's mass and its components, which correlate with the accuracy indicators of the final product through stiffness. The coefficient and bearing capacity of machines (dependability, strength, and performance) are affected by factors of vibration resistance and activity, which impact not only the machine's reliability and performance but also comfort metrics (vibration, noise, safety, etc.). The fundamental indicator of crushing machines' quality, representing their technical standard and competitiveness, is operational dependability, quantitatively determined by the lack of operational issues. The frequent and quick downtimes of crank drive machines under operational conditions are mostly attributed to failures in the kinematic chain joint components, specifically the bearings. Jaw crushers in metallurgical production [5] are utilized to shatter materials by various methods. Specifications for the completed crusher output, mostly for dimensional accuracy and configuration. In jaw crushers, material is broken by crushing, splitting, and partial attrition in the region between the two jaws as they intermittently converge. The motion of the movable cheek, which dictates the characteristics of the final crushed product, depends on the kinematic qualities of the jaw crusher mechanism. A variety of distinct kinematic configurations for the crusher mechanism have been developed and implemented overtime. Jaw crushers are classified according to B.V. Klushantsev's [5] design of the swing jaw, which determines the most important technical and economic aspects of the machine. Different kinematic systems for the swing jaw mechanism may be defined in different ways, but they all rely on joints to allow machine parts to move. The misalignment of the pin within the cage is a major drawback of the joints [5]. When the driving member changes directions (gap over travel) while the mechanism is operating, this crucial circumstance occurs, leading to the interaction of joint components as they move relative to each other inside the gap. As a result, the machine's overall dependability is reduced and wear on the joint parts is increased. New dynamic forces also arise,whichmightbelarge. Therefore, setting circumstances that provide smooth contact between the interrelated components is primarily responsible for the machine's reliable operation. Most solutions to this problem include using conical mating surfaces, which makes their production more difficult, or systems that use spring preload of half-bushes in friction bearings, both of which are inefficient. As a result of the infeasibility of developing automatic or automated control systems for devices that accommodate bearing wear, it is necessary to continuously monitor the status of the spring components and the steel springs due to their weak damping ability. Everything discussed above necessitates the development of efficient methods to create a smooth combination of kinematic pair components (see [5]).To enhance the availability of heavy machinery, reliability-centered maintenance has been extensively employed. Mossadegh et al. [6] emphasized the transition of facilities from reactive to proactive strategies by incorporating RCM concepts into jaw crusher maintenance plans. Maintenance may be prioritized based on the risk and repercussions of failure, utilizing RCM's systematic identification of critical components. Reliability study guides design modifications that enhance performance and facilitate maintenance of the system. Rajpal and Tiwari [7] employed Finite Element Analysis (FEA) to assess the stress concentration zones of the crushing mechanism. The lifespan of the jaw plate was augmented by 25% due to its improved design. The reliability enhancement program executed in an Indian cement industry was described in the paper by Singh et al. [8]. Unscheduled jaw crusher shutdowns decreased by 30% due to the program's integration of real-time monitoring and failure analysis. A mining enterprise in South Africa improved its maintenance strategy by employing Weibull analysis to discern trends in component wear failures. To employ the Runge-Kutta fourth-order (RK4) method for simulating the failure and repair rates of a jaw crusher, a differential equation that delineates the system's reliability is necessary. We will employ a straightforward differential equation for failure and repair rates predicated on system availability, as opposed to conventional approaches such as Markov chains or reliability growth models (see [9-12]). Despite their obvious importance to modern society, the mining and manufacturing industries are notoriously complicated in terms of both processes and systems. Equipment and machinery used in these fields must withstand extreme conditions on the job, including heat, cold, humidity, dust, and precipitation throughout the year. For that reason, when enhancing certain processes, one must prioritise ensuring the reliability and excellence of their functioning. Therefore, it is important to pay close attention to their regular maintenance in order to avoid problems with unavailability caused by unexpected faults. It is possible to use a variety of methods, from the most simple to the most complex. Some of the most popular approaches are Poka-Yoke, the Five Whys, and the Ishikawa diagram, which is used for cause and effect analysis [13–16]. To achieve a desired result, these tactics might be used singly or in combination. It is critical to select the solution that best handles the current scenario because each has its own set of advantages [17–19]. Among these methods is the FMEA, or Failure Mode and Effects Analysis. Effects and Mode of Failure For the mineral processing plant to run efficiently, reliably, and safely, analysis is a crucial part of the technological process. Improving performance and quality, lowering costs, and mitigating negative environmental impacts can be achieved through problem identification and correction. The application of defect and root cause analysis to the technological process of andesite treatment is the focus of this study. The plan calls for figuring out what may go wrong and how serious those problems are. Various approaches for evaluating the importance of known failures have contributed to FMEA's advancement since its common cement in the 1950s [20-21]. A risk priority number (RPN) has long been used in FMEA risk assessment. In order to determine the RPN, three variables are considered: severity (S), frequency (O), and detection (D). Environmental impact, customer consequences, regulatory and legal ramifications of failure, time needed to fix the mistake, and reputational harm are among the crucial issues that are over looked, along with cost, quality, and safety. There have been a great number of authors that have examined different methods for determining the RPNs [22-24]. The limitations of the traditional S, O, and D assessment are outlined by Ouyang et al. [25], who also argue for the combination of SO, SD, and OD risk factors in order to conduct risk evaluations. Risk assessment is improved with the incorporation of risk factors since it takes into account the interrelationships that exist between the variables. They contribute to the establishment of an accurate identification of the most urgent dangers that call for a timely reaction. The manufacturing industry, the automobile industry, healthcare, and information technology services are all areas that can benefit from this examination. In their research, Gargama and Chaturvedi assess two new approaches to prioritizing FMEA assessments. The RPN is calculated using fuzzy theory in the first approach. The second one measures how well an FMEA review panel agrees with one another [26]. To evaluate RPN, Wu and Wu [27] present a fuzzy beta-binomial method that combines fuzzy theory, Bayesian statistical inference, and the beta-binomial distribution. In their groundbreaking Failure Mode and Effects Analysis approach, Yu et al. [28] use a rule-based Bayesian network and tailored evaluative linguistics. To maximize efficiency in maintenance work, Carpitella et al. created a variant of FMEA that makes use of fuzzy theory. Reliability analysis and multi-criteria decision-making approaches are combined in their methodology [29-30].

The Cement Manufacturing Plant

Various epochs, such as the Stone Age, the Iron Age, the Bronze Age, etc., have marked human history. These days, the construction of many kinds of buildings—houses, offices, bridges, and dams—is crucial to human progress. Cement is the main ingredient in these structures. Cement, then, is serving a crucial purpose in this world. Stones with clay, carbonate of lime, and an equal quantity of carbonate of magnesia are crushed and burned to produce cement. The cement manufacturing process can be either the dry or wet method. The dry process involves drying, crushing, and finely grinding the raw materials, which include clay and limestone. A number of epochs have passed since humankind first emerged, each marking a distinct phase in the species' evolutionary trajectory. From homes to workplaces to bridges and dams, the construction of many kinds of structures is crucial to human progress in the modern day. Using cement as a foundation, these structures are built. For this reason, cement is an essential component of several product categories. Limestone, clay, and carbonate of magnesia are the ingredients in the cement, which is made by crushing and burning the stones. Dry process and wet process are the two methods that may be used to make cement. Drying, crushing, and finely grinding the raw material (clay and limestone) is what the process is all about. They are then mined together in calculated proportions. This process is called blending. The corrected mixed power is supplied to rotary kiln, a huge rotating cylindrical kiln set of in an inclined position (angle 150). This is the most important part of a cement plant it has two ends, the charge or feed end and the fuel end. Length of the rotary Kiln varies between 100 to 180 meters. The temperature at different ends lies between 400^0c to 1800^0c. The charge end undergoes dehydration, dissociation, and decomposition as it slides downwards due to rotation of kiln about its own axis. At the lower end, the burnt products come out in the form of green lumpshaped, very hot material called clinker. The clinkers are first cooled in special chambers called clinker coolers and then 2-3 percent of gypsum rock is added to the clinkers. These after, the mixture is very finely pulverized. The fine the pulverization, the better is the quality of cement. The powdered cement is stored in huge silos from where it is drawn for packing and transportation. In the wet process, the grinding of the row materials is done. Separately and in presence of lot of water so that instead of powder a fine dispersion of limestone and clay are obtained. These are stored in separate tanks. They are blended in proper proportions and then this blended slurry is fed into rotary kiln. In this process, the kilns are generally of longer and bigger dimensions. The wet process is considered more. Convenient to control but the dry process is more economical in Nepal, both the processes are used for manufacture of cement. We have considered a process industry that uses dry process for cement manufacturing in our present discussions. The following distinct processes are involved

In the manufacturing of cement by dry process. The processes are presented in the following figure:-


Lime stone
Jaw Crasher
Hammer Mill
Storage in silos
Clay
Grinders
Storage in silos
Raw Mixer
Nodulizer
Burring Rotary kilns
Formatten of Clinker
Clinker Crasher

1. Large stones (up to 1.2 m) are loaded into the crusher's hopper from a massive dumper with a capacity of 4,00,000.kg.

2. Large stones are reduced to smaller ones by use of the jaw crusher. The next step is to use a hammer to break the stones into even smaller bits. From the crusher, a succession of conveys-ours remove the little, crushed limestone, which is now about 75 mm in size, for stacking.

3. All of the quarry's argillaceous or clay elements are thrown into the crusher and piled on top of the limestone.
4. If the quarried materials are deficient in any of the following components, they are added separately: calcium carbonate, lime, alumina, ferrous oxide, and silica.

5. The storage hopper is emptied of the additive ingredient and crushed limestone. A conveyor carries the raw materials to the raw mill, where weigh feeders ensure an even distribution.

6. In the raw mill, the materials are ground to the required fineness. The raw mill's grinding produces a fine powder, which is then sent to the massive continuous blending and storage silo using an aero pole system that uses cyclones to gather the powder in the air.

7. Materials are transported to the storage silo from the blending process using just gravity, which helps to conserve electricity. The ingredients are pushed into the preheater by an aero pole.

8. The material is transferred to the rotary kiln from the base of the preheater. A rotating kiln made of steel tubes is used to conduct the burning process.

9. The revised slurry is introduced into the kiln through the top end. The kiln's bottom end is where the hot gasses or flames are pushed to exit. As the slurry slowly drains down the kiln, it evaporates at the area near the top, which is called the dry zone. The carbon dioxide in the slurry is evaporated in the next stage of the kiln as the temperature rises. At this point, the nodules, which are tiny lumps, begin to develop. In the end, these nodules make it to the burring zone, where temperatures range from 1400 to 1500 degrees Celsius, after slowly rolling down through zones of increasing temperature. Clinkers or raw cement, little hard greenish-blue balls, are created in the burring zone when nodules are transformed into the claimed product.

10. After the rotary kiln produces the desired clinkers, they are finely processed using ball mills and tube mills. A tiny amount of gypsum, around 3 to 4 percent, is added to manage the setting during grinding. You need to be careful when packaging and storing cement since its demands fluctuate. Silos are concrete storage tanks that are purpose-built for this purpose.

System and Notations:

It has been determined via extensive research that a cement production facility is comprised of the six subsystems listed below.

1. **Sub- System R_1 (Jaw Crushers):-**

The mining, building, and demolition recycling sectors all make use of jaw crushers as their principal crushing machinery. Small pebbles, gravel, or rock dust can be contained with its help. The capacity of jaw crushers to process materials that are both hard and abrasive makes them indispensable in the aggregate industry.

Key Components of Jaw Crushers:

i. Fixed Jaw Plate: - The stationary part of the crushers that remains in a fixed position.

ii. Movable Jaw Plate: - The mining part that exerts forces the rock by pressing it against the fixed jaw plate.

iii. Eccentric Shaft: - Drives the movable jaw in an elliptical motion creating the crushing action.

iv. Toggle Plate: - Acts as a safety mechanism, protecting the crusher form damage if uncrushable materials enter the chamber.

v. Flywheel: - Stores energy and helps maintain consistent crushing momentum.

vi. Cheek Plates: - Protective liners on the sides of the crushers frame to prevent wear.

How it Works:-

i. Feed Materials: - Rocs are fed into the crushing chamber from the top.

ii. Crushing Action: - The movable jaw composes the material against the fixed jaw, breaking it into smaller pieces.

iii. Discharge: - The crushed material exists through the bottom opening, which can be adjusted to control the size of the output.

Types of Jaw Crushers:-

i. Single Toggle Jaw Crusher:- It has a single toggle plate and simpler design , suitable for lighter duty application

ii. Double Toggle Jaw Crusher: - Uses two toggle plates and is more robust ideal for heavy- duty crushing.

Applications:-

I. Mining :- Crushing ores and materials

II. Construction: - Breaking down large concrete or asphalt structures.

III. Recycling:-Processing demolition waste for reuse.

IV. Aggregate productions: - Producing gravel and crushed stone for contracts.

Advantage:-

i. High crushing efficiency

ii. Simple structure and easy maintenance.

iii. Can handle hard and abrasive materials.

iv. Adjustable discharge size for different requirements.

2: Sub- System R_2 (Hammer Mill):-

A hammer mill is a type of grinding machine or mill that is used to share or crush materials into smaller pieces. It operate on the principle of rapid impact between hammers mounted on a rotor and the material fed into the mil hammer mill are widely used in various industries for size reduction of materials including agriculture , food processing , recycling and mining .

Key Components of a Hammer Mill:-

i. Rotor:-The rotating component that holds the hammers .It spins at high speed, causing the hammer to strike the material.

ii. Hammers: - The striking tools attached to the rotor. They come in various shapes and size depending on the application.

iii. Screen or Grinding plate: - A perforated screen or plate that determined the final particle size of the materials. The material remains in the grinding chamber until it is small enough to pass through the screen,

iv. Feed Mechanism: - The systems that introduce the materials into the grinding chamber. This can be gravity fed or mechanically assisted.

v. Discharge Mechanism: - The system that removes the ground materials from the mail often is using airflow or gravity.

How It Works:-

I. The material to be processed is fed into the grinding chamber through the fed mechanism.

II. Impact and Grinding: - As the rotor spins, the hammers swing out and strike the materials, breaking it into smaller pieces. The material is repeatedly struck until it is small enough to pass through the screen.

III. Particle Size Control: - The size of the particle is controlled by the size of the screen openings. Smaller opening result in finer particle.

IV. Discharge:- Once the material is ground to the designed size, if passes through the screen and is discharged from the mill while hammer mill are not the primary grinding equipment in modern cement plants they can still be useful for specific application such as crushing raw materials, processing additives , or handling waste materials . However, for fine grinding of clinker and producing cement, more advanced systems like ball mills, VRMs or roller presses are preferred due to their higher energy efficiency and ability to achieve the required fineness. However mills are best used as supplementary equipment in cement plants, particularly for coarse grinding tasks.

3. Sub- System R_3 (Raw Mixer):-

In a cement plants, the raw mixer (also known as a raw meal mixer or raw mix homogenizer) is a critical piece of equipment in the raw materials preparation process its primary function is to ensure the homogenization of the raw materials before they are fed into the kiln for clinker production. Achieving a consistent and uniform raw mix is assent at for producing high quality clinker, and ultimately, cement.

4. Sub- System R_3 (Clinker Section B):-

The clinker section in cement plants is a crucial part of the cement manufacturing process. It involves the production of clinker, which is the intermediate product obtained by heating mixture of raw materials in a kiln. Clinker is then ground to produce cement. Below is an overview of the clinker section and its key components.

Raw Material Preparation:

(i) Raw materials: -The primary row materials used are limestone, clay, shale sand, and iron are.

(ii) Crushing and Grinding: - The raw materials are powder. Crushed and ground into fine power.

(iii) Homogenization: - The raw meal is blended to ensure consistent chemical composites.

Kiln:-

(i) The heart of the clinker section is the rotary kiln, a large cylindrical furnace.

(ii) The saw meal is heated to temperatures of around 1450°c in the kiln.

(iii) chemical reactions occur, leading to the formation of clinker minerals:

a. Limestone Trihydrate
b. Silicate of Dicalcium
c. Alumina Tricalcium
d. Aluminoferrite Tetracalcium

The output is clinker, which appears as small, dark gray nodules.

Cooling:-

(i) The hot clinker exist the kiln and is cooled rapidly in a clinker cooler.

(ii) Cooling is essential to: preserve the quality of the clinker and recover heat for reuse in the process.

Storage:-

The cooled clinker is stored or clinker yards before being transported to the cement mill for grinding.

5. Sub-System R_4(Cement Mill):

The cement mill, also known as finish mill or cement grinding mill, is a critical piece of equipment in a cement plant. It is responsible for grinding clinker, along with additives like gypsum, into fine powder to produce cement. The cement mill is the final stage in the cement manufacturing process, where the product is prepared for packaging and distribution.

Key Function of a Cement Mill:-

(i) Grinding Clinker: The primary propose is to grind clinker into a fine powder.

(ii) Adding Additives: Gypsum (typically 3-5%) is added to control the setting time of cement.

(iii) Producing Cement: The output is Portland cement or other specialized types of cement.

Types:-

(i) Ball Mill:

a. A horizontal cylinder filled with steel balls.

b. The clinker and addition are fed into the mill and the rotation causes the balls to grid the material into a fine powder.

c. Commonly used in older plants

ii. Vertical Roller Mill:-

a) A more modern and energy efficiency alternative to ball mills.

b) Uses rollers to grid the materials against a rotating tables.

c) VRM is preferred in newer plants due to their lower energy consumption and higher grinding efficiency.

iii. Roller Press:-

a) Often used in combination with a ball mill or as a pre-grinding unit.

b) Applies high pressure to the material to crush it if before final grinding.

Component of Cement Mill:-

a) Grinding Chamber: - where the grinding of clinker and additive takes place.

b) Grinding Media: Steel balls or rollers

c) Separator :- A separator divides the fine powder from coarse particles

d) Storage :- The finished cement is stored in silos before packaging or bulk shipment

Key Parameters in Cement Milling:-

a) Fineness: - The particle size of the cement, measured by blaine surface area (m^2 /kg) or sieve residue. Finer cement has better strength but requires more energy to produce.

b) Energy consumption: - cement milling is energy – intensive accounting for a significant portion of the plants operating costs.

c) Temperature control: - Excessive heat during grinding can cause dehydration of gypsum, affecting cement quality water spray system or cooling mechanism is often used.

Common Challenges in Cement:-

Milling:-

a) High Energy Consumption: - Grinding is one of the most energy intensive stages in cement production.

b) Wear and Tear: - Grinding media and mill liners are subject to significant wear, requiring regular maintenance.

(c) Quality Control: Ensuring consistent fineness and chemical composition of cement.

6. Sub-System R_6 (Packing): -

The packing section in cement in cement manufacturing is the final stage of the cement products process. It involves the packing of finished cement into bags to preparation for bulk shipment to customers. The section ensures that the cement is stored, handled, and transported efficiently while maintaining its quality.

Key Junctions of Packing Section

(a) Storage of Cement: - cement form the cement mill is stored in silos before packing.

(b) Packing: - Cement is packed into bags (typically 50 kg or 25kg) or prepared for bulk shipment

(c) Dispatching: - Packaged cement is loaded onto trucks, railcars, or ships for distribution.

Components of Packing Section:

i. Cement Silos:-

a. Large storage tanks where cement is stored before packing.

b. Silos ensure a steady supply of cement to the packing machines.

ii. Packing Machines:-

(a) Automated machines that fill cement into bags.

(b) Common types include rotary packers and ventomatic packers.

(c) Bags are typically made of multilayer paper or woven polypropylene.

iii. Bagging and Stitching :-

(a) Bags are filled with a precise the weight of cement.

(b) The bags are stitched or sealed to prevent leakage.

iv. Bulk Loading System :-

(a) For customers who require cement in bulk, a bulk loading system be used.

(b) Cement is directly loaded into L bulk trucks or railcars.

v. Conveyors and Handing System:-

(a) Conveyors transport filled bags to the loading arle.

(b) Automated systems stack bags into pallets or directly onto trucks.

vi. Dust Collection System:-

(a) Dust collectors are installed to capture cement dust during packing and loading, ensuring clean working environmental regulations.

Types:-

i. Bagged Cement:

(a) Cement is packed in bags of standard weights (e.g. 50kg, 25kg).

(b) Bags are stitched or sealed and labeled with products information.

ii. Bulk Cement:

(a) Cement is transported in bulk using tankers or bulk railcars.

(b) This method is cost-effective for large-scale customers like ready mix concrete plants...

Note:-

i. It is clear that R_1, R_2, R_3, R_4, R_5, and R_6 indicate favorable circumstances of the sub-systems
ii. $\overline{R_3}$ And $\overline{R_5}$ show that subsystems R_3 and R_5 are operating in diminished levels.
iii. $\lambda_{1,,}\lambda_2$, λ_3,λ_4, λ_5, λ_6, λ_7, and , λ_8 denotes consistent maintenance rates of sub-systems
iv. R_1, R_2, R_4, $R_6,\overline{R_3}$, $\overline{R_5}.R_3$, and R_5 respectively.
v. $f_r(t)$ = probability that the system is in r^{th} state at time t (where r=1,2,3,..., 24).
vi. μ_1, μ_2, ..., μ_8 respectively indicate the fixed maintenance rates of sub-systems R_1, R_2, R_4,R_6, $\overline{R_3}$, $\overline{R_5}$,R_3,and R_5.
vii. Small letters ε_1, ε_2, ε_3, ε_4, and ε_5 specify the malfunctioning states of the corresponding subsystems, where s is the Laplace parameter.

For making new mathematical models, we may consider the following things:-

i. Repairs and failures are statistically independent with each. Others and their unit are per day.

ii. These are no simultaneous failure among the subsystems.

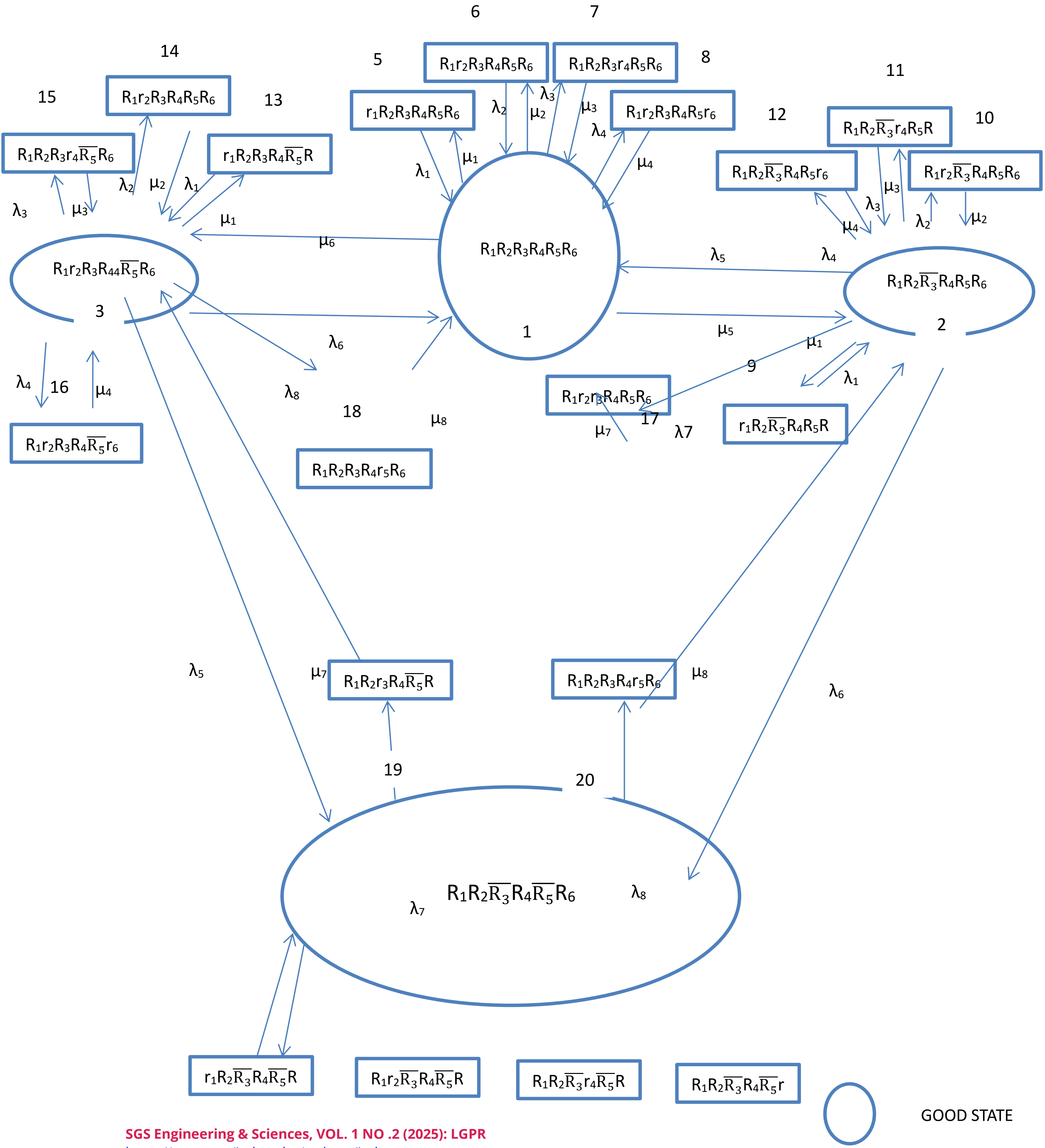
iii. Sub system R_3 and R_5 can Jail completely only through reduce state.

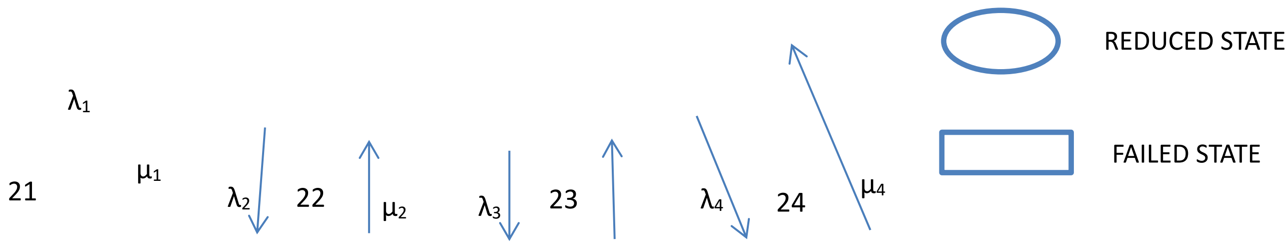
iv. Repaired components are like new. Component.

v. Repair R_3 and R_5 is allowed in reduce state only up to a certain limit.

vi. Repair is carried out when the system is carried out when the system is in the reduced or failed state.

Following the above notations and assumptions the transition diagram of the process is given in the figure:-


6
7
5
$R_1r_2R_3R_4R_5R_6$
$R_1R_2R_3r_4R_5R_6$
8
14
11
15
$r_1R_2R_3R_4R_5R_6$
$R_1r_2R_3R_4R_5r_6$
13
12
10
$R_1r_2R_3R_4R_5R_6$
$R_1R_2\overline{R_3}r_4R_5R$
$R_1R_2R_3r_4\overline{R_5}R_6$
$r_1R_2R_3R_4\overline{R_5}R$
$R_1R_2\overline{R_3}R_4R_5r_6$
$R_1r_2\overline{R_3}R_4R_5R_6$
$R_1R_2R_3R_4R_5R_6$
$R_1r_2R_3R_{44}\overline{R_5}R_6$
$R_1R_2\overline{R_3}R_4R_5R_6$
3
1
2
16
18
9
17
$R_1r_2r_3R_4R_5R_6$
$r_1R_2\overline{R_3}R_4R_5R$
$R_1r_2R_3R_4\overline{R_5}r_6$
$R_1R_2R_3R_4r_5R_6$
$R_1R_2r_3R_4\overline{R_5}R$
$R_1R_2R_3R_4r_5R_6$
19
20
$R_1R_2\overline{R_3}R_4\overline{R_5}R_6$
$r_1R_2\overline{R_3}R_4\overline{R_5}R$
$R_1r_2\overline{R_3}R_4\overline{R_5}R$
$R_1R_2\overline{R_3}r_4\overline{R_5}R$
$R_1R_2\overline{R_3}R_4\overline{R_5}r$
GOOD STATE



In the transient state, probabilistic analysis yields the subsequent first-order differential equations related to the system's transition diagram.

$$\frac{df_1(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)f_1(t)=\mu_1 f_5(t)+\mu_2 f_6(t)+\mu_3 f_7(t)+\mu_4 f_8(t)+\mu_5 f_2(t)+\mu_6 f_3(t)+\mu_8 f_{18}(t)+\mu_7 f_{17}(t) \quad \dots (1)$$

$$\frac{df_2(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\mu_5)f_2(t)=\mu_1 f_9(t)+\mu_2 f_{10}(t)+\mu_3 f_{11}(t)+\mu_4 f_{12}(t)+\mu_8 f_{20}(t)+\mu_5 f_1(t) \quad \dots (2)$$

$$\frac{df_3(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_8+\mu_6)f_3(t)=\mu_1 f_{13}(t)+\mu_2 f_{14}(t)+\mu_3 f_{15}(t)+\mu_4 f_{16}(t)+\mu_7 f_{19}(t)+\lambda_6 f_1(t) \quad \dots (3)$$

$$\frac{df_4(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8)f_4(t)=\mu_1 f_{21}(t)+\mu_2 f_{22}(t)+\mu_3 f_{23}(t)+\mu_4 f_{24}(t)+\lambda_5 f_3(t)+\lambda_6 f_2(t) \quad \dots (4)$$

$$\frac{df_5(t)}{dt}+\mu_1 f_5(t)=\lambda_1 f_1(t) \quad \dots (5)$$

$$\frac{df_6(t)}{dt}+\mu_2 f_6(t)=\lambda_2 f_1(t) \quad \dots (6)$$

$$\frac{df_7(t)}{dt}+\mu_3 f_7(t)=\lambda_3 f_1(t) \quad \dots (7)$$

$$\frac{df_8(t)}{dt}+\mu_4 f_8(t)=\lambda_4 f_1(t) \quad \dots (8)$$

$$\frac{df_9(t)}{dt}+\mu_1 f_9(t)=\lambda_1 f_2(t) \quad \dots (9)$$

$$\frac{df_{10}(t)}{dt}+\mu_2 f_{10}(t)= \lambda_2 f_2(t) \quad ... \quad (10)$$

$$\frac{df_{11}(t)}{dt}+\mu_3 f_{11}(t)= \lambda_3 f_2(t) \quad ... \quad (11)$$

$$\frac{df_{12}(t)}{dt}+\mu_4 f_{12}(t)= \lambda_4 f_2(t) \quad ... \quad (12)$$

$$\frac{df_{13}(t)}{dt}+\mu_1 f_{13}(t)= \lambda_1 f_3(t) \quad ... \quad (13)$$

$$\frac{df_{14}(t)}{dt}+\mu_2 f_{14}(t)= \lambda_2 f_3(t) \quad ... \quad (14)$$

$$\frac{df_{15}(t)}{dt}+\mu_3 f_{15}(t)= \lambda_3 f_3(t) \quad ... \quad (15)$$

$$\frac{df_{16}(t)}{dt}+\mu_4 f_{16}(t)= \lambda_4 f_3(t) \quad ... \quad (16)$$

$$\frac{df_{18}(t)}{dt}+\mu_8 f_{18}(t)= \lambda_8 f_3(t) \quad ... \quad (18)$$

$$\frac{df_{19}(t)}{dt}+\mu_7 f_{19}(t)= \lambda_7 f_4(t) \quad ... \quad (19)$$

$$\frac{df_{20}(t)}{dt}+\mu_8 f_{20}(t)= \lambda_8 f_4(t) \quad ... \quad (20)$$

$$\frac{df_{21}(t)}{dt}+\mu_1 f_{21}(t)= \lambda_1 f_4(t) \quad .... \quad (21)$$

$$\frac{df_{22}(t)}{dt}+\mu_2 f_{22}(t)= \lambda_2 f_4(t) \quad ... \quad (22)$$

$$\frac{df_{23}(t)}{dt}+\mu_3 f_{23}(t)= \lambda_3 f_4(t) \quad ... \quad (23)$$

$$\frac{df_{24}(t)}{dt}+\mu_4 f_{24}(t)= \lambda_4 f_4(t) \quad ... \quad (24)$$

With boundaries $f_1(0)=1$ and 0,otherwise ... (25)

Now, taking the Laplace transforms of equations the (2) and solving recursively,

we get.

$f_2(s) = \delta_1 f_1(s)$ ... (26)

$f_3(s) = \delta_2 f_1(s)$ ... (27)

$f_4(s) = \delta_3 f_1(s)$ ... (28)

$f_5(s) = \phi_1 f_1(s)$ ... (29)

$f_6(s) = \phi_2 f_1(s)$ ... (30)

$f_7(s) = \phi_3 f_1(s)$ ... (31)

$f_8(s) = \phi_4 f_1(s)$ ... (32)

$f_9(s) = \phi_1 \delta_1 f_1(s)$ ... (33)

$f_{10}(s) = \phi_2 \delta_1 f_1(s)$ ... (34)

$f_{11}(s) = \phi_3 \delta_1 f_1(s)$ ... (35)

$f_{12}(s) = \phi_4 \delta_1 f_1(s)$ ... (36)

$f_{13}(s) = \phi_1 \delta_2 f_1(s)$ ... (37)

$f_{14}(s) = \phi_2 \delta_2 f_1(s)$ ... (38)

$f_{15}(s) = \phi_3 \delta_2 f_1(s)$ ... (39)

$f_{16}(s) = \phi_4 \delta_2 f_1(s)$ ... (40)

$f_{17}(s) = \phi_7 \delta_1 f_1(s)$ ... (41)

$f_{18}(s) = \phi_8 \delta_2 f_1(s)$ ... (42)

$f_{19}(s) = \phi_7 \delta_3 f_1(s)$ ... (43)

$f_{20}(s) = \phi_8 \delta_3 f_1(s)$ ... (44)

$f_{21}(s) = \phi_1 \delta_3 f_1(s)$ ... (45)

$_{22}(s) = \phi_2 \delta_3 f_1(s)$ ... (46)

$f_{23}(s) = \phi_3 \delta_3 f_1(s)$ ... (47)

$f_{24}(s) = \phi_4 \delta_3 f_1(s)$ ... (48)

It is clear that

$\phi_1 = \frac{\lambda_1}{s+\mu_1}$ ... (49)

$\phi_2 = \frac{\lambda_2}{s+\mu_2}$ ... (50)

$\phi_3 = \frac{\lambda_3}{s+\mu_3}$ ... (51)

$\phi_4 = \frac{\lambda_4}{s+\mu_4}$ ... (52)

$\phi_7 = \frac{\lambda_7}{s+\mu_7}$ ... (53)

$\phi_8 = \frac{\lambda_8}{s+\mu_8}$ ... (54)

$\psi_1=\frac{\lambda_7\mu_7}{s+\mu_7}$ ... (55)

$\psi_2=\frac{\lambda_8\mu_8}{s+\mu_8}$ ... (56)

$v_1= \frac{(v+\alpha_4)}{(v+\alpha_2)(v+\alpha_4)-\psi_2\lambda_6}$ ... (57)

$v_2= \frac{(v+\alpha_4)}{(v+\alpha_2)(v+\alpha_4)-\psi_2\lambda_6}$ ... (58)

$v_3= \frac{(v+\alpha_4)\lambda_6}{(v+\alpha_3)(v+\alpha_4)-\psi_1\lambda_5}$ ... (59)

$v_4= \frac{\psi_1\,\lambda_5}{(v+\alpha_3)(v+\alpha_4)-\psi_1\lambda_5}$ ... (60)

$\delta_1= \frac{v_1+v_2+v_3}{1-v_2v_4}$ ... (61)

$\delta_2= \frac{v_1+v_3+v_4}{1-v_2v_4}$ ... (62)

$\sigma_3=\frac{\lambda_5(v_1+v_3+v_4)+\lambda_6(v_1+v_2+v_3)}{(v+\alpha_4)1-v_2v_4}$ ... (63)

Also taking Laplace transform of equation (1) and using equation (25), We get

$f_1(s)=[(v+\alpha_1)-\sigma_1(\mu_5+\psi_1)-\sigma_2(\mu_6 + \psi_2)]^{-1}$ ... (64)

Laplace transforms of the reliability function for the system is given by

$R(s)=f_1(s)+f_2(s)+f_3(s)+f_4(s)$

$=(1+\sigma_1+\sigma_2+\sigma_3)f_1(s)$ ... (65)

Where $f_1(s)$ is given by equation (64) the inversion of R(s) gives the reliability function R(t).

But it is difficult to find Laplace inverse since expressions for probability transforms are in very much complicated form and complexity increases with the increase in number of equations. To overcome this difficulty equations (1) to (64) with initial condition (25) have been solved numerically wing Runga-Kutta fourth order method. The numerical integration is performed with t = 0.005 assuming as one day, there for to get the reliability up to 360 days we will have to perform 72000 iteration with the Runga-Kutta fourth order method. The reliability function of the system R(t) is computed by

$$R(t)=f_1(t)+f_2(t)+f_3(t)+f_4(t) \quad \ldots \quad (66)$$

The reliability of the system, as defined in equation (66) has been computed for various values of the repair and failure rates. It may be mentioned here that these values combinations are not exhaustive and we have only considered the main sub-systems in the numerical study.

Steady State:-

The focus of management in process industries is on availability over the long term. Long run calculations hence need steady state probability. Calculable availability taking into account the fact that, $\frac{d}{dt} \rightarrow 0$ as $t \rightarrow \infty$.

We have used $f_1, f_2, f_3 \ldots f_{24}$ for denoting steady state probabilities equations (1) to equations (24) can be given as:

$$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6)f_1=\mu_1 f_5+\mu_2 f_6+\mu_3 f_7+\mu_4 f_8+\mu_5 f_2+\mu_6 f_3+\mu_8 f_{18}+\mu_7 f_{17} \quad \ldots \quad (67)$$

$$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\mu_5)f_2=\mu_1 f_9+\mu_2 f_{10}+\mu_3 f_{11}+\mu_4 f_{12}+\mu_8 f_{20}+\lambda_5 f_1 \quad \ldots \quad (68)$$

$$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_8+\mu_6)f_3=\mu_1 f_{13}+\mu_2 f_{14}+\mu_3 f_{15}+\mu_4 f_{16}+\mu_7 f_{19}+\lambda_6 f_1 \quad \ldots \quad (69)$$

$$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8)f_4=\mu_1 f_{21}+\mu_2 f_{22}+\mu_3 f_{33}+\mu_4 f_{24}+\lambda_5 f_3+\lambda_6 f_2 \quad \ldots \quad (70)$$

$$\mu_1 f_5=\lambda_1 f_1 \quad \ldots \quad (71)$$

$$\mu_2 f_6=\lambda_2 f_1 \quad \ldots \quad (72)$$

$$\mu_3 f_7=\lambda_3 f_1 \quad \ldots \quad (73)$$

$$\mu_4 f_8=\lambda_4 f_1 \quad \ldots \quad (74)$$

$$\mu_1 f_9=\lambda_1 f_2 \quad \ldots \quad (75)$$

$$\mu_2 f_{10}=\lambda_2 f_2 \quad \ldots \quad (76)$$

$$\mu_3 f_{11}=\lambda_3 f_2 \quad \ldots \quad (77)$$

$$\mu_4 f_{12}=\lambda_4 f_2 \quad \ldots \quad (78)$$

$$\mu_1 f_{13}=\lambda_1 f_3 \quad \ldots \quad (79)$$

$$\mu_2 f_{14}=\lambda_2 f_3 \quad \ldots \quad (80)$$

$$\mu_3 f_{15}=\lambda_3 f_3 \quad \ldots \quad (81)$$

$$\mu_4 f_{16}=\lambda_3 f_3 \quad \ldots \quad (82)$$

$\mu_7 f_{17} = \lambda_7 f_2$ ... (83)

$\mu_8 f_{18} = \lambda_8 f_3$ ... (84)

$\mu_7 f_{19} = \lambda_7 f_4$ ... (85)

$\mu_8 f_{20} = \lambda_8 f_4$ ... (86)

$\mu_1 f_{21} = \lambda_1 f_4$ ... (87)

$\mu_2 f_{22} = \lambda_2 f_4$ ... (88)

$\mu_3 f_{23} = \lambda_3 f_4$ ... (89)

$\mu_4 f_{24} = \lambda_4 f_4$ ... (90)

Solving these equations recursively, we get

$f_2 = G_3 f_1$ ... (91)

$f_3 = (G_3 G_3 + G_1) f_1$ ... (92)

$f_4 = G_4 f_1$ ... (93)

$f_5 = \frac{\lambda_1}{\mu_1} f_1$ ... (94)

$f_6 = \frac{\lambda_2}{\mu_2} f_1$ ... (95)

$f_7 = \frac{\lambda_3}{\mu_3} f_1$ ... (96)

$f_8 = \frac{\lambda_4}{\mu_4} f_1$ ... (97)

$f_9 = \frac{\lambda_1}{\mu_1} G_3 f_1$ ... (98)

$f_{10} = \frac{\lambda_2}{\mu_2} G_3 f_1$ ... (99)

$f_{11} = \frac{\lambda_3}{\mu_3} G_3 f_1$ ... (100)

$f_{12} = \frac{\lambda_4}{\mu_4} G_3 f_1$ ... (101)

$f_{13} = \frac{\lambda_1}{\mu_1} (G_2 G_3 + G_1) f_1$ ... (102)

$f_{14} = \frac{\lambda_2}{\mu_2} (G_2 G_3 + G_1) f_1$ ... (103)

$f_{15}=\frac{\lambda_3}{\mu_3}(G_2G_3+G_1)f_1$ ... (104)

$f_{16}=\frac{\lambda_4}{\mu_4}(G_2G_3+G_1)f_1$ ... (105)

$f_{17}=\frac{\lambda_7}{\mu_7}G_3f_1$ ... (106)

$f_{18}=\frac{\lambda_8}{\mu_8}(G_2+G_3+G_1)G_4f_1$ ... (107)

$f_{19}=\frac{\lambda_7}{\mu_8}G_4f_1$ ... (108)

$f_{20}=\frac{\lambda_8}{\mu_8}G_4f_1$ ... (109)

$f_{21}=\frac{\lambda_1}{\mu_1}G_4f_1$ ... (110)

$f_{22}=\frac{\lambda_2}{\mu_2}G_4f_1$ ... (111)

$f_{23}=\frac{\lambda_3}{\mu_3}G_4f_1$ ... (112)

$f_{24}=\frac{\lambda_4}{\mu_4}G_4f_1$ ... (113)

Where

$G_1=\frac{\lambda_6\lambda_7+\lambda_6\lambda_8}{[(\lambda_7+\lambda_8)(\lambda_5+\lambda_8+\mu_6)-\lambda_5\lambda_7]}$ ... (114)

$G_2=\frac{\lambda_6\lambda_7}{[(\lambda_7+\lambda_8)(\lambda_5+\lambda_8+\mu_6)-\lambda_5\lambda_7]}$ ... (115)

$G_3=\frac{\lambda_5\lambda_7+\lambda_5\lambda_8+G_1\lambda_5\lambda_8}{[(\lambda_7+\lambda_8)(\lambda_6+\lambda_7+\mu_5)-\lambda_6\lambda_8]-\lambda_5\lambda_8\lambda_2}$ ... (116)

$G_4=\frac{\lambda_5(G_2G_3+G_1)+\lambda_6G_3}{\lambda_7+\lambda_8}$ ... (117)

Now, using the normalizing condition

$f_1+f_2+f_3+\ldots+f_{24}=1$ ... (118)

$f_1=[(1+\frac{\lambda 1}{\mu 1}+\frac{\lambda 2}{\mu 1}+\frac{\lambda 3}{\mu 3}+\frac{\lambda 4}{\mu 4})(1+G_1+G_3+G_4+G_2G_3)+\frac{\lambda 7}{\mu 7}(G_7+G_4)+\frac{\lambda 8}{\mu 8}(G_1+G_2G_3+G_4)]^{-1}$ ... (119)

$A(\infty)=f_1+f_2+f_3+f_4$

$= [1+G_1+G_2+G_3+G_4+G_2G_3]\, f_1$ … (120)

Behaviour Study

Transient State:-

An application of the Rungh-Kutta fourth order approach has been utilized in order to provide a numerical solution for the system of differential equations ranging from equation 1 to equation 24 with initial condition 25. After gathering information on the repair rates and failure rates of the subsystem on a daily basis, computations have been carried out for a period of up to three hundred and sixty days for a variety of repair and failure rates of the subsystems. In this part, study is done on the influence that a number of different parameters have on dependability. It is possible that the reliability will be impacted if the rates of failure and repair are changed. There is evidence of this impact in the tables that follow, numbered 1 through 2. The total number of days that constitute the mean time before failure (MTBF) for each of the failure rates is displayed in the final raw table. MTBF has been determined by using Simpson's one-third rule to the calculation. In terms of the impact that the failure rates of the jaw crusher have on the system's reliability:

In order to determine the system's dependability, the following combinations of failure and repair rates are utilized, and the results are provided in table 1: At the level of 0.01,0.02,0.03,0.04,0.05, the parameter λ_1 is taken into consideration, and other parameters are also taken into consideration $\lambda_2=0.03, \lambda_3=0.03, \lambda_4=0.07, \lambda_5=0.03, \lambda_6=0.03, \lambda_7=0.003, \lambda_8=0.003, \mu_1=6.0, \mu_2=6.0, \mu_3=4.8, \mu_4=12.0, \mu_5=24.0, \mu_6=24.0, \mu_7=0.30$ and $\mu_8=0.30$.

The table shows the effect of failure rate of jaw crusher ($\lambda 1$) on the reliability of the system. The reliability of the system decreases by approximately 1.2% with the increase of failure rate of jaw crusher from 0.01 to 0.05 and by approximately 0.019% with the increase in the from 30 to 360 days.

The MTBF in days of the jaw crusher is decreased by approximately 1% with the increase of failure rate 0.01 to 0.05

λ_1 → **Days ↓**	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**
30	0.980237	0.977349	0.974481	0.971632	0.968803
60	0.980202	0.977313	0.974445	0.971596	0.968767
90	0.980173	0.977282	0.974414	0.971565	0.968736

120	0.980148	0.977257	0.974388	0.971539	0.968711
150	0.980128	0.977236	0.974366	0.971518	0.968689
180	0.980110	0.977219	0.97448	0.971500	0.968672
210	0.980096	0.977204	0.974333	0.971484	0.968657
240	0.980084	0.977191	0.974321	0.971472	0.968644
270	0.980074	0.977181	0.974310	0.971461	0.968635
300	0.980065	0.977172	0.974301	0.971453	0.968626
330	0.980058	0.977165	0.974294	0.971445	0.968619
360	0.980053	0.977116	0.974288	0.971439	0.968613
MTBF	**353.04**	**352.03**	**351.03**	**350.03**	**349.44**

Table 1

Effect of Repair Rate of Jaw Crusher (μ_1) on the Reliability System:-

The repair rate of jaw crushers significantly impacts their operational efficiency, maintenance costs, and overall productivity in mining and aggregate processing operations. Here are the key effects of the repair rate on jaw crushers:

1. **Operational Downtime:-**
    a. High repair rate: - Frequent repairs lead to increased downtime, reducing the crusher's availability for production. This can disrupt the entire production line, especially in operations where the jaw crusher is a critical component.

    b. Low repair rate: - Minimal repairs mean the crusher operates more consistently, maximizing uptime and production output.
2. **Maintenance Costs:-**
    a. High Repair Rate: - Increased repair frequency results in higher maintenance costs due to need for replacement parts, labor, and potential outsourcing of repair services.

b. Low Repair Rate: - Lower repair frequency reduces maintenance expenses, contributing to better cost efficiency over the crusher's lifespan.

3. **Equipment Longevity:-**

a. High Repair Rate: - Frequent repairs may indicate underlying issues such as poor maintenance practices, sub optional operating conditions, or low-quality components, which can shorten the crusher's lifespan.

b. Low Repair Rate: - Proper maintenance and timely repairs can extend the crusher's operational life, ensuring it remains productive for a longer period.

4. **Production Efficiency:-**

a. High Repair Rate: - Frequent breakdowns and repairs can led to inconsistent production rates, affecting the ability to meet production targets and deadlines.

b. Low Repair Rate: - Consistent operation ensures stable production rates, improving overall efficiency and reliability.

5. **Safety and Reliability:-**

a. Higher Repair Rate: - Frequent repairs may increase the risk of accidents or equipment failure, posing safety hazards to operators and maintenance personnel.

b. Low Repair Rate: - A well- maintained crusher with lesser repairs is safer to operate and more reliable, reducing the risk of unexpected failure.

6. **Quality and Output:-**

a. High repair rate: - Frequent repairs can led to improper adjustments or wear on components, potentially affecting the quality of the crushed materials.

b. Lower Repair Rate:- Properly maintained crushers produce consistent, high-quality output, meeting the required specifications for downstream processes.

7. **Operational Planning:-**

a. High Repair Rate: - Unplanned repairs can disrupt operational schedules, making it difficult to plan production and allocate resources effectively.

b. Lower Repair Rate: - Predictable maintenance schedules allow for better planning and resource allocation, minimizing disruptions.

Factors Influencing Repair Rate:-

a. Quality of Components: - High quality wear parts reduce the frequency of repairs.
b. Maintenance Practices: - Regular inspections, lubrication, and timely replacement of worn parts can lower the repair rate.
c. Operating Conditions: - Proper feed size, material hardness, and avoiding overloading the crusher can reduce wear and tear.
d. Design and Build Quality: - Robustly designed crushers with durable materials tend to have lower repair rates.

Effect of Repair Rate of Jaw Crusher (μ_1) on Reliability of System:-

We again consider the failure and repair rates of different components as:

λ_1 = 0.03, λ_2=0.03, λ_3=0.03, λ_4=0.07, λ_5=0.03, λ_6=0.03, λ_7=0.003, λ_8=0.003, μ_2 = 6.0, μ_3=4.8, μ_4=12.0, μ_5 = 24.0, μ_6 =24.0, μ_7= 0.30, μ_8= 0.30 with the values of μ_1 carried from 2.0 to 10.0 with an increment of 2.0. We have completed the reliability based on this data tabulated the same in table 2.

The table reveals that the reliability and MIBF in days of the system increases by approximately 2.1% with the increase of the repair rate from 2.0 to 10.0, but decreases by approximately 0.005% with the increase in time from 30 to 360 days.

Effect or Repair Rate of Jaw Crusher (μ_1) on Reliability of System:-

μ_1→ **Days ↓**	**2**	**4**	**6**	**8**	**10**
30	0.957461	0.970165	0.974481	0.976654	0.977961
60	0.957452	0.970133	0.974444	0.976614	0.977920
90	0.957445	0.970107	0.974413	0.976581	0.977887
120	0.957439	0.970084	0.974387	0.976553	0.977858

150	0.957434	0.970066	0.974366	0.976531	0.977834
180	0.957430	0.970050	0.974348	0.976512	0.977814
210	0.957427	0.970037	0.974333	0.976495	0.977797
240	0.957424	0.970027	0.974321	0.978482	0.977783
270	0.957421	0.970017	0.974310	0.976471	0.977771
300	0.957413	0.970010	0.974301	0.976461	0.977762
330	0.957418	0.970003	0.974294	0.976454	0.977754
360	0.957416	0.969998	0.974288	0.976447	0.977775
MTBF	**345.12**	**349.522**	**351.027**	**351.784**	**352.243**

Table 2

Conclusion:-

The equation (1) to equation (25) are meant for computing the reliability of cement manufacturing plant for various combinations of repair and failures rates. We have tried to solve the system of differential equations using Laplace transform method. But, it is not easy to find the Laplace inverse of equation (65). Since the expressions for which Laplace inverse is to be focused have a complicate form. The problem becomes even more complex if the number of equation in system increases. However, this method is very convent to use if the system of differential equation is small and it is not so effective for large system of differential equation is formed while discussing the behavioural analysis of any process industry.

Jaws crusher plays a critical role in cement manufacturing by crushing raw materials into smaller particles for future processing. This study highlights the importance of optimizing crusher settings using wear-resistant materials, and implementing regular maintenance to improve performance and reduce costs. Further research should focus on developing energy-efficient designs and automation systems for jaw crushers in cement plants.

References:

[1] Boytsov, B. V. and Kranev, Yu. V. (1997). Forging and Stamping Production 12 2–4.

[2] Jack, de la Vergne. (2008). Hard Rock Miner's Handbook (Edmonton: Stantec Consulting) p 330

[3] Sahani, S.K., Oruganti, S.K., Kumar, S, K,, & Karna, S. K., (2025). Reliability Assessment of a Plywood Production Facility Utilizing Laplace Transform and Runge-Kutta Fourth-Order Differential Equations: Overview of Industrial Plant. *Metallurgical and Materials Engineering*, *31*(4), 417–423. https://doi.org/10.63278/1453.

[4] Sahani, S. K. Oruganti, S.K., & K. Sathish Kumar. (2025). Research Paper Optimization of Maintenance Strategies for Cement Manufacturing Plants: Optimization of Maintenance Strategies for Cement Manufacturing Plants. *SGS - Engineering & Sciences*, *1*(1). Retrieved from https://spast.org/techrep/article/view/5234.

[5] Nikitin, A.G. and Bazhenov, I.A. (2019). Problems and methods of improving the quality of jaw crushers, IOP Conf. Series: Earth and Environmental Science 377 (2019) 012020 IOP Publishing doi:10.1088/1755-1315/377/1/012020.

[6] Mossadegh, R., Aghazadeh, F., & Roshandel, J. (2012). Applying reliability-centered maintenance (RCM) for jaw crusher systems. International Journal of Mining and Mineral Engineering, 4(3), 210–223.

[7] Rajpal, S., & Tiwari, R. (2018). Reliability-based design optimization of jaw crusher. International Journal of Engineering Research and Applications, 8(7), 45–52.

[8] Singh, A.,Verma, D., & Bhardwaj, N. (2020). Enhancing reliability of jaw crushers in cement plant using predictive maintenance tools. Cement Industry Journal of India, 39(4), 22–28.

[9] Sahani, S.K. et al. (2025). Performance and Assessment of Jaw Crusher in a Cement Manufacturing Plant, Communications on Applied Nonlinear Analysis, Vol. 32 No. 3(2025), 904-909.

[10] Sahani, S.K., Sah, B.K., Sahani, K. (2023), Reliability-Centered Maintenance (RCM) in Cement Manufacturing Plants, Advances in Nonlinear Variational Inequalities, Vol. 26, No.1, 2023, 16-25. DOI: https://doi.org/10.52783/anvi.v26.4224.

[11] Sahani, S.K., Sah, B.K., Sahani, K., (2023) Statistical Reliability Modeling of Cement Kilns and Crushers, Panamerican Mathematical Journal, Vol. 33, No. 4,115-120.

[12] Rawal, D.K., Sahani, S.K., Singh, V.V., and Jibril, A. (2022), Reliability assessment of multi- computer system consisting n- clients and the k- out- of-n: G operation scheme with copula repair policy, Life Cycle Reliability and safety engineering, 05 May 2022, DOI: "https://doi.org/10.1007/s41872-022-00192-5.

[13] Montgomery, D.C. (2009). *Introduction to Statistical Quality Control*, 6th ed.; Wiley: Hoboken, NJ, USA, 2009; ISBN 978-0-470-16992-6.

[14] Montgomery, D.C. (2013).*Introduction to Statistical Quality Control*, 7th ed.; Wiley: Hoboken, NJ, USA, 2013; ISBN 978-1-118-14681-1.

[15] Mitra, A.(2021). *Fundamentals of Quality Control and Improvement*, 1st ed.; Wiley: Hoboken, NJ, USA, 2021; ISBN 978-1-119-69233-1.

[16] Liker, J.K.(2007). *Tak to Dělá Toyota: 14 Zásad Řízení Největšího Světového Výrobce, Vyd. 1*; Management Press: Praha, Czech Republic, 2007; ISBN 978-80-7261-173-7.

[17] FMEA-Handbuch, Fehler-Möglichkeits- und -Einfluss-Analyse, Design FMEA, Prozess FMEA: FMEA-Ergänzung -Monitoring & Systemreaktion; Automotive Industry Action Group, Verband der Automobilindustrie, Eds.; 1. Ausgabe, korrigierter Nachdruck, VDA: Berlin, Germany, 2021, ISBN 978-1-60534-367-9.

[18] Analýza Možností Vzniku vad a Jejich Následků: Příručka FMEA, FMEA Návrhu Produktu, FMEA Procesu, Doplňková FMEA Monitorování a Odezvy Systému, 1. Vydání, Česká společnost pro jakost, z.s.: Praha, Czech Republic, 2019; ISBN 978-80-02-02885-7.

[19] Mikulak, R.J., McDermott, R., Beauregard, M. (2017).*The Basics of FMEA*, 2nd ed.; Productivity Press, New York, NY, USA, 2017, ISBN 978-0-429-24477-3.

[20] Liu, H.-C., Liu, L.; Liu, N.(2013). Risk Evaluation Approaches in Failure Mode and Effects Analysis,A Literature Review. *Expert Syst. Appl.*, *40*, 828–838.

[21] Wu, Z., Liu, W., Nie, W.(2021). Literature Review and Prospect of the Development and Application of FMEA in Manufacturing Industry. *Int. J. Adv. Manuf. Technol.*, *112*, 1409–1436.

[22] Wang, Z., Ran, Y.; Yu, H.; Jin, C.; Zhang, G.(2021). Failure Mode and Effects Analysis Using Function–Motion–Action Decomposition Method and Integrated Risk Priority Number for Mechatronic Products, FMEA Using FMA Decomposition Method and IRPN for MPs. *Qual. Reliab. Eng. Int.*, *37*, 2875–2899.

[23] Ouyang, L., Che, Y.. Yan, L., Park, C.(2022). Multiple Perspectives on Analyzing Risk Factors in FMEA. *Comput. Ind.*, *141*, 103712.

[24] Gargama, H., Chaturvedi, S.K.(2011). Criticality Assessment Models for Failure Mode Effects and Criticality Analysis Using Fuzzy Logic. *IEEE Trans. Reliab.*, *60*, 102–110.

[25] Wu, X., Wu, J.(2021). The Risk Priority Number Evaluation of FMEA Analysis Based on Random Uncertainty and Fuzzy Uncertainty. *Complexity* 2021, 8817667.

[26] Yu, J., Xu, Y.; Yu, Y.; Wu, S.(2024). A Novel Failure Mode and Effect Analysis Model Using Personalized Linguistic Evaluations and the Rule-Based Bayesian Network. *Eng. Appl. Artif. Intell.*, *127*, 107345.

[27] Carpitella, S., Certa, A.,Izquierdo, J., La Fata, C.M.(2018). A Combined Multi-Criteria Approach to Support FMECA Analyses: A Real-World Case. *Reliab. Eng. Syst. Saf.*, *169*, 394–402.

[28] Shang, K.,Hossen, Z.(2013).*Applying Fuzzy Logic to Risk Assessment and Decision-Making*; Society of Actuaries, Schaumburg, IL, USA; Casualty Actuarial Society, Arlington County, VA, USA, Canadian Institute of Actuaries: Ottawaon, Canada, https://www.soa.org/globalassets/assets/files/research/projects/research-2013fuzzylogic.pdf (accessed on 20 September 2024).

[29] Bojadziev, G. *Fuzzy Logic for Business, Finance, and Management*, 2nd ed.(2017).Advances in Fuzzy Systems-Applications and Theory Series, World Scientific Publishing Co Pte Ltd., Singapore,ISBN 978-981-270-649-2.

[30] Mercorelli, P.(2024). Recent Advances in Intelligent Algorithms for Fault Detection and Diagnosis. *Sensors*, *24*, 2656.