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Research Article

Process Plant Upgradation Using Reliability, Availability, and Maintainability (RAM) Criteria

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The objective of this study is to propose a solution for process plant upgradation becoming extinct due to obsoleteness of spares. The study will help in reliability, availability, and maintainability (RAM) based upgradation of control system of process plants in developing countries. Available options for plant upgradation are compact control, modular, and semiautomatic. RAM based upgradation provides solution which is high in reliability and availability (usually all parts are replaced with upgraded and compatible technology) and is easy to maintain throughout the service life of process plant. Case study for stacker and reclaimer of cement plant upgradation is considered to both implement and evaluate the idea. Upgradation methodology is finalized by expert's feedback regarding selection of hardware with respect to availability, market survey to validate the opinion, and economical availability viability of selected hardware. Pre- and postupgradation scenarios are analyzed to validate the implementation of study and conclude the expected outcomes. The process plant upgradation yielded a cost-effective solution to the problem with automation increasing by 17%, plant maintainability increasing by 80%, and downtime of plant decreasing by 17%. Among all available options, modular design Op1 is considered the best choice that can satisfy RAM criteria.

1. Introduction

In process plant, different disciplines, such as electrical, instrumentation, automation, and mechanics, depend on each other. Consequently, the development of cross-disciplinary success factors in automated production systems (aPS) requires rigorous investigation [1]. The complication of automation in aPS containing software and hardware is creating a continuously increasing problem in the process industry (cement, fertilizer, chemical, food, and beverages). Modern trends in aPS largely depend upon small sizes, mass customization, higher unpredictability types of products, and a variability product portfolio in factory automation and process plant [2]. Currently the large-scale technology plays a crucial role in diminishing traditional technology, meeting the contemporary timelines, and increasing the size of the industry; however, this could be possible by using categorically competent programmed and well trained staff. Pakistani industry is confronting the difficulty of obsoleteness which is major cause of shutdown of the industry or producing lower quality products and these products lack the potential to compete in international markets [3]. Process accuracies of any industrial unit depend upon the mechanism of mechanical parts and installed control system, its performance, and its accuracy. Both the product and process quality depend on executed process which requires quality control schemes and their implementation by using modern control system such as object oriented programming techniques and modular design [4].

The basic objective of the study is to select the optimal alternative among various options such as compact box, modular design, and semiautomatic option; meanwhile further these options contain subaspects of cost, efficiency, maintenance, and breakdown. First, the compact control system (mostly single module interfacing with all inputs and outputs and centrally processing) has high cost, high efficiency, difficult maintenance, and less breakdowns [5]. Second, the modular option is characterized by low cost, low efficiency, easy maintenance, and less breakdowns. The third option contains the semiautomatic options having low cost and efficiency, complicated maintenance, and high breakdowns [6]. These are not the only decision criteria; the important thing is where we can apply certain technique. A CNC machine upgradation might be easy to handle with compact control system, while a process plant might have some limitations in implementation due to a variety of IOs and communication issues. In few cases, we might have to compromise on modular approach in few sections because hardware is not compatible for automation and portion if it is operated manually. The improvements in the field of electronic and electrical innovation have been so advanced that various technologies have gone obsolete and supplanted with new innovative ones. The application of advanced surface mount devices (SMD) and application specific integrated circuits (ASICs) have replaced most of the old parts because they have reduced the cost, require less space, and brought new design in field of electronics. The mechanical innovations have made the problems of practicality of the current enterprise frameworks due to obsoleteness of components such as an inaccessibility of hardware, highly priced management frameworks, and repair issues due to unavailability of old mechanical parts that need replacement due to deterioration [5].

New technology is moving towards disposing a particular part after certain lifetime without going for replacement. The problem of accuracy in mechanical processes and methods of first rate of the object exclusively relies upon control framework of any mechanical plant. Relatively small industry is being obscured to the current mechanical devices or maybe current plants which are facing expensive control systems, maintainability problems, and unavailability of hardware [4]. There is a dire need to explore some factors which may be created to spare the end of present mechanical flowers and give them a framework that settles viability problems. Especially the situation is noticeably horrific in developing countries like Pakistan where both the plants are refurbished or semiautomatic or have troubles of destitute preparation control [7]. This leads the plants to face troubles like viability, accessibility of spares/obsoleteness, and high maintenance expenses. In return, plants performance and quality of product decline if we keep on compromising these issues, finally resulting in complete breakdown [8].

Pakistani industry is considered as a traditional industry, with most of plants being second-hand or very old, and few remained shut down due to energy or maintenance crises. However, experts who have been working in similar situation come up with innovative ideas of upgradation or part replacement to make it functional. Concept of bath tub curves of reliability explains that electronics are worst if new due to high infant mortality rate and mechanics are worst if old due to wear and tear plus deterioration of moving parts. Most of the mechanical plant life (manual or semimanual) is outdated because of maintainability issues. Productivity, product quality, and the process accuracy are being compromised and manufacturing sector is paying huge price in the form of quality, cost, benchmark level productivity, and so forth [9]. The major reason for process and quality compromise is that either different automation or process control parts (electronic sensors, modules, processors, or control cards) are obsolete and not available and to keep plant running process automation is bypassed [10]. In order to overcome this problem, we need to come up with some solution that can overcome these obsoleteness issues [11].

The objective of this study is to train and instruct the local process automation industry to develop some upgradation technique using the same process flow but with implementation using different hardware that is more reliable and easily available, thereby increasing plant maintainability [12]. There is a close coordination with similar industry and continuous replacing of obsolete parts with equivalent readily available parts or process modification. The modular technique for the development of process control upgradation design has been carried out and then data concerning reliability of plant, downtime of plant, productivity improvement, and process development has been collected. The objective of this study is to train and instruct the organization performing the task of the automation industry and upgradation of industrial process plants by selecting most suitable and optimal solution among compact control box, modular option, and semiautomatic option based on cost, efficacy, and maintainability issues [10].

For upgradation, we need to study similar process and problem faced by them due to these spares' unavailability and obsoleteness. With selection of replacement, their performance evaluated by similar experts will enhance or knowledge database availability of spares. These are just the prerequisite to make your upgradation task easy which can fulfill RAM criteria. Data regarding plant upgradation is analyzed using some statistical tool; we used Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) to rank the best option for process plant upgradation. F-TOPSIS ranks the best option (among compact control box, modular design, and semiautomatic option) combining the respondents; the study will address the following as well:

(1) To figure out maintainability problem of process plants and key performance indicators (KPIs) being affected
(2) To study and explore the maintainability problem and its effects on process by comparing the pre- and postupgradation scenario established by KPI's improvement and vice versa
(3) To design the strategies for control upgradation which increase the process plant's maintainability and reliability, thus improving performance of the manufacturing in process plant

When we talk about modular approach of upgradation, we want to make sure that a problem in particular area or process of plant might not affect the complete plant or process. Modular approach helps us in separating problematic area and sometimes also helps us to bypass the problem to decrease the downtime. In old plants, this is necessary to decrease downtime of process plant significantly.

The rest of the paper is organized as follows: Section 2 contains the literature review of the proposed study, Section 3 explains the methodology used in this research, Section 4 elaborates the results and discussions obtained, and Section 5 presents conclusion of the study.

2. Literature Review

Various researchers have been concerned with the characterized practicality such as "the likelihood that a failed framework may be repaired in a selected intervening time of downtime." Lee et al. [13] have defined maintainability as the basic objective of design for maintainability (DFM) is to ensure the maintenance of the product throughout its life-cycle at suitable cost. Existing literature shows [3] that the requirements of maintainability can be categorized as quantitative and qualitative, while both types of maintainability requirements have been used to define the characteristics of maintainability in a system. The overall objective of design maintainability is to reduce costs, ensure safety, and reduce risk, in addition to reliability, availability, maintainability, and supportability (RAMS) [14]. Reliability centered maintenance (RCM) is an essential tool for implementing and scheduling maintenance techniques [15, 16]. RCM is especially effective in frequent failures which causes more time delays; it reduces the life-cycle cost and increases the life-cycle profit. Sillivant [17] suggested that the applications of preventive maintenance are similar in industrial plants. Sondalini [18] conducted the remedial maintenance as next stage from preventive maintenance and it can be defined as follows: once the item is failed, we usually replace it with another one. Based on the existing configuration techniques, Mehairjan [19] proposed that the risk assessment and management system (RAMS) is based on the results of a powerful database, which can indicate the proposed method and work plan to achieve the objectives of RAMS database. It can collect literature to establish an up-to-date database that can determine the fault nature of process system. Stenström et al. [20] identified the weak links, failure rate, and remedial measures in the equipment according to the experience of different users. Mkandawire et al. [21] proposed a method of inputting information in RAMS database in order to correctly format the faults in the list.

Chopra et al. [22] pointed out the quality tests and quality assurance procedures in order to ensure the reliability over a specified period of time under given conditions, whereas reliability becomes more beneficial concerned in testing instrument. Morris et al. [23] stated that, for a system having maintainability problems, its quality and reliability cannot be assured, whereas, for a system having maintainability issues, initial design can be reentered for correction of the problem. Stenström et al. [24] concluded that most of degradation, failure situation, and or variation of outcomes information is grey, whereas the database lacks clarity and consequently RAMS database is facing similar issues. Cheng et al. [9] pointed out that the major problem associated with O&M of process industry is log of maintenance, while minor changes are made by technicians to keep plants running which hook up together to create reliability issues and cause major failure sometimes. Process plant upgradation planning problems encompass uncertain structure due to various options having the contradictory objectives. Fuzzy MCDM approach has the advantage of choosing the best possible alternative, whereas Fuzzy TOPSIS can be transformed into fuzzy numbers having the capability with uncertainty in option choices. However, the application of Fuzzy VIKOR (F-VIKOR) method can be used to choose and categorize the options and recognize the best offer [25,26]. Consequently, the F-VIKOR tool will be used to assess the various choices in order to choose the best possible option. It focuses on prioritizing the options in order to select the solutions of a problematic decision having the contrary criteria. These existing studies have used numerous applications of Fuzzy TOPSIS in various applications. Various researchers have conducted different studies; however, they lack the pre- and postupgradation survey together with the application of Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) to rank the best option for process plant upgradation.

3. Research Methodology

Reliability is the probability of the process functioning without chance of failure during the given time interval under specified conditions [27]. Higher costs lead to engineering solutions to reliability problems for decreasing commercial expenses, increasing reliability, and satisfying customers with quality products, on-time deliveries by reducing cost, increasing equipment availability, and handling the problems arising from products that fail easily [28]. Improving reliability involves decreasing the frequency of process system failure. Improving reliability means decreasing the measure of the probability for failure-free operation, and mathematically it can be shown as

$$R(t) = e^{(-(t/MTBF))} = e^{(-\lambda t)}. \tag{1}$$

Reliability of system with series components is expressed as follows:

$$R(\text{reliability of system}) = R1\,(R \text{ of component } 1) \times R2\,(R\,of\ component\ 2) \times \ldots. \tag{2}$$

Reliability of system with parallel components is expressed as follows:

$$\begin{aligned} R\,(\text{reliability of system}) &= 1 - R1\,(R \text{ of component } 1) \\ &\quad \times R2\,(R \text{ of component } 2) \\ &\quad \times \ldots, \\ \text{reliability} + \text{unreliability} &= 1. \end{aligned} \tag{3}$$

3.1. Availability. Availability is the probability of a process system being available when required and it can be represented as a percentage of total time [29]. Mathematically, it can be expressed as

$$\begin{aligned} &\text{Total time} = \text{MTBF}\,(\text{cruel time between failure}) + \text{MTTR}\,(\text{cruel time to settle a disappointment}), \\ &\text{availability} = \frac{\text{time operational}}{\text{total time}} = \frac{\text{MTBF}}{\text{MTBF and MTTR}}, \\ &\text{availability} = \left(1 - \left(\frac{\text{MTTR}}{(\text{MTBF} + \text{MTTR})}\right)\right), \\ &\text{availability} + \text{nonavailability} = 1. \end{aligned} \tag{4}$$

3.2. Maintainability. Maintainability is a significance of design and installation which can be expressed as the probability that an item will be restored or retained for a stated condition within a specific time period [30]. Maintainability analysis has been used to assess the outline and design related to resource requirements and maintenance procedures. Generally the characteristics of maintainability are determined by design of the equipment's set, while the order of maintenance procedures define the time span required for maintenance or repairs. The major characteristic of maintainability is the mean time to repair (MTTR) which shows the ease with which software or hardware can be reinstated to operational state [31]. Quantitative maintainability is the total downtime for maintenance comprising all the time needed for identification of problem, trouble-shooting, active repair time, disassembling, and replacement/removal, verification testing of adequate repair, logistic-movement delays, and administrative tardiness.

$$\begin{aligned} M\,(t) = 1 - e^{(-(t/\text{MTTR}))} &= 1 - e^{(1-\mu t)}, \\ \text{maintainability} + \text{nonmaintainability} &= 1, \end{aligned} \tag{5}$$

where μ is a constant characterized by maintenance rate and MTTR is the mean time to repair. MTTR is easy to imagine as compared to probability value. It is anticipated to attain short repair times in order to ensure that the availability remains high. Three main parameters regarding downtime are active repair time, logistic time, and administrative time [32]. Figure 1 shows research methodology path flow for identification of hardware required for plant upgradation and RAM data analysis in parallel with plant upgradation.

Figure 2 shows the practicality square chart of stacker and reclaimer plant with respect to process flow. More detailed is the process flow design; more maintainable is the upgraded solution.

There are numerous unanswered questions considering the whole situation, so we need to know what sort of questions will ensure the correct idea of the situation. Many research methods and investigation strategies are available; nevertheless, there is a need to choose the technique which explores the relationship between the conventional control systems that have reliability and maintainability issues and when the plants are upgraded with most reliable and maintainable control system. The following are the main steps taken to complete this study selection of organization, data sampling questionnaire designing, and the selection of KPIs that need to be asked in survey [33]. Various performance measures for reliability and maintainability have been used in the process industry. Most popular indicators are on-stream factor with slowdown, on-stream factor, turnaround rate, availability (inherent, achievable, or operational), annualized dispatch index, and routine maintenance cost index. Obviously these indicators are used in the operational stage, whereas a few of these indicators can be used to assess different designs. Availability is the ability of an item to accomplish its necessary function at a stated time frame, in order to achieve a high level of availability for plant operations which ensure the profitable status for the manufacturing sector. Generally the process plant availability can be categorized into numerous types such as achievable, operational, and inherent. In essence, the availability of plant operations rejects system availability containing planned and unplanned maintenance time while time is lost to operative logistics and administration.

An achievable availability rejects planned and unplanned availability of maintenance time. The inherent availability

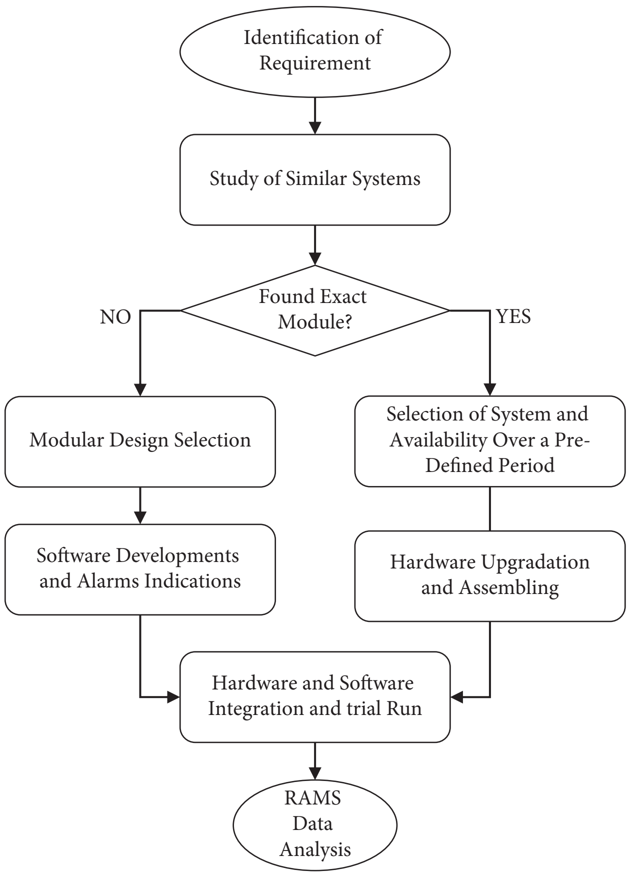

Figure 1: Schematic diagram of research methodology.

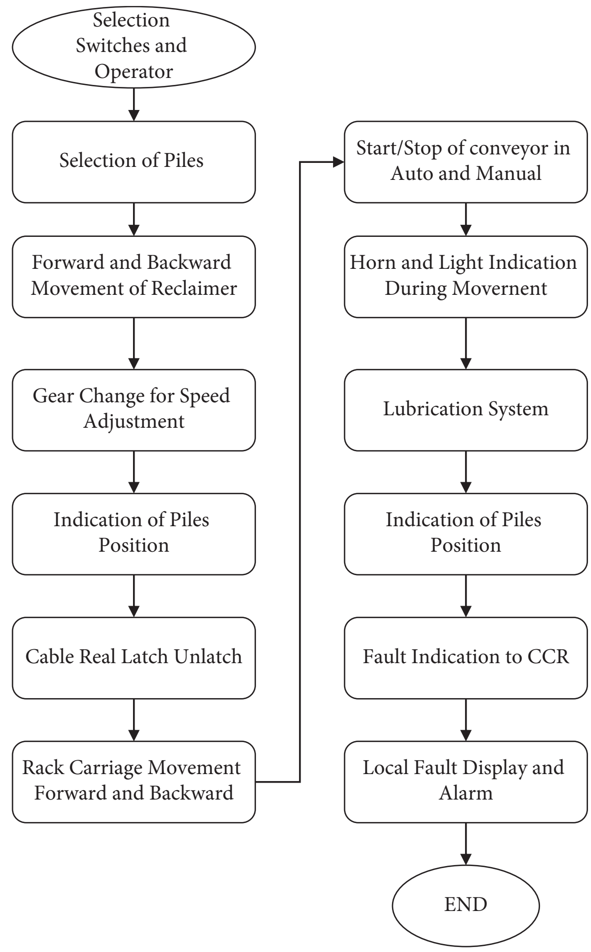

Figure 2: Schematic graph of investigation strategy.

assessment of process plant only evaluates the availability that can be expected when taking into account unprepared maintenance. The most realistic and operational availability is less important in design assessments as administrative and logistics downtime which is outside the control of the designer. Plant availability is considered as the function of the characteristics of reliability and maintainability of process plant. Maintainability actually is the capability of an item to be retained or restored to a condition, in which it can perform its obligatory functions during the maintenance process and using prescribed procedures and resources. Postupgradation responses show that a process engineer can increase the process plant availability at the stage of design development by enhancing maintainability or reliability or both. Although the problem of increasing plant availability stage of design development is relatively complex because several decisions can contribute to plant's maintainability and reliability characterized throughout its life cycle, at this stage, simple short-cut process models have been used for screening purposes, while the assumptions are made about the operational logistics and future control strategy. Within the conceptual stage of the engineering process, additional layers of complexity are added to the process plant models to relax basic engineering assumptions. The process model evolves from the conceptual stage to the engineering stage; a simple risk assessment and management (RAM) systems model can be constructed at the conceptual stage at the defined later stages. The development of a simple RAM model has been used at the conceptual stage which can also be used in combination of the process model to provide preliminary conceptual RAM targets. It can be used to support design engineers making critical design decisions. Figure 3 completely explains the RAM methodology and sequence.

3.3. Reliability and Durability. The basic step in any service is to identify the problem and it can be done by testing where a test stimulus is applied to module or to the system and the output is investigated to see the test specifications. If the outcomes are not specific, then the analysis needs to separate where the fault has been identified. It needs visibility and assessment of investigation for replaceable item. In order to complete the process, it is necessary to assess the input and output of each module as illustrated in Figure 4. This diagnostic capability provided externally or internally built into the system can reduce the cost of maintenance by saving diagnosis time.

The capability of internal diagnostics depends on inputs from electronic signals, built-in system test BIST, and sensors to control the operating parameter about specification. It can be measured through the fault tree analysis in order to suggest the most likely fault and related

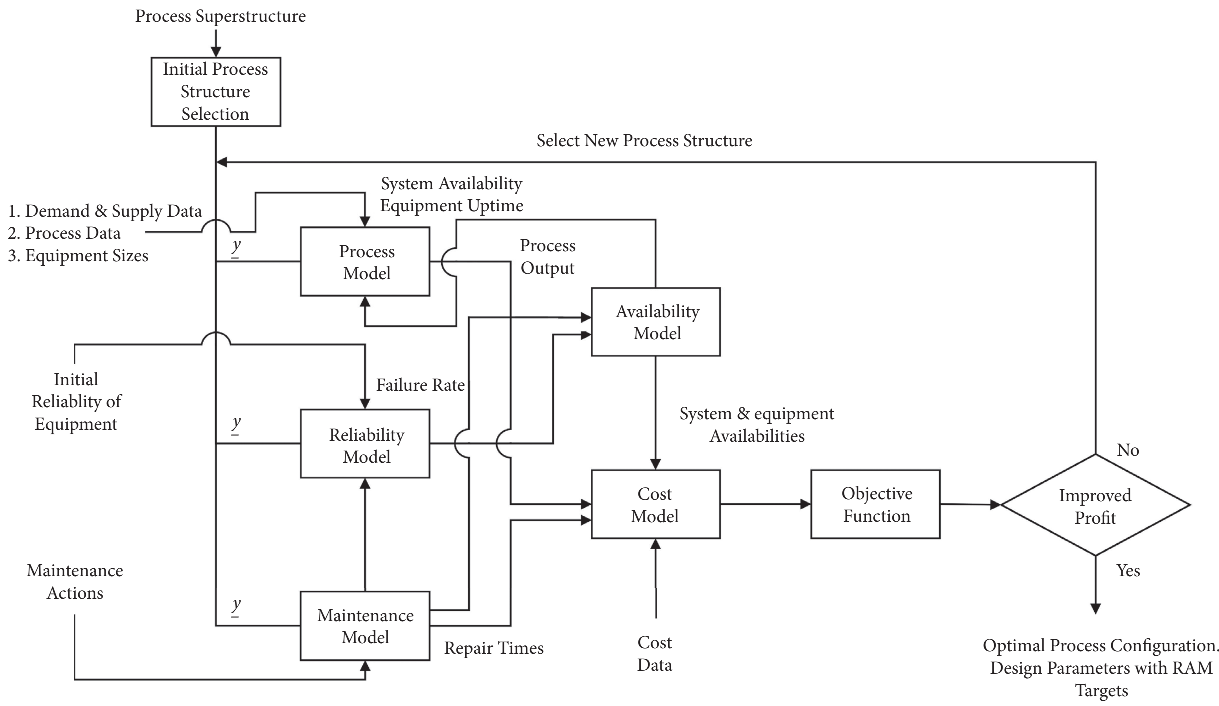

Figure 3: Models interactions: joint integrated process synthesis and availability optimization problem.

maintenance action. Further integration of operating history such as cycles, hours of operations, cycles, and miles can improve the fault tree analysis to the degree that the product is more reliable and durable. The products will require less service. Techniques such as failure reporting, analysis, and corrective action systems (FRACAS) and failure modes and effects analysis (FMEA) can be used to increase the reliability and durability. Reliability of design principles has been found as follows:

(i) Design based on expected range of operating environments
(ii) Provide cabinet AC to all control cabinets where temperature can rise and affect electronics
(iii) Provide critical subsystem redundancy
(iv) Use more reliable/robust parts (industrial grade components are better option)
(v) Reduce part count and interconnections
(vi) Provide modular design making fault isolation and module replacement easy
(vii) The major decisions about enhancing the reliability of a reactor, compressor, and the control system. In our study, we case modular blocks of our control system which is considered active redundancy for the compressor additional control cards for weaker links thereby creating redundancy.

The method of reliability-availability analysis has been used to estimate the availability related parameters for the configuration of given system with maintenance resources, repair characteristics of components, predetermined failure, and the interdependencies between various components. Dismantled parts can be either repaired or supplanted or total module may be changed. Moreover, for a given period of time, there is no issue of obsoleteness and regularly fault reporting components are held in stock to diminish downtime (Figure 5).

3.4. Maintenance Data. Maintenance data provides the equipment date of replacement, date of failure, and maintenance times. Generally the MTTR is calculated from the data which is major contributor to life of process plant. If a plant requires frequent maintenance which shows the low reliability index and low efficiency, this sometime leads us to the decision of replacement and upgradation of plant. The reliability of the device is measured by using Cronbach's alpha coefficient. One essential characteristic of these calculations is that if the data inputs are correlated, then the value of alpha coefficient is increased. Conversely, a high alpha coefficient does not always mean a high degree of validity because alpha coefficient also depends upon the degree of the test. If the length of the test is too short, the value of alpha coefficient is significantly reduced, while the results lose their validity [34]. FMEA have a way to become aware of unsuccessful ways by figuring out weaker links whether they come from layout or from manufacturing. Once we have identified the general failure mode, we can build a solution to avoid it without difficulty. Figure 6 shows the methodology of data collection for RAM criteria and data collection for application of statistic tools.

3.5. Fuzzy Technique for Order of Preference by Similarity to the Ideal Solution (F-TOPSIS). The TOPSIS is a popular method of Multicriteria Decision Analysis (MCDA) in

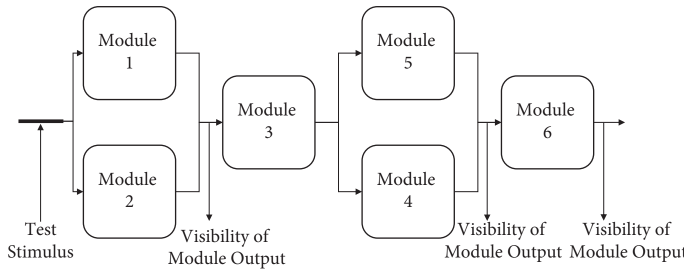

Figure 4: Fault diagnosis internal and external points.

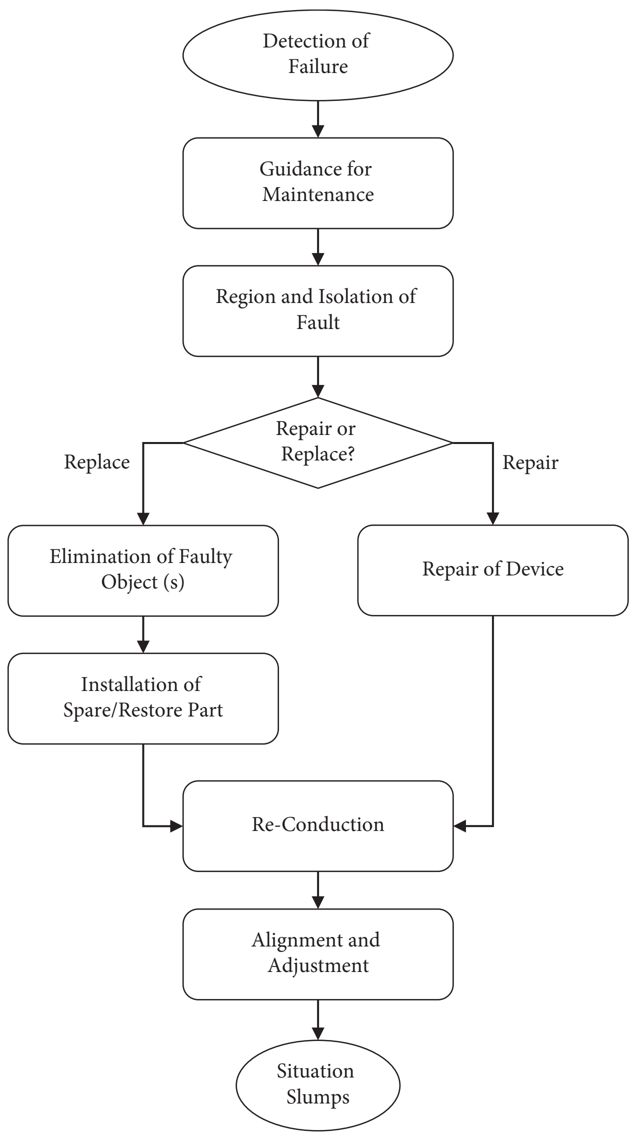

Figure 5: Maintenance cycle of industrial unit.

various applications. The basic objective of this method is to measure the maximum and minimum gaps between positive ideal and negative solutions. However, this method has numerous limitations and indefinite issues and even sometimes fails to ensure the clear information in real-life example. A more significant tool is to assess the various proposed options by means of linguistic variables instead of subjective values. By this, the shift engineers are able to attain an immeasurable and imperfect information through the theory of fuzzy sets. The fuzzy set application was proposed by [35] in economics and engineering. Therefore, the triangular fuzzy number (TFN) is repeatedly being used in MCDA techniques in order to resolve complex problems due to various options. A TFN is a triad $A = (p_u, q_u, r_u)$ where $p_u, q_u, r_u \in \mathbb{R}\,(p_u \le q_u \le r_u)$, having subsequent membership function form:

$$\mu A(x) = \begin{cases} \dfrac{x - p_u}{q_u - p_u}, & \text{if } p_u \le x \le q_u, \\ \\ \dfrac{r_u - x}{r_u - q_u}, & \text{if } q_u \le x \le r_u. \end{cases} \tag{6}$$

The triangular fuzzy numbers (TFNs) have been used to indicate the linguistic variables, which are generally used for the assessment of various options having different criteria. Currently, the TFN rating scale is frequently being used in MCDM problems, shown in Table 1.

The F-TOPSIS technique based on the linguist variables can be obtainable in the following way, where $i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$.

(1) Define the matrix of fuzzy decision X:

$$X = \left(x_{ij}\right)_{m\times n}, \tag{7}$$

where $x_{ij} = (p_{ij}, q_{ij}, r_{ij})$.

(2) Develop the normalized decision matrix of fuzzy numbers M:

$$M = \left[m_{ij}\right]_{m\times n}. \tag{8}$$

Here, $i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$.

$$m_{ij} = \left(\frac{p_{ij}}{r_j^+}, \frac{q_{ij}}{r_j^+}, \frac{r_{ij}}{r_j^+}\right), \tag{9}$$

where $m_j^+ = \max m_{ij}$ (positive i.e., maximum benefit criteria).

$$m_{ij} = \left(\frac{p_j^-}{r_{ij}}, \frac{p_j^-}{q_{ij}}, \frac{p_j^-}{p_{ij}}\right). \tag{10}$$

$p_j^- = \min p_{ij}$ (negative, i.e., smaller the best and cost criteria).

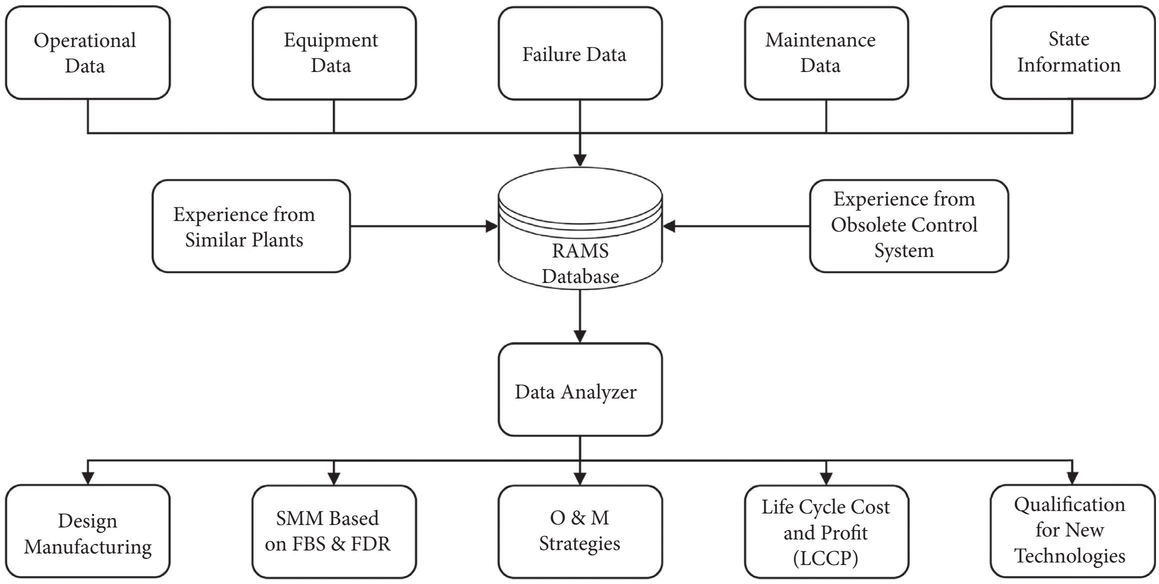

Figure 6: Schematic of proposed RAMS database.

Table 1: Rating scale of linguistic variables and triangular fuzzy number (TFN).

No.	Linguistic variables	(TFN)
1	Very bad (VB)	(1, 1, 3)
2	Bad (B)	(1, 3, 5)
3	Medium (M)	(3, 5, 7)
4	Good (G)	(5, 7, 9)
5	Very good (VG)	(7, 9, 9)

(3) Calculate the weighted normalized fuzzy decision matrix N:

$$N = \left[n_{ij}\right]_{m\times n}. \tag{11}$$

Here, $n_{ij} = m_{ij} \times w_j$.

(4) Identify the fuzzy positive and negative ideal solutions.

$$A^{+} = \left(n_1^{+}, n_2^{+}, n_3^{+}, \ldots, n_n^{+}\right), \tag{12}$$

where $j = 1, 2, 3, \ldots, n$.

$$\begin{aligned} N_j^{+} &= \max n_{ij} \text{ if } (j \in J); \\ &\quad \min n_{ij} \text{ if } (j \in J'), \end{aligned} \tag{13}$$

$$A^{-} = \left(n_1^{-}, n_2^{-}, n_3^{-}, \ldots, n_n^{-}\right), \tag{14}$$

where $j = 1, 2, 3, \ldots, n$

$$\begin{aligned} N_j^{-} &= \max n_{ij} \text{ if } (j \in J); \\ &\quad \min n_{ij} \text{ if } (j \in J'). \end{aligned} \tag{15}$$

(5) Calculate the distances of all alternatives by using equation 18

$$d_i^{+} = \sum_{j=1}^{n} d\left(n_{ij} - n_j^{+}\right), \tag{16}$$

where $j = 1, 2, 3, \ldots$.

$$d_i^{-} = \sum_{j=1}^{n} d\left(n_{ij} - n_j^{-}\right), \tag{17}$$

where $j = 1, 2, 3, \ldots, m$.

Now, the distance between the sets of two fuzzy numbers $A = (s_1, s_2, s_3)$ and $B = (t_1, t_2, t_3)$ is

$$d(A, B) = \sqrt{\frac{1}{3}\left[\left(s_1 - t_1\right)^2 + \left(s_2 - t_2\right)^2 + \left(s_3 - t_3\right)^2\right]}. \tag{18}$$

(6) Compute the coefficient closeness (CC_i) of each alternative by using the following equation:

$$\mathrm{CC}_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}, \tag{19}$$

where $i = 1, 2, 3, \ldots, m$; d_i^{+} is the distance between the d_i^{-} fuzzy negative ideal solution and fuzzy positive ideal solution.

(7) Rank and prioritize each optimal option and choose one with higher value of CC_i. The optimal solution and alternative is the one having smaller distances to d_i^{+} and d_i^{-}.

After the completion of the above phases, the F-TOPSIS would guarantee the prioritization and ranking of optimal alternatives through distance to positive and negative ideal solutions.

3.6. Population and Data Sampling. The population consists of workers from all levels who are specifically included with plant operation and chosen as respondents. To know the results closely related to actual situation, sample survey has been used as a questionnaire to those who have confronted the problems by pre- and postupgradation scenarios. It mainly contains operators, maintenance staff, assistants, shift engineers, repair workers, and front-line managers. The proposed population is helpful to identify significance and its operational capability of the study. In the sampling process, we select the representative of a sample to make the observation neutral and represent the quality of the whole population set [36]. In order to avoid bias sampling in industry, production personnel should ensure that the best samples for quality inspection have very accurate tolerances [37]. Valid, reliable, and unbiased samples need to meet two criteria. Sample must characterize the attributes of the population or target and amount of samples should be adequate to represent the population. In order to evaluate the accurate sample size, the level of precision, the level of confidence, and the degree of variability in the attributes have been measured [38]. Yamane's Formula has been used for sampling purpose and it was selected for determining the sample size. A 95% confidence level and $p = 0.5$ were assumed for equation.

$$n = \frac{N}{\left(1 + N\left(e^2\right)\right)}. \tag{20}$$

Pepsi Cola Lahore has been selected as it has currently upgraded its semiautomatic beverage line to be fully automatic. All parameters concerning reduction in downtime, maintainability, and throughput have been resolved. The personal staff has reduced to 50%.

4. Results and Discussion

A number of overall performance measures have been used in the machine enterprise as signs to explain the overall performance of a plant associated with its reliability and maintainability. The reliability of the instrument has been measured by Cronbach's alpha coefficient which is commonly accepted at the value of 0.60, whereas the sizes of the errors are assessed based on reliability index. For instance, if the reliability of test is 0.6, then error variance comes out to be 0.64 (random error) in the scores ($0.60 \times 0.60 = 0.36$; $1.00–0.36 = 0.64$). Usually the system reliability never surpasses component reliability. For a reliability index of 0.8, the error variance value comes out to be 0.36 which is an indication that the reliability of measurement increases and the error variance will decrease [39].

4.1. Preupgradation

4.1.1. Reliability Estimations of Free Variable. Cronbach's alpha coefficient for variables is 0.885. In this study, the variables consist of repairability traceability, local repairing, availability of spares, frequency of faults, concentration/strain stage, alternate solution, user-friendliness, safety, and job security.

In Table 2, there are 10 subfactors of maintainability variables in this study and their Cronbach's alpha coefficient value is given. Respondents' demographic profile for hierarchy stage is shown in Table 3 along with histogram analysis in Figure 7 which shows that about 57.1% of respondents have been working as "operators/assistants" in the groups. About 17.1% of respondents were "preservation personnel (technicians)" within the employer. 14.3% of respondents were "shift engineers" in the organization. Most effective 11.4% of respondents were from "top control" in the corporation.

4.2. Descriptive Analysis. Likert scale data analysis has been performed on interval measurement scale. The mean and standard deviations of all the variables have been measured in order to clarify the respondent responses. The mean and standard deviation of all the variables are given in Table 4. The related histogram analysis is shown in Figure 8. The variable concentration stress level has highest mean value of 4.40 and the standard deviation value is 0.689, whereas the variable alternate solution has the lowest mean value of 1.47 and the standard deviation value is 0.756.

Table 5 shows the amount of traceability. It appears that 45.7% of respondents accept that issues are never traceable. 27.1% of respondents say they are rarely traceable, 15.7% of respondents say they are sometimes traceable, and 5.7% of respondents think they are always traceable.

Table 6 indicates frequency distribution for repairability. It indicates that 38.6% of respondents believe faults are never repairable, 18.6% of respondents believe they are hardly repairable, 24.3% of respondents believe they are sometimes repairable, and 18.6% of respondents believe they are repairable.

Table 7 represents the alternate solution. It appears that 65.7% of respondents said that faults' alternate solution is never available, 34.3% of respondents accepted that alternate solution is rarely available, while 7.1% of respondents accepted that alternate solution is sometimes available, and 2.9% of respondents said alternate solution is often available. Table 8 gives frequency of faults. It shows that 20% of respondents said that faults happen sometimes, 61.4% of respondents stated that faults often occur, and 18.6% of respondents believe that faults always occur. None of the respondents believed that fault rarely occurs which means these plant lifes are often on breakdown and loss of production which is directly proportional to downtime of plant life. This is usually a not unusual phenomenon with aged vintage plants.

Table 9 shows the frequency distribution of safety of preupgradation. It indicates that the majority of respondents considered preupgradation system very dangerous and unsafe. 11.4% of respondents considered it a little bit safe.

Table 10 shows the frequency distribution of job protection security. It indicates that the majority of respondents

Table 2: Reliability statistics.

Cronbach's alpha	No. of items
0.885	10

Table 3: Hierarchy level.

Hierarchy level	Frequency	%
Operators/assistants	40	57.1
Maintenance staff (technicians)	12	17.1
Shift engineers	10	14.3
Top management	8	11.4
Total	70	100.0

considered preupgradation device more jobs secured. In Table 10, 15.7% of the respondents showed neutral response. Since most process and control activities are completed by machines rather than people, job safety is usually compromised by the shift to automation.

Table 11 shows the frequency distribution of repairability. It indicates that the majority of respondents stated faults are always repairable. Due to the modular design method, the modern structure is easy to maintain, so the method of directly replacing the module is often used for maintenance.

Table 12 shows the frequency distribution of concentration level. It indicates that the majority of respondents stated that upgraded systems are stressful. 11.4% of respondents showed a neutral response.

Table 13 shows the frequency distribution of safety from system's hazards. It shows that the majority of respondents stated that upgraded system is usually safe for operation due to automation. A design can be made simpler; the hardware can be reduced considerably. 31.4% of respondents considered safety as often, while 68.6% of respondents said that maintainability always ensures the protection.

In Table 14, independent t-test has been carried out to show the values of frequency along with their sign.

4.2.1. Postupgradation

(1) Descriptive Analysis. Mean and standard deviations of variables are given in Table 14, whereas they are compared in Table 15. The related histogram is given in Figure 9. The variable local repairing has highest value of 5, while the concentration of stress level has a value of 1.57, whereas the standard deviation of the variable local repairing is 0.000 and the standard deviation of job security is 1.57.

Table 16 shows frequency distribution of traceability. It indicates that the majority of respondents said faults are always traceable.

Table 17 shows frequency distribution of repairability. It indicates that the majority of respondents think that the faults are always repairable. Modern systems are easily repairable. Due to the modular design method, this purpose can be achieved by simply replacing parts.

Table 18 shows frequency distribution of local repairing. It indicates that all respondents considered that the faults are always locally repaired.

Table 19 shows the frequency distribution of availability of spares. In indicates that the majority of respondents think that the spares are always available.

In each section of postupgradation, we notice that consequences are leading towards the circumstances that after upgradation plants are repairable and maintainable, and along with this definite other characteristics of user-friendliness and safety can also achieved. The alternate solution in Table 20 shows that the majority of respondents suggested that alternate solution was not needed due to automation.

Table 21 shows frequency distribution of frequency of faults. It indicated that the majority of respondents said that faults rarely occur because of automation.

The user-friendliness table shows that the majority of respondents said that upgraded system is always user-friendly due to automation, whereas very few people who lack education, sufficient knowledge of system, and training considered that it is not user-friendly. However, this was not due to system but due to lack of knowledge of operator (Table 22).

Table 23 shows frequency distribution of concentration/stress level. It indicates that the majority of respondents said that upgraded system requires less concentration and also caused less stress due to automation.

Table 24 shows the frequency distribution of safety. It indicates that the majority of respondents believed that upgraded system is always safe for operation due to automation. A design can be made simpler; the hardware can be significantly decreased by safety and it will be easily maintainable and the cause of maintainability is never accepted or advised. Upgraded system is both more supportable and harmless.

Table 25 shows frequency distribution of job security. It indicates that the majority of respondents said that upgraded system has caused job insecurity.

One-way ANOVA has been used to measure the significant difference in the opinions of respondents because of hierarchy level and time spent in the organization. The results of one-way ANOVA show that there is a significant difference in the opinions of respondents due to hierarchy level and years with organization. In order to measure the difference between means of more than two independent data units, we have used one-way ANOVA to comprehend whether upgradation has influencing factors of alternate solution, repairability, safety, frequency of faults, traceability of faults, local repairing, concentration/stress level, user-friendliness, and job security. The opinions have been analyzed and the results show fluctuated responses based on job level, age group, and experience. One-way ANOVA (Tables 26 and 27) shows that at least last two groups were different. It is similar to collective status concluding that last two were different and not able to differentiate between even any two of them. The one-way analysis of variance (ANOVA) was used to determine whether there is statistical significance.

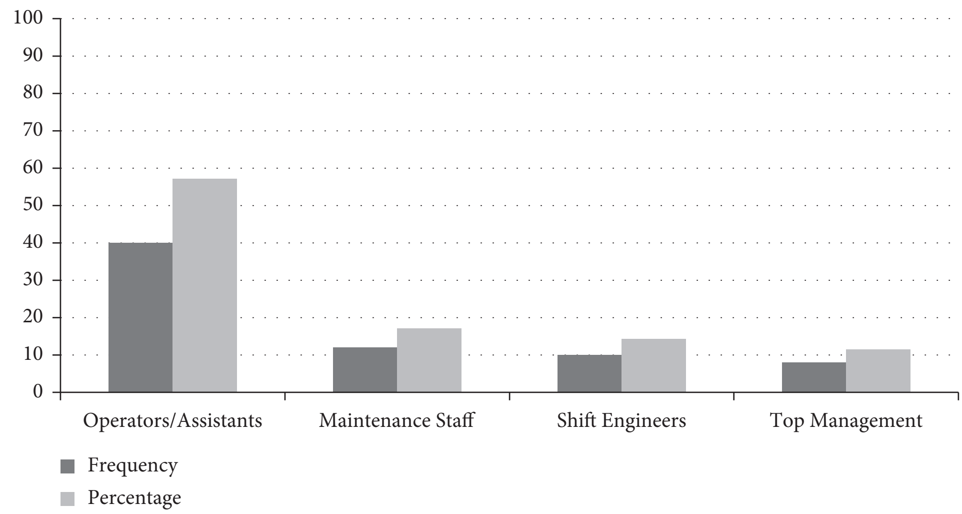

Figure 7: Respondents' demographic profile for hierarchy stage.

Table 4: Descriptive statistics.

Descriptive statistics	N	Mean	Std. dev.
Traceability	70	1.99	1.173
Repairability	70	2.23	1.157
Local repairing	70	1.90	0.935
Availability of spares	70	1.54	0.502
Alternate solution	70	1.47	0.756
Frequency of faults	70	3.99	0.625
User-friendliness	70	1.74	0.736
Concentration stress level	70	4.40	0.689
Safety	70	1.63	0.837
Job security	70	3.87	0.658
Valid N (list-wise)	70		

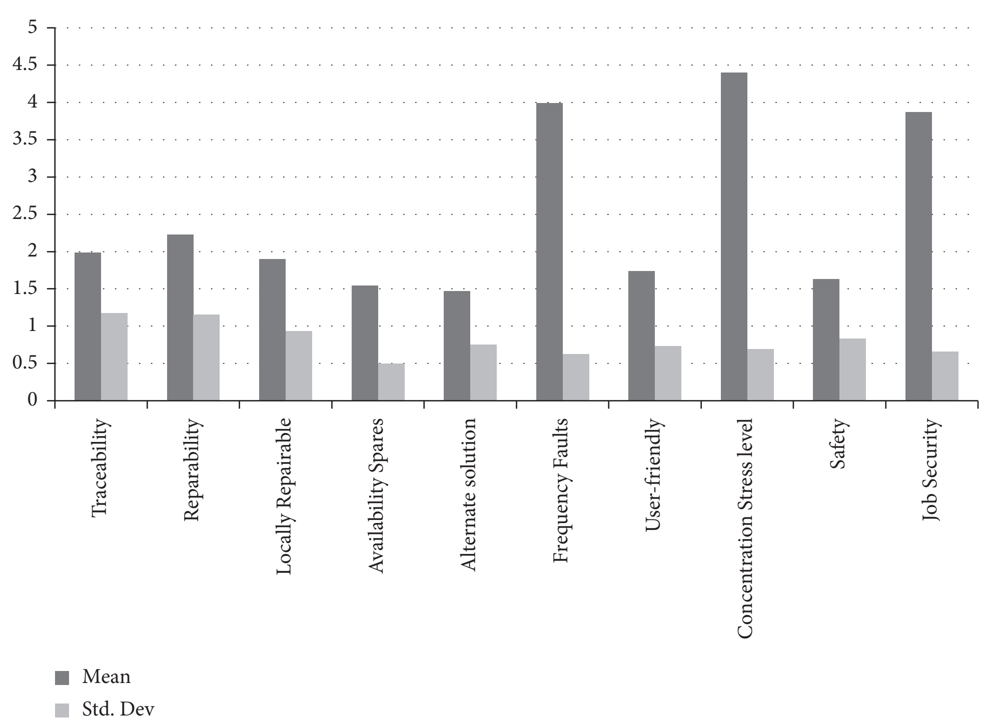

Figure 8: Respondents' demographic mean and standard deviations of all the variables.

Table 5: Traceability.

Traceability	Frequency	%
Never	32	45.7
Rarely	19	27.1
Sometimes	11	15.7
Often	04	5.7
Always	04	5.7
Total	70	100.0

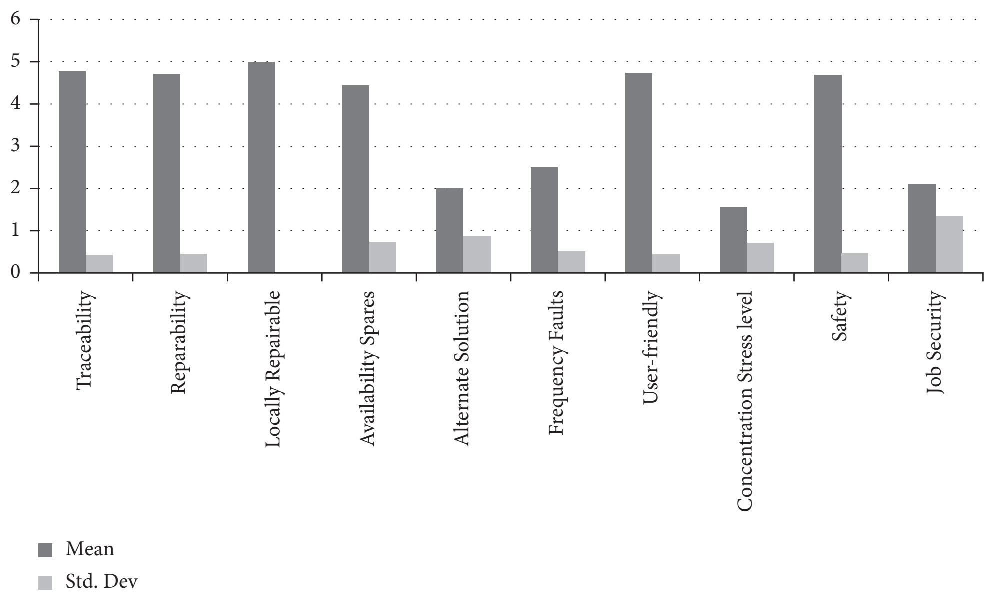

Figure 9: Respondents' demographic profile for hierarchy stage.

Table 6: Repairability.

Repairability	Frequency	%
Never	27	38.6
Rarely	13	18.6
Sometimes	17	24.3
Often	13	18.6
Total	70	100.0

Table 7: Alternate solution.

Alternate solution	Frequency	%
Never	46	65.7
Rarely	17	24.3
Sometimes	5	7.1
Often	2	2.9
Total	70	100.0

Table 8: Frequency of faults.

Frequency of fault	Frequency	%
Sometimes	14	20.0
Often	43	61.4
Always	13	18.6
Total	70	100.0

Table 9: Safety.

Safety	Degree	%
Never	38	54.3
Rarely	24	34.3
Sometimes	4	5.7
Often	4	5.7
Aggregate	70	100.0

Table 10: Job protection.

Job protection	Frequency	%
Rarely	3	4.3
Sometimes	11	15.7
Often	48	68.6
Always	8	11.4
Total	70	100.0

Table 11: Repairability.

Repairability	Frequency	%
Often	20	28.6
Always	50	71.4
Total	70	100.0

Table 12: Concentration/stress level.

Concentration/stress level	Degree/frequency	%
Never	39	55.7
Rarely	22	31.4
Sometimes	9	12.9
Total	70	100.0

Table 13: Safety.

Safety	Frequency	%
Often	22	31.4
Always	48	68.6
Total	70	100.0

Table 14: Independent t-test.

Sr.	Variables	Frequency	Sig.
1	Traceability	8.482	0.005
2	Repairability	153.000	0.000
3	Availability of spares	6.817	0.011
4	Alternate solution	53.691	0.000
5	Frequency of faults	33.333	0.000
6	User-friendliness	6.827	0.011
7	Concentration/stress level	0.482	0.490
8	Safety	0.419	0.520
9	Job security	2.583	0.113

Table 15: Descriptive statistics.

Descriptive statistics	N	Mean	Std. deviation
Traceability	70	4.77	0.423
Repairability	70	4.71	0.455
Local repairing	70	5.00	0.000
Availability of spares	70	4.44	0.735
Alternate solution	70	2.01	0.876
Frequency of faults	70	2.50	0.504
User-friendliness	70	4.74	0.440
Concentration/stress level	70	1.57	0.714
Safety	70	4.69	0.468
Job security	70	2.11	1.357

Table 16: Traceability.

Traceability	Frequency	%
Often	16	22.9
Always	54	77.1
Total	70	100.0

Table 17: Repairability.

Repairability	Frequency	%
Often	20	28.6
Always	50	71.4
Total	70	100.0

Nevertheless, in order to enable reprocessing of several functions, they can be bought up to date and utilized as company specific maintenance. Moreover, on account of standardization of application and basic modules, software maintenance is regularly revamped. The company benefits from standardization by introducing automated testing techniques. For reprocessing, some functions can be standardized and used as company specific libraries; the main reason is to keep and make improvement with more effectiveness and efficiency. The standardized application of software can easily improve by company. The main advantage of standardization is to produce large number of software applications. Additionally, different management can be combined into the software development process if

Table 18: Local repairing.

Local repairing	Frequency	%
Always	70	100.0

Table 19: Availability of spares.

Availability of spares	Frequency	%
Sometimes	10	14.3
Often	19	27.1
Always	41	58.6
Total	70	100.0

Table 20: Alternate solution.

Alternate solution	Frequency	%
Never	26	37.1
Rarely	17	24.3
Sometimes	27	38.6
Total	70	100.0

Table 21: Frequency of faults.

Frequency of faults	Frequency	%
Rarely	35	50.0
Sometimes	35	50.0
Total	70	100.0

Table 22: User-friendliness.

User-friendliness	Frequency	%
Often	18	25.7
Always	52	74.3
Total	70	100.0

Table 23: Concentration/stress level.

Concentration/stress level	Frequency	%
Never	39	55.7
Rarely	22	31.4
Sometimes	9	12.9
Total	70	100.0

Table 24: Safety.

Safety	Frequency	%
Often	22	31.4
Always	48	68.6
Total	70	100.0

Table 25: Job security.

Job security	Frequency	%
Never	32	45.7
Rarely	19	27.1
Sometimes	5	7.1
Often	7	10.0
Always	7	10.0
Total	70	100.0

Table 26: ANOVA due to hierarchy level.

ANOVA due to hierarchy level		Sum of squares	Df (N-1)	Mean square	F	Sig.
	Between groups	2.743	3	0.914	6.286	0.001
Traceability	Within groups	9.600	66	0.145		
	Total	12.343	69			
	Between groups	3.394	3	1.131	6.856	0.000
Repairability	Within groups	10.892	66	0.165		
	Total	14.286	69			
	Between groups	0.000	3	0.000	.	.
Local repairing	Within groups	0.000	66	0.000		
	Total	0.000	69			
	Between groups	16.296	3	5.432	17.093	0.000
Availability of spares	Within groups	20.975	66	0.318		
	Total	37.271	69			
	Between groups	25.611	3	8.537	20.582	0.000
Alternate solution	Within groups	27.375	66	0.415		
	Total	52.986	69			
	Between groups	13.125	3	4.375	66.00	0.000
Frequency of faults	Within groups	4.375	66	0.066		
	Total	17.500	69			
	Between groups	13.371	3	4.457	.	.
User-friendliness	Within groups	0.000	66	0.000		
	Total	13.371	69			
	Between groups	11.543	3	3.848	10.76	0.000
Concentration/stress level	Within groups	23.600	66	0.358		
	Total	35.143	69			
	Between groups	5.186	3	1.729	11.524	0.000
Safety	Within groups	9.900	66	0.150		
	Total	15.086	69			
	Between groups	109.294	3	36.431	135.146	0.000
Job security	Within groups	17.792	66	0.270	000	00
	Total	127.086	69			

the software presently used by the customer is known. As automated testing, kind management and alike programs form a slightly new drift in machine and plant automation, with some aspects, such as quality. Meanwhile software formation and generation can be easier, and the reason is that there are also challenges in this approach because of mechanical restrictions; the machines have a single flow of material. For a new combination of processing stations, the individual modules themselves can be arranged and automatically generated as they work independently from one another.

So far, often process plants and test of machinery can be a lengthy task during the implementation of test requirement. The obstacle is also known as lacking in instrument to maintain for automatic test. In order to test design, the methods of derived testing are often invisible, nonreplicable, and nonstandard and have comprehensive principles, and depend on the intelligence of specific engineers. The subject of quality assurance and testing process can be addressed through the investigation of production process and maintainability. Initially, the procedure of quality process can be addressed, and participants can then be asked whether to apply tests on the device and whether to conduct code reviews. Some companies ensure that there is a trial phase in the software enhancement process to identify faults in a timely manner. In this process, the test processing is carried out, including the equipment and machine flow related to alarm test.

4.3. Fuzzy-TOPSIS Results. The ranking of process plant upgradation has been examined through F-TOPSIS method. The analysis provided by the decision-makers has been developed by the calculation of fuzzy matrix into a TFN by

Table 27: ANOVA due to years with organization.

ANOVA due to years with organization		Sum of squares	Df	Mean square	F	Sig.
Traceability	Between groups	1.293	3	0.431	2.574	0.061
	Within groups	11.050	66	0.167		
	Total	12.343	69			
Repairability	Between groups	2.662	3	0.887	5.038	0.003
	Within groups	11.624	66	0.176		
	Total	14.286	69			
Local repairing	Internal groups	0.000	3	0.000	.	.
	Within groups	0.000	66	0.000		
	Total	0.000	69			
Availability of spares	Between groups	6.738	3	2.246	4.855	0.004
	Within groups	30.533	66	0.463		
	Total	37.271	69			
Alternate solution	Between groups	13.220	3	4.407	7.314	0.000
	Within groups	39.766	66	0.603		
	Total	52.986	69			
Frequency of faults	Between groups	3.373	3	1.124	5.253	0.003
	Within groups	14.127	66	0.214		
	Total	17.500	69			
User-friendliness	Between groups	7.218	3	2.406	25.803	0.000
	Within groups	6.154	66	0.093		
	Total	13.371	69			
Concentration/stress level	Between groups	4.201	3	1.400	2.987	0.037
	Within groups	30.941	66	0.469		
	Total	35.143	69			
Safety	Between groups	2.731	3	0.910	4.864	0.004
	Within groups	12.355	66	0.187		
	Total	15.086	69			
Job security	Between groups	49.502	3	16.501	14.037	0.000
	Within groups	77.584	66	1.176		
	Total	127.086	69			

Table 28: The final ranking of the selected wind sites.

Site	(d_i^+)	(d_i^-)	CC_i	Rank
Op1	16.421	0.612	0.041	1
Op2	14.978	0.587	0.039	2
Op3	14.797	0.578	0.037	3

Table 29: Possible alternatives.

	Complete box	Modular design	Semiautomatic option
Cost	Low	Low	Low
Efficiency	High	Low	Low
Maintenance	Easy	Easy	Complicated
Breakdown	Less	Less	High

the linguistic variables. The linguistic variables of rating matrix were obtained after the comparison of all choices against each of the subcriteria. Subsequently, the matrix of fuzzy normalized decision set, the matrix of fuzzy decision set, and the matrix of fuzzy weighted normalized decision set were obtained through the detailed process of fuzzy decision theory. The ranking of each option, that is, decision alternatives, has been obtained in coordination of coefficient closeness (CC_i) values presented in Table 28.

The present study provides wide-ranging implementation of F-TOPSIS insights and research framework associated with the different methodologies. The outcomes are yielded by enriched methodology with the four major aspects being complete box, modular design, and semiautomatic option and its subaspects to rank the alternatives. All these three underlying options are critical for decision-makers concerning the option selection for upgradation of process plant projects. The results reveal that, in the implementation of Fuzzy-TOPSIS, the selection of process plant upgradation having the bigger CC_i value is prioritized and ranked as the utmost suitable option in order to upgrade the projects. Essentially, results concluded that option 1 (Op1) is considered as the best choice followed by option 2 (Op2) and option 3 (Op3), respectively. This ranking and prioritization of numerous options are critical; in the mean time, experts use scientific decision projects and take into account essential features as well as robust practice. Option 1 (Op1) has satisfactory characteristics across all the relevant features and infrastructure in their surroundings. Essentially, this work can help decision-makers and engineers in the prioritization of feasible option (Table 29).

We have three options, namely, complete box, modular design, and semiautomatic option, further having subaspects of cost, efficiency, maintenance, and breakdown. The complete box is characterized by low cost, high efficiency, easy maintenance, and less breakdowns. The modular design option is characterized by low cost and efficiency, easy maintenance, and less breakdowns, whereas the semiautomatic option is characterized by low cost and efficiency, complicated maintenance, and high breakdowns.

5. Conclusion and Recommendation

Due to unavailability of the equipment and spares, it is not possible to essentially keep plant running. It has been found that the plants are made functional by using cheaper and most reliable mechanism of control upgradation. The study is implemented on process plant upgradation and the outcome of the study is evaluated. The main focus is not only to evaluate study but also to verify the RAM criteria. Reliability of plant is significantly improved by 80%. Availability and maintainability are increased as the plant is facing less failures, downtime is reduced, and, due to spare availability, plant is more maintainable. Pre- and postupgradation scenarios analysis was conducted involving majority of stakeholders plus experts of the field. The results show that there are specific factors such as frequency of occurrence of faults, traceability, repairability, user-friendliness, maintainability, safety, and job security. Significant improvement has been found after control upgradation in all factors except job security. Modular approach of control design has been facilitated in order to build control system by constructing the independent unit. The fault tracing is made easy by using alarms and spare modules are available and ready to replace without affecting other hardware. Traceability and maintainability are improved and easy as compared to the scenario before upgradation. This has drastically reduced the downtime of plants and improved productivity which has effect on financial position of the firm. This improves the market values of product and production unit. With control upgradation, productivity is enhanced by 17%, plant maintainability is increased by 80%, and downtime of plant is decreased by 17%. Further the results show that option 1 (Op1) is considered as the best choice followed by option 2 (Op2) and option 3 (Op3), respectively. In the future, maintainability may be calculated using the following path for which we want to discover MTBF and MTTR. For this reason, we will have to collect failure records after which reliability tools RCM and λ prediction shall be used. For future work, useful life consumption can be reduced to improve its performance. Overall performance of the proposed database can be enhanced beyond 80%. Significant improvement has been found after control upgradation in all factors except job security. Also fault localization and fault traceability become issues in this study.

Data Availability

The data can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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