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# Systematic Approach to Calculate Risk and Reliability in Uncertainty Condition

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## ABSTRACT

This study introduces a systematic model of decision-making based on reliability and risk of the system. First, a model of systematic decision-making has been introduced, and then it has been applied for risk conditions. The reliability index is used for predicting the future under uncertain conditions. However, the value of a system's reliability cannot be exactly known as reliability is a probable index. Therefore, the reliability of a system, when deviation from prediction value leads to significant costs, does not offer a perfect criterion for decision-making, and the process of system design should be formulated systematically, and the risk of failure should be calculated. This means that reliability always does not lead to less expenditure; but the risk of a system's failure should be also calculated. Employing an effective strategy for improving the reliability should be taken place through a systematic process. The systematic process and its members and relations are discussed hereafter, and a pattern has been offered for calculation of the reliability of process and risk assessment. Finally, the researcher has tested this decision-making model in an industrial factory.
**KEY WORDS:** systematic approach; decision-making; risk; reliability; uncertainty.

## 1. INTRODUCTION

Uncertainty is part of the real world with which we always face in the process of decision-making. The result of uncertainty is entering of some uncertain details in the problem, to the extent that we are not able to determine the parameters of system, and, therefore, later delicate and critical decisions for future will be challenging with these uncertain minutiae. Decision-making is a repetitive process with a variety of subjects. When the result of decision is important, decision-making, in every step of the process, needs reliance. In the first step, one may say that reliance on data is the basis of every kind of decision-making. Various studies have been carried out in regard with uncertainty of data [1-4]. Lack of exact information triggers wrong assessment of parameters of a subject; and lack of knowledge about the parameters of a subject will lead to inapt decisions, and comes up with unpredictable errors.

Also, when uncertainty exists in the system or environment, various systems are exposed to risks, i.e. financial risks, loss of human life, or toll on the environment; therefore, different futuristic and futurological approaches have been innovated and applied to date. The concept of uncertainty, following increasing number of nuclear plants and due to high safety risks of operations in these plants, has resulted in many studies. For instance, studies [5-11] have analyzed the relation between maintenance, reliability and risk in devices.

Reliability is one of indices used for predicting satisfying performance of a system in future. Reliability is normally used as an indicator for future decision-making, while its results is necessary for dealing with various issues like profit and revenue, production trend, humans health trend, and natural effects. For this reason, all variations in reliability will induce improper alternatives, improper maintenance activities, customer's dissatisfaction, and unpredictable excessive costs.

It is the nature of reliability that it is probable and uncertain; consequently, when uncertainty should be avoided and precise decision-making about present and future is needed, we cannot use it exclusively as it does not offer a perfect basis for precise decision-makings.

Principally, decision-making is somewhere between two modes of absolute certainty and absolute uncertainty. Under absolutely certain conditions, all environmental variables are controllable, and future would follow past trends. However, under absolutely uncertain conditions, all variables are uncontrollable. This is why providing a sustainable model for evaluation and calculation of reliability indices is a difficult tasks. Related studies in this field are of Wattanapongskorn et al. [12], in which a model has been offered for studying reliability and its optimization under uncertain conditions, of M. Eidukeviciute et al. [13], in which the validity of measuring uncertainty for decision-making models has been analyzed, of Kiureghian [14] , in which uncertain parameters in reliability evaluation index has been studied.

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Most real systems have complex operational components and processes. The final output of system heavily depends on the final output of every single component. In these systems, evaluation, prediction and analysis of operational effects are not easily possible. Some studies have been carried out on optimizing reliability of the system by taking reliability of components, failure rate and uncertainty into consideration [15-16]. Rekab [15] have analyzed the uncertainty of reliability evaluation in a serial system, in which all components are independent and in sequence. All above studies have tried to decompose intricate problems into their components, and then to solve each component separately. This method has been widely used by organizations to solve micro problems, while most of them had a transient and short-lived success.

The major flaw of in-depth and specialized studies is their divergence from understanding of the relation between components, and their ignorance of continuance of actions and activities and the mutual effect between the factors.

This study uses the systematic approach to offer a decision-making framework in case of uncertainty. The systematic approach has been developed over past decades, and provides a much more vivid macro view to the subject. The effectiveness of systematic approach has been also proved. The systematic approach also considers environmental interaction, in addition to functional interaction between components of the system.

## 2. CONCEPTS OF UNCERTAINTY, RELIABILITY AND RISK INDEX

The features of a system are not the result of the separate, unconnected activities of its components, but of the interaction between them. Therefore, a system must be considered as a whole, and understanding of a system is not feasible just by analyzing it exclusively. The real-time utilization of analysis and combination is therefore necessary to gain an understanding of a system. By analyzing the structure, the subject will come clear and determining how component function will be possible. Therefore, it improves our knowledge of the subject. On the other hand, combination, puts the parameters of subject besides each other, focuses on function, and provides a holistic understanding of the subject. Taking functional interaction between the components of a system into consideration, the systematic approach also considers environmental interaction.

If the system tends toward complication, understanding, assessment and control of the system will be problematic, and unreliable behaviors will be likely to emerge from the system. These kinds of behavior can incur excessive costs, including waste of individual, organizational and social attempts, and jeopardizing the environment, human life or similar related issues. One of the indices normally used for determining reliability of a system's performance in future is the reliability index. It is defined as the probability of satisfactory performance of a system in a definite period of time.

This definition is constructed from four components of (1) probability, (2) performance, (3) satisfactory, and (4) definite time. Probability is stated by a number. Performance is among the engineering parameters. Being satisfactory is among management and engineering parameters. The time and condition can be continuous or intermittent. For assessing reliability of a system, we need the data of system. The parameters can be acquired from the system's data. To achieve this, in the first step, we have to fully understand the system, and to become certain of the future of system on the basis of the data we have in hand. Future performance of a system strongly depends on the class of the system. The performance cannot be defined, by any means, definitely; because the performance of systems has an accidental nature, and assessment of the accidental processes is only possible by using probability theories.

As the nature of reliability is uncertain, it is clear that reliability theory can not solely assess the satisfactory performance.

In order to gain an understanding of a system, we need to know about its feature. These features, depending on the complexity of the system, are gained through various methods. The more complex the systems become the more elusive understanding of system become through conventional methods; therefore, for a better understanding of the system, more suitable tools need to be used. The average and the variance of reliability are the two main parameters which we normally seek for gaining an understanding of them using the probability theory and statistics. The average value of a probability distribution, which represents the average of data, is always between or equals to 0 and 1.The issue of reliability allocation can be formulated as follows:

$$H\,(R_1\times R_2\times R_3\times \ldots\ldots\ldots\ldots R_n) \geq R^* \qquad (1)$$

In which, $R^*$ represents the reliability of a certain system's objective, $R_i$ is the reliability of $i$, and the function H relates the reliability of system and its constituents to each other. Policy-making for reliability starts by calculating the function H. The more complex systems are, the harder calculation of the function H is.

Under uncertain conditions, or when the factors or relations of a subject are vague or incomplete, risk, as an indicator for decision-making, analyzes threatening factors, vulnerability, and the effect of uncertainty in general. The use of different definitions for risk indicates its different usage. A traditional, basic definition of risk is:

$$\textit{Risk} = \textit{Probability of an accident} * \textit{Consequence of its happening} \qquad (2)$$

The analysis of risk in places like nuclear power plants, spaceships, and chemical plants has wide applications. For every field, there exist complex definitions and understandings of risk. Risk measurement helps us gain an understanding of the effects of uncertain internal and environmental parameters of a system.

In statistics, risk is distinguished by counting and calculating the number of undesirable accidents. To calculate the probability of an accident occurring, we need to have the number of occurred incidents and then calculate the believable scenarios from results. In the set of scenarios, the set of risks is distinguished, and the degree of regret or success in its expected value.

The variety of subjects which risk management deals with is so vast. Risk management can be used specifically for every subject under an uncertain condition; however, risk management is not only related to a certain kind of subject. Reliability examines the possibility of achieving success and satisfactory performance. In contrast, risk examines the possibility of loss and damage incurred by failure and wrong performance of the system itself or its environment. Reliability and risk are two managerial tools. Their applications are listed in Table1, considering the magnitude of change in the complexity of system and environment.

## 3. SYSTEMATIC DECISION-MAKING METHODOLOGY

Decision-making is a process in which decision-maker predicts and evaluates the outcome using existing data, and chooses a certain solution for attaining the objective. For simple issues, decision-maker has the ability to fulfill all stages of decision-making, including data gathering, analysis of and choosing the solution. However, for complex systems, decision-making is done through a process shown in Figure 1.

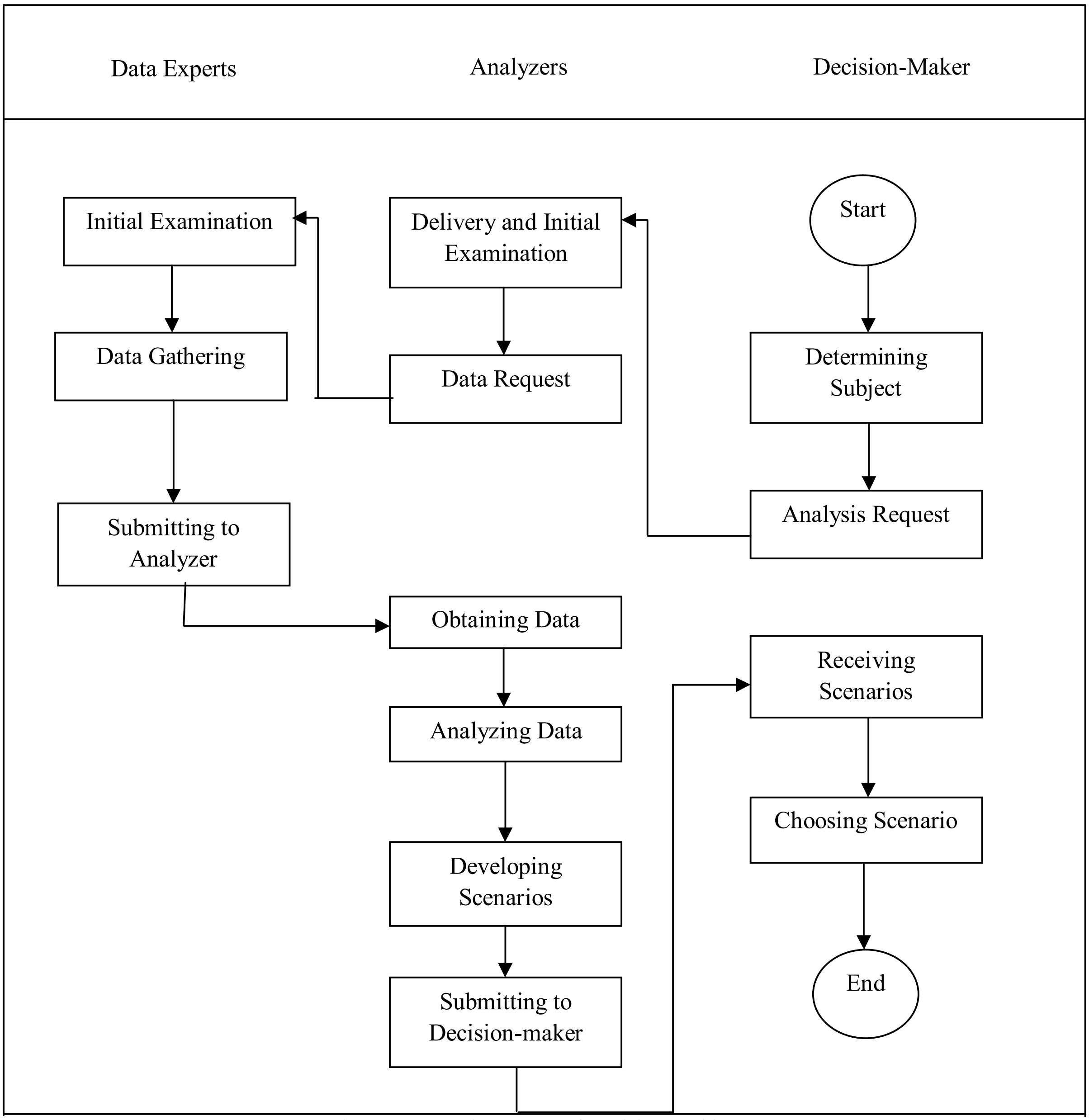


Fig. 1. Systematic Process of Decision-Making

Table 1 – Risk and Reliability as Managerial Tools

| **Magnitude of change** | **Frequent (certainty)** | **Course** | **Continuous changes** | **Discrete changes** | **Vague (absolute uncertainty)** |
|---|---|---|---|---|---|
| Managerial tools | Record of events | Statistics | Probability theory | OR technique | Innovation |
| | | Reliability engineering | | | |
| | | **Risk management** | | | |

In complex systems, it is not possible for decision-maker to make a decision due to indistinct parameters of subject. For these complex subjects, a decision-maker asks analyzers to analyze the subject in order to control all details. Analyzers need data for analysis, and they can have access to data via data experts. After acquiring required data, analyzers analyze the data and prepare a scenario from choices for decision-maker. The decision-maker then chooses a choice and, thus, the decision-making process is complete.

Integrated use of both tools, i.e. reliability and risk, when both have a common ground, allows us to calculate the effects of wrong prediction of the future. Thus, reliability can be regarded as an input to risk management.

The analyzing team, depending on the complexity of subject, has specializations in various fields, e.g. mechanic, electricity, system design and maintenance. They interpret data and provide an estimate for the reliability of system, and prepare scenarios to increase, decrease or stabilize the reliability of system. Finally the data are sent for next step.

Since the possibility of component's failure has been calculated in the previous stage, data experts list the failure costs in this stage and give it to the analyzers at this stage. The analyzers at this stage, according to the class of subject, can be experts at safety, economic, technical or designing issues. They merge the probability of failure with its costs and then determine the system's risk using the system's reliability. Analyzers at this stage construct various scenarios for the decision-maker, which include take, reduce, transfer or separation of risk. At the stage of decision-making, assessing the possible profit or loss of the decision-making performance of system will be more precise, as the system's reliability has been already determined.

## 4. GENERAL MODES OF FINAL SCENARIOS

Final scenarios, which are compiled by analyzers for the use of decision-maker, include four general modes: (1) Accepting the risk, (2) Avoiding the risk, (3) Reducing the risk, and (4) Transferring the risk.

### 4.1. RISK ACCEPTANCE

The strategy of acceptance means accepting the damage whenever it occurs. The acceptance of risk is an acceptable strategy for slight risks. The cost of protection against risks may be more than all incurred losses, considering the amount of time spent for dealing with that risk. Risks of this type are divided into two main categories. The first category includes those risks which cannot be removed due to existing limitations; therefore, they are accepted. The second category includes those risks whose occurrence would not cause disaster; on the other hand, their removal is not economical. For example, for a simple process in which the time of diagnosis is short, total automation of the process may not seem economical. Moreover, total automation of the production line may produce new flaws and failures. In this mode, therefore, decision-maker can adopt the strategy of accepting the risk. Consequently, whenever costs of failure and damage can be overlooked, this scenario is chosen. In non-mechanized industries, damages incurred to machines and sudden stops of machines usually do not pose severe problems for manufacturers or at least there is no need for predicting these problems; in addition, most production facilities have a simple design, which makes working with them and their maintenance easy; thus, there is no need to use systematic maintenance. In this mode, most production and industrial units maintain and repair a device or facility only when it is out of order. In fact, the maintenance system is normally use in case of breakdown, which is called Breakdown Maintenance (BM).

### 4.2. RISK REDUCTION AND CONTROL

The strategy of risk reduction is defined as using methods for reducing the intensity of damage. When the increasing trend of breakdown is in a way that affects the quality and quantity of production and it gives rise to dissatisfaction of industry owners, managers and experts work toward an effective solution to stop the increasing growth of flaws. To achieve this, Preventive Maintenance (PM) is used as a solution in the country.
There are various advanced methods for handling tragic accidents and controlling likely costs, which is referred to as the system's behaviors in case of failure. These methods are used whenever the existing errors of system incur irreparable damages on humans, devices or environment, and it is necessary to increase the system's reliability in the best way. Improving the quality of elements or increasing additional elements can build up more confidence in the system.

### 4.3. RISK AVOIDANCE

The strategy of avoidance is defined as not doing an activity that poses a risk. For instance, if the reliability of a system is as much as that its wrongdoing poses a high risk, and increasing the reliability to the maximum possible will not decrease the risk of process to the endurance extent, then the operation of the device can be halted. That certain operation could be done with more suitable devices in order to avoid former troubles. Also, it is possible to predict the breakdown of that device. The Preventive Maintenance has been developed to address the new needs of industry, which is referred to as the Productive Maintenance. Productive maintenance not only focuses on improving accidental damages and unexpected breakdown of facilities using sciences, statistics, probability theory, simulation, economy of engineering, but also invents techniques and models for different modes of facilities, which can be used by experts and analyzers for arranging maintenance operations, predicting breakdowns, and planning for future maintenance. To prevent from failure, advanced controlling methods like fail-safe control systems have been introduced. These methods not only are able to recognize the existing errors of a process, but also their internal errors. If an error occurs, the system acts in a flexible manner and switches itself into the safe mode, remaining there until the error is rectified. The advantage is that the process and its outcome would not stop.

### 4.4. RISK TRANSFER

The strategy of transfer is defined as making another part of system accept the risk. This is usually done by making a contract, exercising caution or getting insurance. In such case, reliability normally is retained at a moderate level, while risk is transferred to an insurance firm. In production systems, a certain internal operation can be done by outsourcing in order to avoid its costs or problems. Although avoiding the risk leads to removal of the risk, it is likely that it ruins the creation of value in business to a certain extent.

## 5. REAL CASE STUDY

The case study here examines a factory which manufactures chassis for heavy vehicles. In this factory, there are vague and uncertain issues about breakdown of components of machineries. What makes decision-making about increasing reliability difficult is that there is no parallel machine to many machines of this factory, so failure of some parts will result in complete stoppage of production, and therefore, will incur considerable costs. Making decision about purchasing new pieces is not easily feasible due to variation of pieces and the huge costs it has. The management intends to make decisions about alternating and purchasing new pieces according to the above methodology. First, we explain the methods of understanding and analysis of risk. Fig. 2 depicts a schematic of the factory.

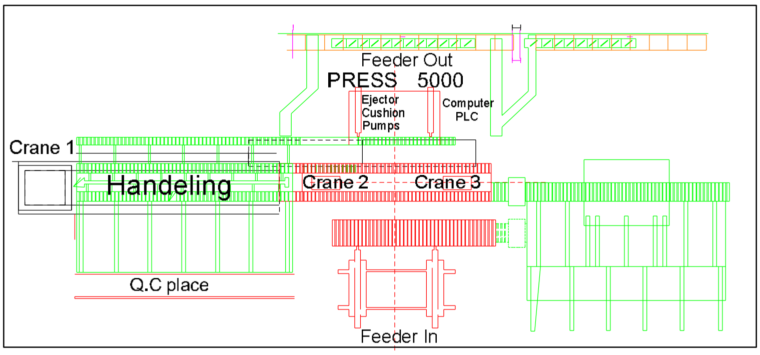


Fig. 2. Schematic of the Factory

To begin the analysis, a part of critical Fault tree of the machine has been drawn in Figure 3. In this case study, three parts of the Fault tree were investigated. These three parts are: the press's computer which controls all the system; PLC control which is the connector of the hardware and the software of the press; and cushion pumps have the duty of making pressure over the parts pressed. These parts are included as the essential components of the production institute, which may be defected due to exhaustion, and providing their similar ones imposes some costs to the organization. Over the past 13 years, there are only limited data about the failures of the control computer which is not possible to make direct decisions through statistical methods upon them. The director manager of this institute aims at deciding based on the previous data and the experts' opinions about how to react to the risk resulted from this three part collection.

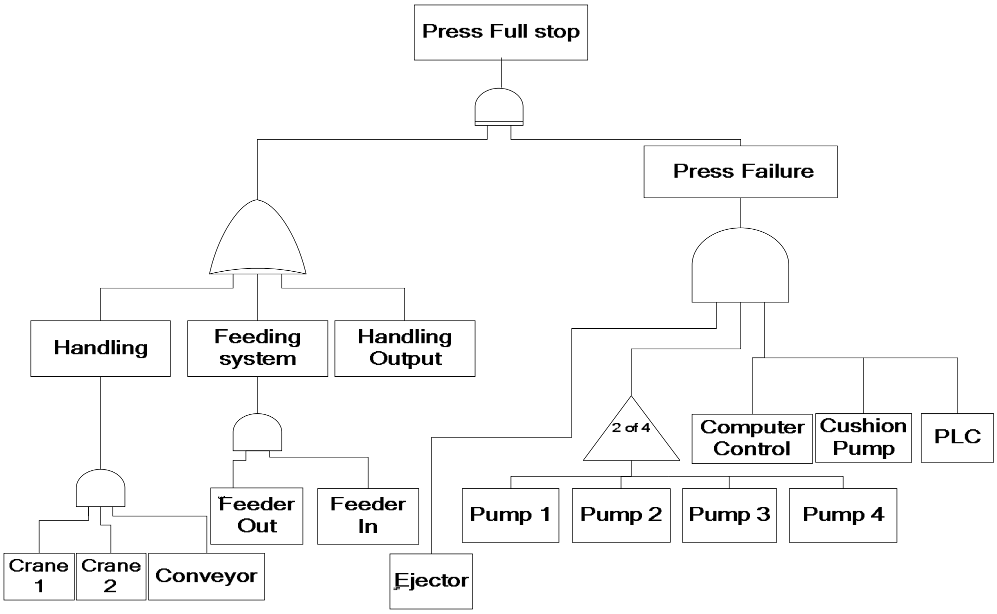


Fig. 3. Fault Tree of the Machine

### 5.1. DESCRIBING KEY INDICATORS

Risk is the probability of occurrence multiplied by the magnitude of damage. The magnitude of a risk indicates the scale of damage that will be incurred if the risk is realized. The subject firstly has to be determined, and then an estimate of reliability will be made. The output of this part is the probability of risk, which shows the occurrence probability of a risk in a definite period of time. Classification of risks according to their probability of occurrence is also possible. The classification of Table 2 shows a fuzzy categorization of relative probability of an accident or breakdown occurring as a result of uncontrolled risk. This table helps us to understand the importance of an accident according to the probability of its occurrence. It is worth mentioning that in similar categorizations, the probability of accidents occurring can be defined in a quantitative way; in this mode, the data expert must gather data in a quite precise way.

Table 2 – The Probability of A Risk Occurring

| Probability of Occurrence | Risk Level | Probability Rang | Risk Description |
|---|---|---|---|
| **High** | A | 0.8-1 | Occurs repeatedly. |
| **Medium-High** | B | 0.6-0.8 | Occurs several times during the system's lifetime. |
| **Medium** | C | 0.4-0.6 | Occurs occasionally during the system's lifetime. |
| **Low-Medium** | D | 0.2-0.4 | The probability of the risk occurring is low. |
| **Low** | **E** | **0-0.2** | **The probability of the risk occurring is extremely low.** |

It is a problem with fuzzy uncertainties that can be obtained from expert's opinion. It is shown a category from failure probability in Fig 4.

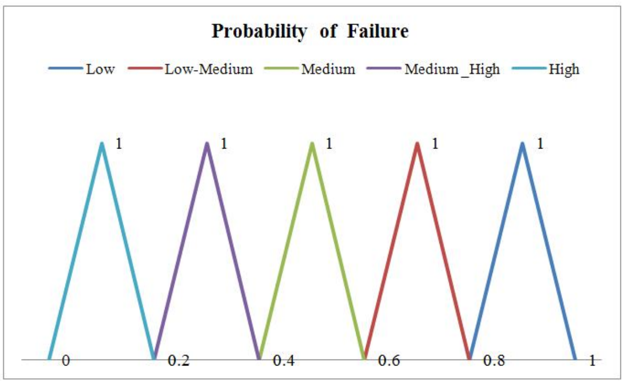


Fig. 4. Fuzzy Uncertainties in Probability Of Failure

Once the probability of system's breakdown is calculated, it will be used by risk experts to determine the risk of system's failure. In this stage, the existing risks are categorized according to their magnitude. These types of classification may differ as they may be based on the number, names, objectives or purposes of categories. A system of classification for risk magnitude was presented by the United States Military Standard* in 1984. In this classification, risks are divided into four categories, i.e. Catastrophic, critical, marginal and trivial. Although this standard was especially for assessment of military systems, it is widely used in industries nowadays.

Based on standard, researchers show this system which presents a fuzzy indicator for the relative magnitude of possible consequences under risky conditions. (Table 3)

Table 3 – The Categorization of Risk Magnitude

| Risk Type | Category | Consequence Rang | Definition |
|---|---|---|---|
| Major | 1 | 0.8-1 | Annihilation of the system or fatality |
| Moderate-Major | 2 | 0.6-0.8 | Infliction of severe damage on the system or occupational casualties and diseases |
| Moderate | 3 | 0.4-0.6 | Infliction of moderate damage on the system or occupational injuries and diseases |
| Minor-Moderate | 4 | 0.2-0.4 | Infliction of minor damage on the system or occupational injuries and diseases |
| Minor | 5 | 0.2-0 | Infliction of extremely minor damage on the system or superficial occupational injuries and diseases |

Applying both the classification system of probability and risk magnitude simultaneously, it is possible to assess and analyze the risks in keeping with the magnitude of possible consequences of a risk and their probability of occurrence. Integrating the two above factors will yield a matrix of hazard risk, which has integrated elements of Table 4 and 5 with each other in order to provide an appropriate tool for estimating an acceptable level of risk degree. By creating a two-character measurement system for risk occurrence based on magnitude and probability of a hazard, risk can be categorized and assessed according to the acceptability degree it has. This matrix is called hazard risk assessment matrix. (Fig.5)

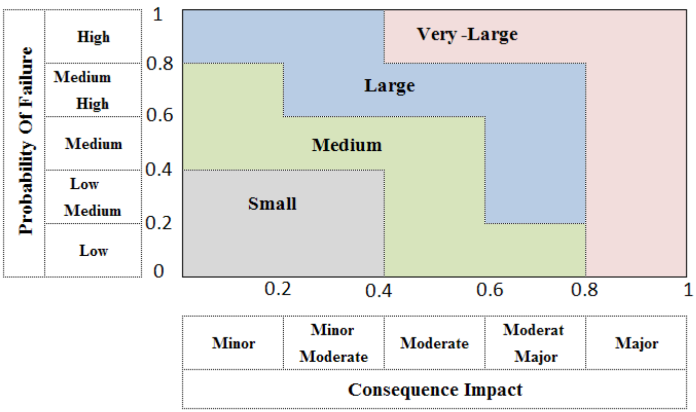


Fig. 5 – Hazard Risk Assessment Matrix

In risk management, we can undertake a proper assessment if we have much acquaintance with uncertainty; therefore, we need to identify all factors and activities and look through the interrelated subjects. Analyzing the subject into its factors and examining each one thoroughly makes it possible to identify all interrelated subjects.

The method of identification should be interactive and two-sided. In this method, the subject is first analyzed hierarchically into its components and then data gathering will start from the lower levels.

## 5.2. CALCULATE RISK OF SYSTEM

The production system of this factory needs to have certain kinds of equipment as factory-based. A system can be successful if different parts of production have an appropriate reliability that can address all the system's needs. In order to achieve the production strategy, it is necessary to consider a set of decisions related to performance of devices, investing, or alternating other production systems.

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* MIL_STD_88213

Analyzers and data experts are a team made up of technical experts who should examine and answer the question 'Is it possible to identify the system's risks and compile indices for them?' The CEO and Board of Directors are the final decision-makers who need the decision-making's criteria. For risk level, the standard of Table 4 has been used.

Table 4– Various Experienced Scenarios

| Device | Probability of failure | Consequence Failure | Risk level | Risk Type | Sever Damage | Strategy | Comments |
|---|---|---|---|---|---|---|---|
| **Cranes** | Low | Major | Very Large | Human | There will be a possibility of mutilation of the operator's body | Avoiding the risk | Improve specification of crane So that Reduced Rick factor |
| **Pumps** | Medium High | Moderate | Large | Financial Human | There will be a possibility of bursting, and causing harm to the operator's eye | Reducing the risk | Increasing the reliability; using high pressure and standard pipes |
| **Motor** | High Medium | Minor | Medium | Financial | The production system will halt for two hours. | Accepting the risk | Repairing; preventive and emergency maintenance |
| **Computer** | High Medium | Moderate Major | Large | Financial | Total pressing operations will stop. | Transferring the risk | Purchasing an additional system for the machine's processor |
| **Feeder in** | Low Medium | Minor | Small | Financial | The production by machine press will be limited only to a light item. | Accepting the risk | 1.Preventive maintenance 2. Changing production and repairing the damaged engine |
| **Feeder out** | Low | Minor | Small | Financial | The production by machine press will be limited. | Accepting the risk | 1.Preventive maintenance 2. Change of product |
| **PLC** | High Medium | Moderate Major | Large | Financial | The Control line will stop working. | Accepting the risk | Preventive and predictive maintenance |

Once the failure probability interval and the consequence of system failure are determined, we can use the risk assessment matrix to find the level of risk for each component. For this purpose, the researchers have used a fuzzy model, and put probability intervals in a band, the grading of this band starts from low breakdowns and ends to high breakdowns. For consequence magnitude, the grading band starts from minor breakdowns and ends to major breakdowns, After blending, and drawing a two-dimensional risk diagram, it is found that the X axis of this diagram is related to the consequences, while the Y axis shows the probability of the occurrence of failure, of which each section represents the failure risk of each machine. Fig.6.

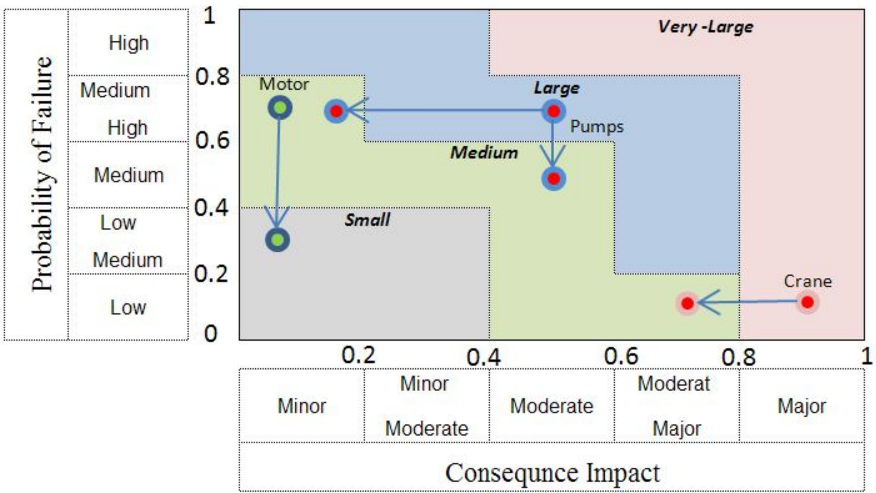


Fig. 6– Hazard Risk Assessment Matrix for Press Machine

For instance, calculations for a crane are as above from the various experienced scenarios Table 8. We find that the failure risk of the crane in the status quo is at the very-large level. Other results pertaining to other machines are shown in Table 8. In this table, the first column is the name of machine, the second column is the failure probability, the third column is the magnitude of the failure consequences of machine, and the fourth is the risk of machine which has been determined on the basis of the failure probability and the magnitude of the consequences of the system. Classification of the consequences in a risk assessment matrix for this case study is done according to the past records and expert opinions. If we do not have adequate data available, we may use quantitative and precise numbers for calculation of a probability. However, in this case study, due to lack of information, we can only determine a range for the failure probability and magnitude of consequences.

Risk diagram shows to reduce risk of motor we should reduced risk of failure, and thus, increasing reliability is achieved by moving in X-axis. It is possible for pumps both reduce probability of failure and reduce consequence of failure, risk diagram is showing that carne is in very-large risk area, and only it should be decreases consequence impact.

## 6. CONCLUSION

Uncertainty is a distinctive characteristic of modern systems, and the decision-makers' approach to risk influences the assignment of reliability to the system's components.

Rational and right decisions are reached based on information that describes risk and conditions of uncertainty or at least helps to gain an understanding of them. The combination of risk management and reliability engineering changes the content structure in reliability engineering. Thus, the final result of an integrative model of the system's reliability and risk management helps system administrators make informed decisions.

It is impossible to gain top information under uncertain conditions by resorting to reliability engineering. However, it is possible to test information by assessing risk and uncertainty percentage of each assessment, and then to arrive at the final decision. The combination of reliability and risk will include execution guarantees, as well as improvements in reported information. This paper mainly aims to explore the relationship between reliability and risk management, and to examine the systematic measurement and decision-making. For this, a conceptual model of risk assessment methods and their relation with reliability was examined.

In fact, in a world whose distinctive feature is that access to information is costly and limited, evaluation of reliability can not be defined uniquely and objectively. In decisions based on reliability engineering, mutual effects of indefinite factors should be taken into consideration.

The principles for risk measurement are considered critically important in the processes of measuring. Under uncertain conditions, these principles have the ability to accept or prove the assessments, and are a useful tool for filling the gap between reliability assessments, potential risks, and the economy. Assessing reliability is indeed a method of measurement, and as we know, errors are inevitable in every kind of measurement. Especially, errors of estimate exist in measuring reliability, which is based on probability and previous data. Risk management examines the bounds on error of estimate, and determines and controls possible damages and failures which will occur if the extent of measurement error broadens.

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