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University An Integrated Casual Loop and Cumulative Sum Control Chart for Reliability Assessment in a Maintenance System

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Abstract

Measuring the reliability of a maintenance system is a crucial issue, in which the system reliability could be one of the essential performance indicators to evaluate whether the system is capable or not. The objective of this study is to develop a novel approach for reliability assessment in a maintenance system. Due to the dynamic nature of this system, the concept of system dynamics is employed to determine and analyze its most critical elements, structural characteristics, relationships and feedbacks with respect to reliability. Therefore, series of casual loop diagrams assisting in better understanding of casual influences of maintenance system are developed. The casual loop diagrams plotted here provide a tool for management to hypothesize the dynamic influencing effectiveness of maintenance management, particularly the impact on reliability indices. Then, cumulative sum control chart (CUSUM) being analyzed as a visual objective to determine performance accuracy is considered. In addition, the ability of the CUSUM schemes to detect important types of changes in the optimal reliability indices are analyzed. As a result, these discussions would help system administrators to have better perception and use quantified indices to configure the reliability index in maintenance systems.

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INTRODUCTION

As our society grows in complexity, so do the critical reliability challenges and problems must be solved [1]. For the purpose of making good products with high quality and designing highly reliable systems, the importance of reliability has been increasing greatly with the innovation of recent technology [2]. Reliability is widely recognized as a critical metric for system design, operation and maintenance. It is defined as the ability of a system to perform the required functions under stated conditions for a specified amount of time [3]. Estimation of reliability plays an important role in performance assessment of any system. Knowledge of reliability beforehand allows a more accurate forecast of appropriate preventive and corrective maintenance [4]. System reliability can be improved by reducing the frequency of occurrence of faults and by reducing the repair time by means of various design and maintenance strategies [5]. From a system reliability perspective, it is actually possible for a component/ subsystem to depend on or to influence other components/subsystems within the system [6]. Optimization of maintenance policy has attracted considerable attention in the reliability literature. The best maintenance schedule can be interpreted as a tradeoff between the costs related to the inspection and repair activities and the level of reliability [7]. Reliability assessment of a maintenance system is very critical and needful. For this purpose faults and effect of these faults on the system and its components should be analyzed [8]. In the past few decades, numerous studies have been conducted on the reliability assessment and the corresponding applications. The analytical resolution of systems with dynamic redundancy is very difficult to

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accomplish. Therefore risk analysts require the use of other techniques in order to construct a comprehensive but achievable and efficient study of the system [9]. Having reviewed the previous studies, it is found that most research has just focused on the relationship between cost and time factors, but ignoring the quality measures. In addition, the system reliability theory has been neglected when quantifying the project quality. Therefore, in this study, a maintenance system is viewed as a system, composing of different system components. System reliability evaluation methods have been the focus during the past several decades, is Monte Carlo simulation, fault tree analysis, Bayesian approach, reliability block diagram, fuzzy reliability methods, and multi-state system reliability methods [10]. A reason that explains the limited application of reliability methods is the lack of sufficient data for building credible probability models for the random variables defining many problems [11]. System Dynamics (SD) is a realistic tool for sustainability assessment utilized to better understanding the sustainable development in a considered period and forecast the future trends [12]. It is a methodology for framing, understanding and discussing complex issues and problems and widely used to gain understanding of a system with complex, dynamic and nonlinearly interacting variables. It allows a system to be represented as a feedback system [13]. Compared to other simulation approaches, System Dynamics model is more beneficial to explain the developing trends of dynamic behaviors in the long-term (simulation duration) due to its feedback structure and capability to function under different parameter settings and initial inputs. It describes cause–effect relationships with stocks, flows, and feedback loops.

Casual loop diagramming, an inherent feature of system dynamics, is a qualitative technique used to construct models of real world issues. The causal loop diagram gives a qualitative description of system problems, and is the basis of modeling and simulating with System [14]. A causal loop diagram seeks to highlight the feedback and complex interactions between variables, where causes and effects are often indiscernible. It is a useful tool for hypothesizing the structure that underpins systemic behaviors. The integrated diagram combines all aforementioned diagrams and allows decision-makers to assess how different variables interact with each other as well as evaluate their relative strength of different casual loops [15].

The methods of statistical process control (SPC) are of great importance in many fields of science. One of the main goals of SPC is to monitor whether the process under investigation shows a supposed behavior or not. Control charts can be regarded as the main tool of SPC [16]. They are efficient instruments for checking changes or variations in the process. By far the most implemented SPC charts are the Schewhart-type charts. However, they are incapable of detecting small, incremental process shifts. In Schewhart control charts, all emphasis is placed on the last sample point plotted. The problem is that small, but increasing shifts take a long time to show up a chart. This is an undesirable property, especially in a maintenance system, where small shifts are more likely to occur [17]. The choice of the control charts to be used depends on the characteristics to be measured in the process. If the process is adjusted to control small variations and the sample consists of an individual unit, it is recommended to use a control chart of Cumulative Sum (CUSUM) or Exponentially Weighted Moving-Average (EWMA) control chart [18]. CUSUM charts are control charts used in the quality control. They are well suited for checking a measuring system in operation for any departure from some target or specified values [19]. CUSUM control charts are designed to use more than just the information in the last sample point. The CUSUM chart uses all historical data up to the present sample point. They assign equal weights to all historical data. In other words, they are effective for detecting small shifts quickly and for detecting persistent causes [17].

In this study, a novel approach to evaluate and improve the reliability and performance of a maintenance system is presented. In addition, a system dynamics approach is adopted to determine and analyze the maintenance systems' most critical elements, structural characteristics, relationships and feedbacks with respect to reliability. Therefore, series of casual loop diagrams assisting in better understanding of casual influences of maintenance system are developed. Also, this article focused on the use of CUSUM charts to detect important types of changes in the optimal reliability indices as a visual objective.

The aim of this paper is to present a common scientific methodology for the assessment of reliability of maintenance systems. The developed methodology will enable performing the research of maintenance systems reliability and evaluating its influence on different elements in or out of the system. The remainder of the paper is organized as follows. After a brief literature about reliability, system dynamics and casual loops, the casual loop interpretation is presented in section 2. Work methodology is presented in section 3. In section 4, a hypothetical example is presented and the conclusion of the paper is in section5. Herein, a concise background and some recent studies about reliability, system dynamics and casual loops are presented.

The reliability theory was proposed at the beginning of the 1930s as the theoretical basis for utilizing statistical methods in quality control of industrial products. However, it had not been brought into wide use until World War II [20]. Later, Allan et al. [21] discussed various modeling aspects for the reliability indices evaluation of distribution system. The review about the latest studies and advances about multi-state system reliability evaluation, multi-state systems optimization and multi-state systems maintenance is summarized by GuYingkui and Li Jing [22]. GONG Qi et al. [23] combined neural networks with importance sampling techniques for reliability evaluation of explosive initiating device. A modeling methodology aimed at supporting maintenance management of railway infrastructures based on reliability analysis introduced by Marco Macchi et al. [24].

System dynamics (SD) modeling and simulation was designed for modeling and analysis of complex socio-economic systems by Jay W. Forrester at the Massachusetts Institute of Technology. Since then, it has been applied to help business policy making and solving dynamic industrial management problems (Senge, 2006; Erma et al., 2010). Some related studies are as follows, sterman (2000) discusses case studies about modeling logistics problems by SD methodology. Ozbayrak et al. developed a systems dynamics model of a manufacturing supply chain system to model the operation of the supply chain network under study and obtain a true reflection of its behavior. This methodology can be used in the simulation of complicated, nonlinear, multi-loop feedback systems by developing the causal and feedback loop [25]. Xu and Coors [12] combined system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development. MiangGoh et al. [15] presented a system dynamics group model building approach to create a casual loop diagram of the underlying factors influencing the OHS performance of a major drilling and mining contractor in Australia.

The first control chart was introduced by Schewhart in 1924. The cumulative sum control chart was initially proposed in England by Page (1954) and has been studied by many authors. Bissel (1969) considered the CUSUM method and its relevance to quality control. He proposed extensions of this technique to facilitate its application to pratical situations. Montgomery (1996) introduced the cumulative sum control chart, applied for monitoring process average and variability. He mentioned that it was possible to project CUSUM procedures for other statistical variables, such as Binomial and Poisson variables for modeling non-conformities and continuous processes [17]. Zhang wu et al. [26] presented optimization designs of the combined Schewhart-CUSUM control charts. Saddam AkberAbbasi et al. [27] presented a method for enhancing the performance of CUSUM scale chart.

The casual loop interpretation

The integrated casual loop diagram presented in this section is made of total 51 variables, which are mainly categorized as reliability, quality, maintenance, efficiency, cost and market share. Even though the integrated casual loop diagram is complex, the diagram is disaggregated into four parts to assist understanding to prevent overloading the intended audience. Fig 1 illustrated the integrated casual loop diagram.

A part of the integrated casual loop diagram denotes a section of the casual loop diagram that describes how the organization is actively seeking to improve the reliability. As is shown, such different variables influence on reliability. Maintainability is one of important factors which have a positive influence on reliability. In engineering, maintainability is the ease with which a product can be maintained in order to isolate defects or their cause, correct defects or their cause, meet new requirements, make future maintenance easier or cope with a changed environment. The more that machines and equipment in a maintenance system are maintainable, the reliability is more. Maintainability depends on the optimality of maintenance system. As the maintenance system is more sophisticated, the maintainability of equipment increases. With an optimal maintenance system, thoroughness of risk assessment in system increases and therefore reporting the existing hazards increase. So, the system tries to rectify more significant hazards and the reliability of system developed to a higher level. On the other hand, the higher level of reliability in maintenance system results in achieving more international achievements and therefore the optimality of maintenance system developed. Failure rate is another important factor that has a kind of tradeoff with reliability. Failure rate is the frequency with which an engineered system or component fails. In this case, more failure rate in system will result less reliability level. Another important factor that influences on reliability indirectly is preventive maintenance. Preventive maintenance is the care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects. As the preventive maintenance is more regular, the safety of machines and equipment is more. With more standardized equipment and processes across the organization, the corrective maintenance will be decreased because results of safety improvement will be become applicable throughout the organization. Reliability influences on corrective maintenance, too. Corrective maintenance can be defined as a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the tolerances or limits established for in-service operations. In other words, a system with high reliability level will encountered less corrective maintenance.

The other part of the integrated casual loop diagram denotes the other section of the casual loop diagram that describes how the organization is actively seeking to increase the market share. As is shown, such different variables influence on market share. No organization exists in a vacuum. All organizations are influenced by external variables. Market share is one of significant factors that every organization tries to acquire more. With earning more market share, the sales increases and therefore the profit of the company increases. Market share is the percentage of a market (defined in terms of either units or revenue) accounted for by a specific entity. Market share is closely monitored for signs of change in the competitive landscape, and it frequently drives strategic or tactical action. Increasing market share is one of the most important objectives of business. Increasing market share results in more reputation which it results in more products demand. Market share depends on the level of international standards achievements, too. The more international standards achievement, market share is more. With high reliability level, the system achieves more international standards and acquires more market share. So, the reputation of company increases.

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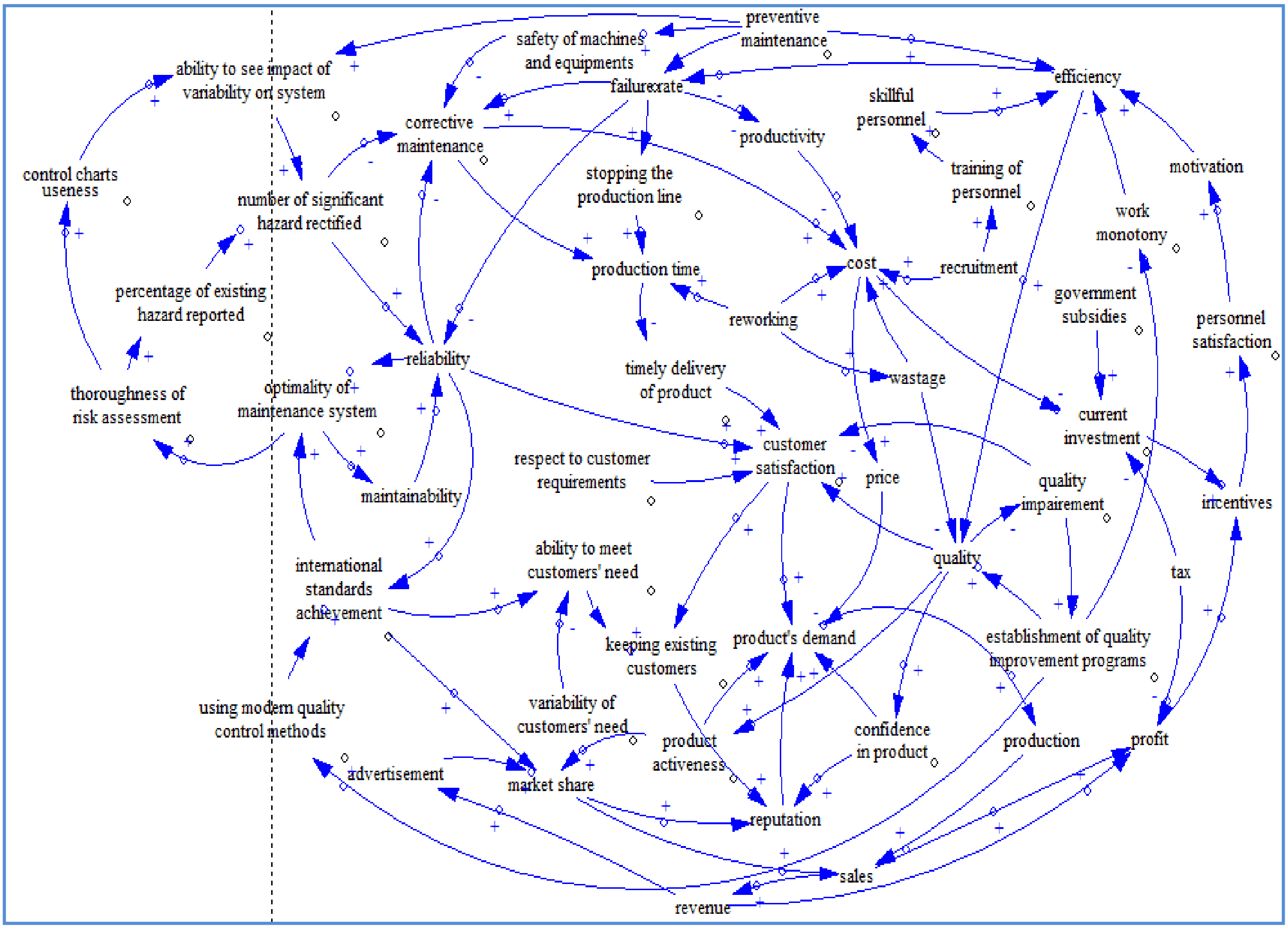

Fig 1. The integrated casual loop diagram

As a result, the number customers increase and finally, company earns more profit. On the other hand, with achieving more international standards, company's ability to meet customers' need increases and it causes to keep existing customers. In other words, when the organization achieved international standards, so, it tries to meet the need of a wide range of customers in different business units within the organization. With keeping existing customers, the reputation of organization increases and therefore, the sales of the company increases. With more sales, the company earns more revenue that it will have more profit with itself. International standard achievement depends on using modern quality control methods. On the other hand, using modern quality control methods depends on establishment of quality improvement programs. As the establishment of quality improvement is more, the company uses more modern quality control methods and it result in more international standards achievements. The other factor that influences on market share is advertisement. Advertising is a form of communication for marketing and used to encourage or persuade an audience (viewers, readers or listeners; sometimes a specific group) to continue or take some new action. With more advertisement, company earns more market share that it relies on the quantity of revenue that company earns. As the revenue of the company is more, the company will be able to do more advertisement. So, it will be earn more market share. Product activeness is the other significant factors that influences on market share. As the product is more attractive, the market share is more. Also, with more product activeness, the product's demand increases. Another factor that has indirect influence on market share is confidence in product. With more confidence in product, the reputation of product increases that it has direct influence on market share.

Also, the more confidence in product, product's demand is more. And the more product demand, the production is more that it has influence on sales and then market share and profit of the company.

One part of the casual loop diagram illustrates the casual influences that may negate the impact of the efforts to increase cost expenditures on a company performance. As is shown, different variables have influence on quantity of cost in a company. Productivity which is defined as a measure of the efficiency of production is one of important factor that has a trade off with cost. Productivity is a ratio of production output to what is required to produce it (inputs). The measure of productivity is defined as a total output per one unit of a total input. With more productivity, the company faces less cost. Also, the more productivity, the failure rate is

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less. As the failure rate increase, the stopping of production line increases which is leads to more production time. Production time covers the period from the moment of entry of the means of production into an enterprise up to the completion of the finished product. Reworking has influence on cost, too. As the reworking in a company is more, the wastage increases, the production time increases and also the more important of them, the quantity of cost increase. Recruitment is another significant factor that has influence on cost directly. It influences on efficiency indirectly, too. As recruitment of the company increase, it needs to training of personnel to have skillful personnel and increase the efficiency of the company.

The other section of the casual loop diagram describes how the organization is actively seeking to improve the efficiency, quality and customer satisfaction. As is shown, such different variables influence on efficiency, quality and customer satisfaction. Motivation of personnel in a company is one of significant factors that have influence on efficiency. With more personnel satisfaction, the motivation of the personnel increases. Personnel satisfaction can be the result of more wage and incentives that paid to personnel and more incentives can be the result of more profit that company earns or it may be the result of more current investment. Government subsidies which are assistance paid to a business or economic sector increase the current investment. Preventive maintenance influences on efficiency, too. The more that preventive maintenance in system is regular and correct, the efficiency is more. Efficiency in general describes the extent to which time or effort is well used for the intended task or purpose. It is often used with the specific purpose of relaying the capability of a specific application of effort to produce a specific outcome effectively with a minimum amount or quantity of waste, expense, or unnecessary effort. Work monotony is negative factor that decrease the efficiency of an organization. With establishment of quality improvement programs, the monotony of work decrease and as result the efficiency of organization increases. Establishment of quality improvement programs can be the result of quality impairment influences on quality of product in a company. It influences on product quality in a company. As the quality of the product increase, customer satisfaction and confidence in product increases and therefore the product demand increase. The general manager of the participating organization intends to use the diagram to discuss possible strategies with senior management. Similarly, other leverage points can be determined based on a causal loop diagram and improvement strategies can be identified. The hypotheses in turn can lead to possible improvement strategies.

Work methodology

In this section, the work methodology is described. The relevant between reliability and CUSUM control chart is a key parameter for plotting and analyzing the integrated CUSUM control chart. Reliability index is calculated with different functions that each of them follows a special distribution such as uniform distribution, normal distribution, poisson distribution, weibull distribution, exponential distribution and etc. The general reliability formula for calculating the reliability is presented in equation (1).

$$R(t) = \Pr\{T > t\} = \int_t^\infty f(x)\,dx \qquad (1)$$

Where $f(x)$ is the failure probability density function and t is the length of the period of time (which is assumed to start from time zero).

In this study, it is assumed that the reliability function follows exponential distribution. Herein, some reasons for choosing the exponential distribution used in reliability calculation is presented.

Despite the inadequacy of the exponential distribution to accurately model the behavior of most products in the real world, it is still widely used in today's reliability practices, standards and methods. An important property of the exponential distribution is that it is memoryless. This says that the conditional probability that we need to wait, for example, more than another 10 seconds before the first arrival, given that the first arrival has not yet happened after 30 seconds, is equal to the initial probability that we need to wait more than 10 seconds for the first arrival. Because of the memoryless property of this distribution, it is well-suited to model the constant hazard rate portion of the bathtub curve used in reliability theory. It is also very convenient because it is so easy to add failure rates in a reliability model. The exponential distribution models the behavior of units that fail at a constant rate, regardless of the accumulated age. In fact, for components undergoing regular maintenance or replacement, the exponential assumption can be acceptable. In other words, as more of an exception than the norm, the distribution can be effectively incorporated into reliability analysis if the constant failure rate assumption can be justified. Additionally, prior efforts and standards that extensively utilized the exponential distribution should be commended for introducing and formalizing the reliability methods that formed the basis of more advanced analysis techniques and for applying more rigorous scientific approaches within the field. We cannot underestimate the exponential distribution's contribution to the development of current reliability principles/theory. However, today's high product reliability goals require the use of more sophisticated analysis methods and metrics that more accurately reflect real world conditions. Such models have been developed and computer technology addresses the more complex mathematical formulations they require. Another reason for the extensive use of the exponential distribution is reliance by some practitioners on antiquated techniques of reliability prediction, which is not based on actual life data for the products. These analyses provide little, if any, information and insight as to the true reliability of the products in the field.

Because of all reasons pointed above, exponential distribution is assumed in this study to calculate the reliability and reliability components were in casual loop

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diagrams introduced before. So, several reliability indices for each j ($R(j)$) is used as initial data for CUSUM chart and furthermore an integrated CUSUM chart could be analyzed.

And for calculating the reliability index with exponential distribution, the equation (2) could be used.

$$R(t) = k.e^{-2kLt} + (1-k).e^{-2(1-k)Lt} \quad (2)$$

Where L is failure rate and K is the distribution shape parameter.

The reliability function described above is a general formula. But, as introduced and illustrated in previous sections, the reliability depends on several items such as maintainability, failure rate, preventive maintenance, corrective maintenance, market share, cost, quality, efficiency and etc. So, the reliability function consists of several items. In other words, each factor has its own special relevant with reliability which could be parallel or series in system. For instance, 5 factors assumed to show the calculation method of reliability and the relevant with reliability is described. The items are failure rate, market share, efficiency, quality and cost. It is assumed that failure rate and cost have series relevant with reliability and market share, efficiency and quality are parallel in system.

A series system is a configuration such that, if any one of the system components fails, the entire system fails. Conceptually, a series system is one that is as weak as its weakest link. In a series system: "system success"="success of every individual component"; Therefore, the probability of the two equivalent events, that define total system reliability for mission time T, must be the same. In this case, the failure rate and cost work as series components in system. A parallel system is a configuration such that, as long as not all of the system components fail, the entire system works. Conceptually, in a parallel configuration the total system reliability is higher than the reliability of any single system component. For example, for a simple parallel system composed of 2 identical components; the system can survive mission time T only if the first component, or the second component, or both components, survive mission time T. In this case, market share, efficiency and quality are parallel components in system.

As pointed before, when small variations in a process are valuable, the CUSUM control chart could be useful. CUSUM control chart uses all information contained in sample point. For example, suppose samples with $n \geq 1$. If the $\bar{x}_j$ is the mean of sample j and the ideal value of mean in process is μ_0; the cumulative sum control chart achieved by plotting the C_i that is based on equation (3).

$$C_i = \sum_{j=1}^{i} (\bar{x}_j - \mu_0) \quad (3)$$

That is based on sample i.So, in this case that our initial data is the reliability functions computed for each casual loop diagram; the reliability function ($R(j)$) is used instead of $\bar{x}_j$ in above formula. Therefore, the C_i will be calculate by equation (4).

$$C_i = \sum_{j=1}^{i} (R(j) - \mu_0) \quad (4)$$

After plotting all C_i in a diagram; because of existence of control limits defined in all control charts, it is clear that some of the points will be situate out of control limits. Control limits are used to detect signals which are defined as any single point outside of the control limits in process data indicate that a process is not in control and therefore not operating predictably. A process is also considered out of control if there are seven consecutive points, still inside the control limits but on one single side of the mean. When a point falls outside the limits established for a given control chart, those responsible for the underlying process are expected to determine whether a special cause has occurred.

A hypothetical example

For better understanding the methodology described in previous section, a hypothetical example is presented in this section. Hence, 100 random reliability data are considered. They are following from exponential distribution. At first, the mean of reliability that in this case, 10 is considered, subtracted from each of them. Then, by using equation 3, C_i is calculated and CUSUM control chart is plotted. Fig2 illustrated the CUSUM control chart. By using V-mask procedure, the CUSUM control chart could be analyzed. A V-Mask is an overlay shape in the form of a V on its side that is superimposed on the graph of the cumulative sums. It will be useful for managers to decide better strategies and improve the organization reliability level.

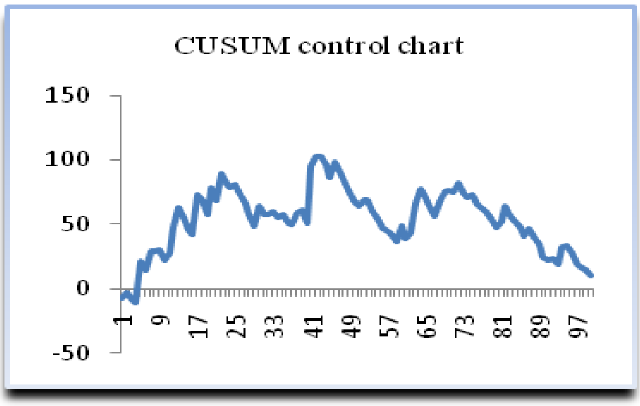

Fig 2. The CUSUM control chart with reliability data

CONCLUSION

In this paper, An Integrated Casual Loop and Cumulative Sum Control Chartfor Reliability Assessment in a Maintenance System were presented. The objective of this study is to develop a novel approach for reliability assessment in a maintenance system. Due to the dynamic nature of this system, the concept of system dynamics was employed to determine and analyze its most critical elements, structural characteristics, relationships and feedbacks with respect to reliability. Therefore, series of casual loop diagrams assisting in better understanding of casual influences of maintenance system were developed.

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REFERENCES

1. Hoang Pham. (2003). Handbook of Reliability Engineering. United States of America: Springer.
2. Toshio Nakagawa. (2005). Maintenance theory of reliability. Verlag London: Springer.
3. Yong Wanga, Lin Li a, Shuhong Huang b, Qing Chang. (2012). Stochastics and Statistics Reliability and covariance estimation of weighted k-out-of-n multi-state systems. European Journal of Operational Research 221, 138–147.
4. Snehamoy Chatterjee a, Sukumar Bandopadhyay. (2012). Reliability estimation using a genetic algorithm-based artificial neural network: An application to a load-haul-dump machine. Expert Systems with Applications 39, 10943–10951.
5. H. Zhenga, Y. Chenga, B. Goub, D. Frankc, A. Bernc, W.E. Muston. (2012). Impact of automatic switches on power distribution system reliability. Electric Power Systems Research 83, 51– 57.
6. Salvatore Distefano a, Francesco Longob, Kishor S. Trivedi. Investigating dynamic reliability and availability through state–space models. Computers and Mathematics with Applications.
7. P. Beaurepaire a, M.A. Valdebenito b, G.I. Schuëller a, H.A. Jensen. (2012). Reliability-based optimization of maintenance scheduling of mechanical components under fatigue. Comput. Methods Appl. Mech. Engrg. 221–222, 24–40.
8. MobinSefidgaran, Mohammad Mirzaie, AtaollahEbrahimzadeh. (2012). Reliability model of the power transformer with ONAF cooling. Electrical Power and Energy Systems 35, 97–104.
9. Gabriele Manno a, FerdinandoChiacchio a, LucioCompagno b, Diego D'Urso b, Natalia Trapani. (2012). MatCarloRe: An integrated FT and Monte Carlo Simulink tool for the reliability assessment of dynamic fault tree. Expert Systems with Applications 39, 10334–10342.
10. Zhonglai Wang, Hong-Zhong Huang, Yanfeng Li, Yu Pang, Ning-Cong Xiao .(2012). An approach to system reliability analysis with fuzzy random variables. Mechanism and Machine Theory 52, 35–46.
11. Jorge E. Hurtado, Diego A. Alvarez. (2012). The encounter of interval and probabilistic approaches to structural reliability at the design point. Comput. Methods Appl. Mech. Engrg. 225–228, 74–94.
12. Zhao Xu, Volker Coors. (2012). Combining system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development. Building and Environment 47, 272-287.
13. YelinXu, Chengshuang Sun, Miroslaw J. Skibniewski, Albert P.C. Chan e, John F.Y. Yeung f, Hu Cheng. (2012). System Dynamics (SD) -based concession pricing model for PPP highway projects. International Journal of Project Management 30, 240–251.
14. LI Chen, ZhouLisha, LI Na, Zeng Ming. (2012). Modelling and Simulation of Power Grid Engineering Project based on System Dynamics on the Background of Smart Grid. Systems Engineering Procedia 3, 92 – 99.
15. Yang MiangGoh, Peter E.D. Love, Greg Stagbouer, Chris Annesley. (2012). Dynamics of safety performance and culture: A group model building approach. Accident Analysis and Prevention 48, 118–125.
16. OlhaBodnar, WolfgangSchmid. (2011). CUSUM charts for monitoring the mean of a multivariate Gaussian process. Journal of Statistical Planning and Inference 141, 2055–2070.
17. Shing I. Chang, Thomas R. Samuel.(1998). A Controlpointmethodology for CUSUM controlcharts. Computers ind.Engng Vol. 34, No. 3, pp. 565-572.
18. Vera do Carmo C. de Vargas, Luis Felipe Dias Lopes, AdrianoMendonc¸a Souza. (2004). Comparative study of the performance of the CuSum and EWMA control charts. Computers & Industrial Engineering 46, 707–724.
19. MattiPastell, Henrik Madsen. (2008). Application of CUSUM charts to detect lameness in a milking robot. Expert Systems with Applications 35, 2032–2040.
20. Ran Tao, Chi-Ming Tam. (2012). System reliability optimization model for construction projects via system reliability theory. Automation in Construction 22, 340–347.
21. Allan RN, Dialynas EN, Homer IR. (1979). Modeling and evaluating the reliability of distribution systems. IEEE Trans PAS 98, 2181–9.
22. GuYingkuia, Li Jing. (2012). Multi-State System Reliability: A New and Systematic Review. Procedia Engineering 29, 531 – 536.
23. GongQia, ZhangJianguoa, TanChunlinb, WangCancana. (2012). Neural Networks Combined with Importance Sampling Techniques for Reliability Evaluation of Explosive Initiating Device. Chinese Journal of Aeronautics 25, 208-215.
24. Marco Macchia,n, MarcoGaretti a, DomenicoCentronea,LucaFumagallia,GianPieroPavirani.(2012).Maintenance management of railway infrastructures based on reliability analysis. Reliability Engineering and System Safety 104, 71–83.
25. Ching-Fang Leea, Chien-Ping Chung. (2012). An Inventory Model for Deteriorating Items in a Supply Chain with System Dynamics
26. Khoo. (2008). Optimization designs of the combined Shewhart-CUSUM control charts. Computational Statistics and Data Analysis 53, 496_506.

27. Saddam AkberAbbasi, Muhammad Riaz, Arden Miller. (2012). Enhancing the performance of CUSUM scale chart. Computers & Industrial Engineering 63, 400–409.

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