African Journal of Business Management Vol. 6(4), pp. 1367-1374,1 February, 2012
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM11.1420
ISSN 1993-8233 ©2012 Academic Journals

*Full Length Research Paper*

# A six sigma approach to boost up time domain reliability in multi-stage services

**S. Raissi* and Z. Gatmiry**

Industrial Engineering Faculty, Islamic Azad University, South Tehran Branch, Tehran, Iran.

Accepted 10 October, 2011

**Reliability function, R(t), is defined as the probability that the system will not fail during the stated period of time under a given operating conditions. In production process, attaining reliability as a function of time is a common task but in multi-stage services, it is not straightforward due to intricacy of gathering data. Through the present work, we have addressed a systematic method for measuring multi-stage service reliability function using failure rate analysis beside a systematic six sigma approach to improve total system reliability. The proposed methodology furthermore could help practitioners to integrate six sigma metrics with the reliability function and the way to measure existing reliability situation based on sigma level. The proposed method is applied in a given multi-stage central repairing shop for an automobile producer which promotes 86% in total system reliability beside 58% improvement in the sigma level.**

**Key words:** Service reliability, six sigma, failure rate, multi-stage processes, sigma level.

## INTRODUCTION

In today's technological world, almost every person depends upon the continued carrying out of a broad array of compound machinery, equipments and services for our everyday safety, security, mobility and economic welfare. We expect our home appliances and automobile, lights, hospital monitoring control system, aircrafts, power plants, data exchange systems and any service systems, to function whenever we need them. When they fail, the results can be catastrophic, injurious or even cause loss of life.

As our society grows in complexity, so do the critical reliability challenges and problems that should be solved. The area of reliability engineering especially in service system presently received a tremendous attention from numerous researchers and practitioners as well.

In the past years, a lot of efforts were put on the reliability analysis of sensitive and complicated industries, such as military and nuclear power plant industries, but now, reliability is a public worry (Karbasian and Tabatabayi, 2009). Today, reliability is held as one of the most important quality characteristics for customers and is used for products, systems, processes and components of systems in a widespread area that extends from electronics to software as an interdisciplinary concept. Hence, service reliability is one of the most important areas in quality engineering and control (Günes and Deveci, 2002).

Now, reliability is the core of quality service. Little else matters to customers when the service is reliable. A company with 100,000 weekly transactions and with a 98% reliability rate still undermines the confidence of 2,000 customers each week. When a firm makes frequent mistakes in delivery, when it does not keep its promises, customers lose confidence in the firm's ability to do what it promises dependably and accurately (Berry et al., 1994). Results of Johnson and Nilsson (2003) research show a greater effect of reliability on customer satisfaction for services compared to products. But, unlike pure goods, pure services are coproduced with customers at a time. The inseparability of production and consumption for services means that service reliability is more outside the control of the firm. And because service production involves more of the human resources of the firm and customers themselves, it adds greater inherent

*Corresponding author. E-mail: Raissi@azad.ac.ir.

variability to the service production process. As results, these create more inherent reliability problems for services (Johnson and Nilsson, 2003).

Therefore, addressing service reliability and providing systematic method for measuring and improving them, is important. But survey of the literature show that very few publications focused specifically on the “reliability” aspect of a service and mainly books on reliability engineering and management, provide the concepts and techniques in reliability engineering commonly applied to products, components and physical systems (Gunawardane, 2004).

This paper, considering mentioned necessities and gaps, try to provide a practical and systematic solution for measuring and improving the sigma level and reliability of a multi-stage service system as a function of time. By integrating six sigma approach and reliability engineering method we proposed a systematic plan to boost up multi stage system reliability.

## LITERATURE REVIEW

### The state of the art in service reliability

According to definition, a service is a function provided by a person or machine for use by a person or machine (a “client”, “user”, “customer” or “consumer”) (Tortorella, 2005). Service systems can be divided into two catalogues: machine-based service systems that are provided by a set of machines, and man-machine service systems that consist of the combination of machines and personnel and are more complicated than machine-based serviced systems because of its activity-base. Concepts and models of service reliability will depend on service systems (Li and Thompson, 2007). In recent years, analyzing and improving reliability of another kind of service systems, such as those found in educational, health care, banking and financial organizations, has been considered by researchers. Günes and Deveci (2002) presented one of the few researches on reliability analysis of such service systems. They proposed the use of failure rate analysis to determine reliability rate of these systems. But their application was suitable for measurement of reliability in a single stage service process. Then, Gunawardane (2004) extended their approach to multi-stage service systems where the service to customer is provided by a system composed of several sub-systems, each processing part of output and applied techniques of reliability engineering for improving reliability of this kind of service systems. But in these two researches, they assumed service processes independent of time and only used the failure rate as the reliability rate of the service systems, meanwhile, in the present research; we address the issue service reliability as a function of time and a systematic method to calculating reliability distribution function in multi-stage service systems using failure rate analysis proposed.

The concept of failure rate is vital in reliability and survival analysis. Nevertheless, obtaining the failure rate in numerous practical situations is regularly not so simple, as the structure of the system to be considered, for instance, can be rather complex or the process of the failure development cannot be explained in the simple way. In these cases, an “appropriate model can help a lot in deriving reliability characteristics. There are several models that can be effectively used for deriving and analyzing the corresponding failure rate and eventually the survivor function. Denote by $T \geq 0$ a lifetime random variable and assume that the corresponding cumulative distribution function (cdf) or *F(t)* is absolutely continuous. Then the following exponential formula exists:

$$F(t) = 1 - \exp\left[-\int_0^t \lambda\ (u)\, du\right] \quad (1)$$

Where $\lambda(t)$, $t \geq 0$, is the failure rate. In many occasions, a conventional statistical analysis of the overall random variable T presents certain difficulties, as the corresponding data can be scarce (for example, the failure times of the highly reliable systems). On the other hand, information on the structure of the system or on the failure process can often be available. This information can be used for modeling $\lambda\ (t)$, to be called the observed or achieved failure rate, and eventually, for estimation of F(t). The reliability function $R(t)$ is given by:

$$R(t) = \Pr\{\text{the system doesn't fail during } (0,t)\} = 1 - F(t) \quad (2)$$

In Equation 2, we assume that the age of the system before the start of the mission is zero. Thus, Equation 2 is valid only for new systems or those systems whose failures are not age related (that is, the time to failure follows exponential distribution).

The other important problem that can be approached in this way is the analysis of the shape of the failure rate, which is crucial for the study of the aging properties of the cumulative distribution functions under consideration.

Time-domain modeling is concerned with the behavior of system reliability over time. The simplest time-dependent failure model assumes that failures arrive randomly with inter arrival times exponentially distributed with constant rate λ. The reliability in such system will be:

$$R(t) = e^{-\lambda t} \quad (3)$$

Generally, researchers organize their reliability analysis via using exponential cumulative distribution function when failure rate has a constant rate. A service system consists of many processes, so reliability of total systems can be measured by its processes' reliabilities. By

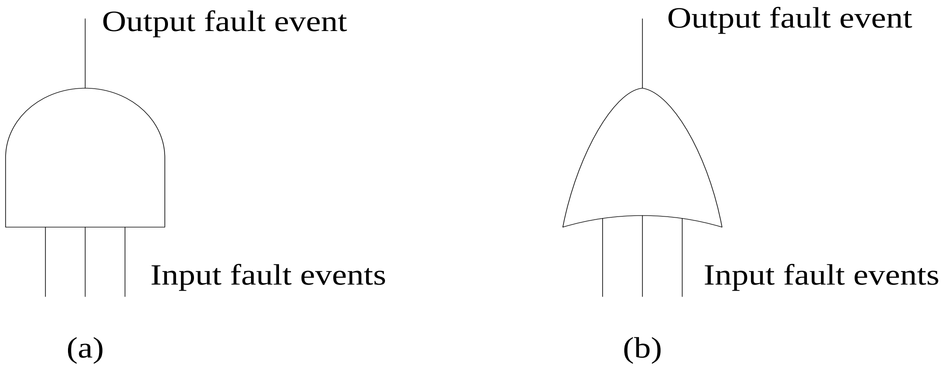


**Figure 1.** Symbols for basic logic gates: (a) OR gate; (b) AND gate.

definition, reliability of a service process is its capability of meeting its specified performance requirements in a given period of time. Therefore, the process inability in accommodation to its operational goals results in its failure and since the failure of each process is due to its sub-processes failure, so for measuring the reliability of a multi-stage service process, first the reliability of each sub-process should be individually determined. Therefore, each sub-process's expected task need to be recognized and then, the failure rate of each sub-process should be separately determined in the specified time range. Gunawardane (2004) proposed a method for measuring the reliability of a multi-stage service process by measuring the reliability of its sub-processes, using failure rate analysis (the basic technique used by Günes and Deveci, 2002). But his proposed method was suitable for time-independent service processes. However, the method proposed in this paper, considering the time domain reliability using an extension to the technique anticipated by Gunawardan in 2004.

## PROPOSED METHODOLOGY

Our proposed systematic methodology has five fundamental phases to improve reliability based on the well known define-measure-analyze-improve and control (DMAIC) methodology in six sigma. But in order to express the architecture of service system, we recommend using the fault tree which is a widely used method in reliability analysis of engineering systems. This method is described in detail in Pham (2003). Nonetheless, such tool makes use of a few symbols such as Rectangle, AND, OR and Circle in developing a basic fault tree to express the effects of component's faults on behavior of total system. Rectangle is used to denote a fault event that results from the combination of failure events through the input of a logic gate and AND gate denotes that an output fault event occurs if all the input fault events occur. OR gate denotes that an output fault event occurs if any one or more of the input fault events occur. Finally, a Circle is used to denote basic fault events; more specifically, those events that need not be developed any further (Pham, 2003). Figure 1 shows a symbol for the most two important gates.

In our suggested method, six sigma metric could be set based on the amount of difference between the presence system reliability, $R_a(t)$ and the target, $R_g(t)$. In such state, defect may be considered as the additional number of failures that a customer is likely to face due to not meeting the reliability target. So, the sigma level of a service system corresponding to meeting the reliability target can be derived by calculating the difference between the target and the achieved reliability. The defects per unit, *DPU* for not meeting the target reliability is given by:

$$DPU = R_g(t) - R_a(t), \qquad R_a(t) < R_g(t) \tag{4}$$

Hamaker in 1978 (Patel and Read) proposed an approximation method for calculating standard normal quantiles expressed in terms of a given value of *p*. Based on his theorem, if Z is a random normal variable with zero mean, unit standard deviation and $\emptyset(z_p) = \Pr(Z \le z_p) = p$ then $Z_p$ expressed in terms of a given value of $p$ $(0 < p < 1)$ as shown in Equation 5:

$$Z_p = sgn(p - 0.5)[1.238u(1 + 0.0262u)] + \epsilon(p) \tag{5}$$

*Where:* $u = \sqrt{-ln(4p - 4p^2)}$

The accuracy of such approximation say $|\epsilon(p)|$ is less than4.5 × $10^{-4}$. Consequently, the sigma level can be deduced using such method as shown in Equation 6:

$$Sigma\ level = 1.5 + Sgn(DPU - 0.5)[1.238U(1 + 0.0262U)] \quad (6)$$

where the value of u is given by:

$$u = \sqrt{-\ln\ (4DPU - 4DPU^2)} \quad (7)$$

By using the corresponding Excel@ function, sigma level is given by Equation 8 as:

$$Sigma\ level = 1.5 + \mathrm{NORMINV}\ \left(R_g(t) - R_a(t), 0{,}1\right) \quad (8)$$

Our proposed systematic algorithm has five fundamental phases to improve reliability based on the well known DMAIC (define-measure-analyze-improve and control) methodology which is defined as:

Step 1: Define a six sigma project to improve the service reliability

1. Focus on the service system voice of customers to recognize the failures types on each sub-process.
2. Determine a few performance metrics for each sub-process.
3. Map the scope of the project using SIPOC (suppliers, inputs, processes, outputs and customers) form beside a conceptual architecture of providing service network.
4. Establish a target reliability value, $R_g(t)$

Step 2: Measure the time domain system reliability using failure rate analysis

1. Survey of failure data of each sub-process in specific time periods (for example per month)
2. Estimate failure rate of each sub-process periodically over the time domain.
3. Compare the failure rate of each sub-process in several periods
4. Deduce a expected failure density function for each subsystem and ensure the relevant goodness of fits (if a component failure rate roughly deploys a constant rate over the time domain, hence exponential distribution is a valid option. Otherwise, refer to Appendix 1 to find proposed expected density function as the most appropriate alternative).
5. Calculate component reliability as a function of time for each sub-process.
6. Construct a general fault tree diagram based on conceptual system architecture using appropriate gates and nodes to calculate overall system reliability.
7. Consider a target sigma level. Six could set as sigma level to work in world class category
8. Estimate the existing sigma level from Equation 6.

Step 3: Analyze the gap between the exiting and the target circumstances

1. Construct a few cause and effect diagrams (or fish bone charts) to analyze why the current process is not able to meet the main customer requirements.
2. Identify the problems in the inputs and the processes.
3. Assess the impact of inputs and process related problems on the customer requirement.
4. Prioritize the problems.
5. Identify root causes.
6. Generate a few ideas to eliminate deficiencies on inputs and process.

Step 4: Trace the improving methods

1. Screen the ideas to choose the best feasible course of action.
2. Talk about the way to well implement the solution.

Step 5: Keep system to be in control

1. Establish a system to sustain the improvement
2. Follow a systematic plan for updating the measures.

## CASE STUDY

Here, application of proposed method is presented for measuring and improving reliability of providing service in central repair shops of an Iranian automobile after-sale service company. The performance of mentioned process is considered monthly from August 2009 to March 2010.

The two groups of customers are denoted by A and B which are the owners of automobiles who come to the repair shop to fix their automobiles.

Repair service process includes automobile reception, repair, quality control and release as sub-processes respectively. Repair sub-process consists of two repair hall called 1 and 2 for repairing the automobiles of two distinct groups of A and B, respectively. Therefore, the schematic diagram of repairing services in central shop is presented in Figure 2.

As a common rule in the central shop, performance of the reception unit, repairing halls and releasing unit are measured by means of their direct staff's performance scores, hence, any deficiency in the monthly allocated score to all staffs from their minimum threshold scores is defined as a failure for the mentioned sub-processes. Consequently, if one consider $X_i(t)$ as daily score of staff $i$ in month t, hence $\mathrm{i} = 1, 2, \ldots, \mathrm{N},\ \mathrm{t} = 1, 2, \ldots, T$ and also $Y_i(t)$ as minimum daily score of staff $i$ in time $t$ then $\lambda_k$ the failure rate of the automobile reception unit ($k = 1$), the repair halls ($k = 2$) and the automobile releasing unit ($k = 4$) may be estimated from Equation 9:

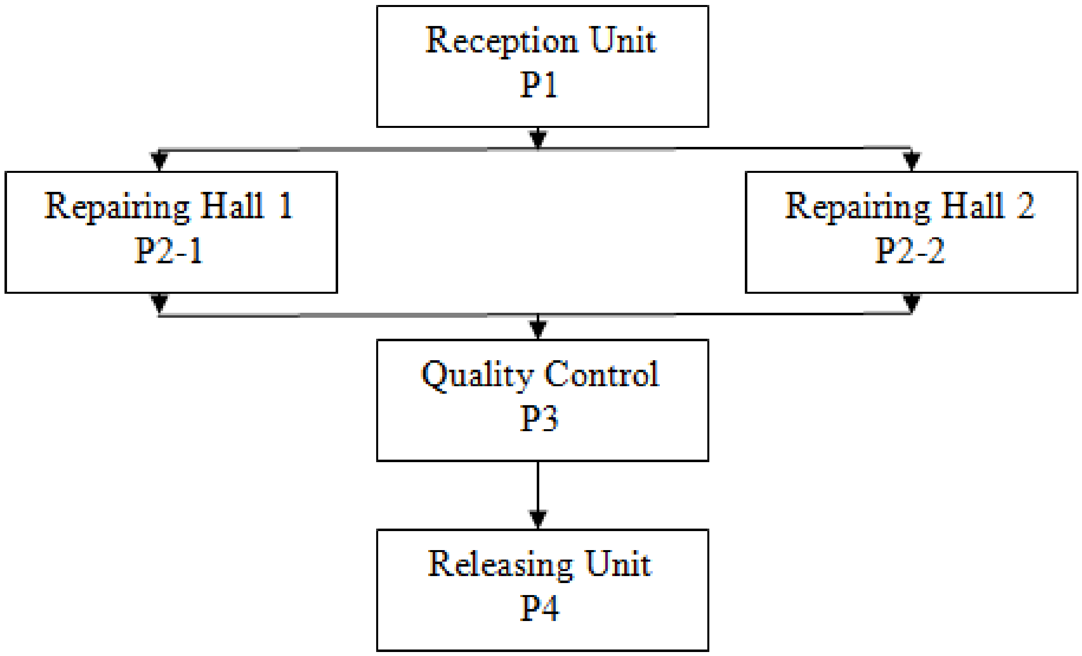


**Figure 2.** Schematics flows on repair process for two distinct types of automobiles in central shop.

**Table 1.** Failure rates of different sub process during August 2010 to March 2011.

| Sub process | Months | | | | | | | | Average rate |
|---|---|---|---|---|---|---|---|---|---|
| | August | September | October | November | December | January | February | March | |
| Reception unit | 0.15 | 0.16 | 0.16 | 0.16 | 0.17 | 0.16 | 0.16 | 0.16 | 0.16 |
| Repair hall 1 | 0.29 | 0.29 | 0.28 | 0.29 | 0.3 | 0.28 | 0.29 | 0.3 | 0.29 |
| Repair hall 2 | 0.22 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.24 | 0.23 | 0.23 |
| Quality control | 0.006 | 0.007 | 0.01 | 0.008 | 0.008 | 0.009 | 0.008 | 0.008 | 0.008 |
| Release unit | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 |

$$\lambda_k(t) = \frac{Number\ of\ deficiedies\ per\ observed\ time}{Observed\ duration} = \begin{cases} \frac{\sum_{i=1}^{N}[Y_i(t)-X_i(t)]}{Observed\ duration} & if\ Y_i(t) > X_i(t) \\ 0 & else \end{cases} for\ k = 1,2,4\ \ and\ t = 1,2,\ldots,8 \tag{9}$$

In quality control sub-process, number of automobiles returned back to central shop before passing 72 h due to mall functions, say $M_t$ considered as its failure. So, failure rate of quality control sub process at time $t$ could be estimated by Equation10:

$$\lambda_k(t) = \frac{M_t}{Observed\ duration} \tag{10}$$

Results of calculating the monthly failure rates of sub-processes during August 2010 to March 2011 presented in Table 1 show significantly constant failure rates. Therefore, time to failures of each sub process could be deduced to deploy from exponential distributions based on their relevant average failure rates as showed in Table 1.

As a result, reliability functions of all sub-process could be estimated from Equation 11 (Rausand and Hoyland, 2004):

$$R_k(t) = P\ (T_k > t) = \int_t^{\infty} f_k(x)dx = e^{-\lambda_k t} \qquad ; t > 0 \tag{11}$$

Where $f_k(t) = \lambda_k e^{-\lambda_k t}$ denotes probability density function; pdf of sub process $k$. Table 2 shows the probability and reliability functions of the referred sub processes based on Equation 12.

According to Table 2, repairing halls have highest

**Table 2.** Estimation of hazard rate, pdf and reliability functions for each sub process.

| Sub-process *k* | $\lambda_k(t)$ | $f_k(t)$ | $R_k(t)$ |
|---|---|---|---|
| Reception unit | *0.16* | $0.16e^{-0.16t}$ | $e^{-0.16t}$ |
| Repair in hall 1 | *0.29* | $0.29e^{-0.29t}$ | $e^{-0.29t}$ |
| Repair in hall 2 | *0.23* | $0.23e^{-0.23t}$ | $e^{-0.23t}$ |
| Quality control | *0.008* | $0.008e^{-0.008t}$ | $e^{-0.008t}$ |
| Release unit | *0.013* | $0.013e^{-0.013t}$ | $e^{-0.013t}$ |

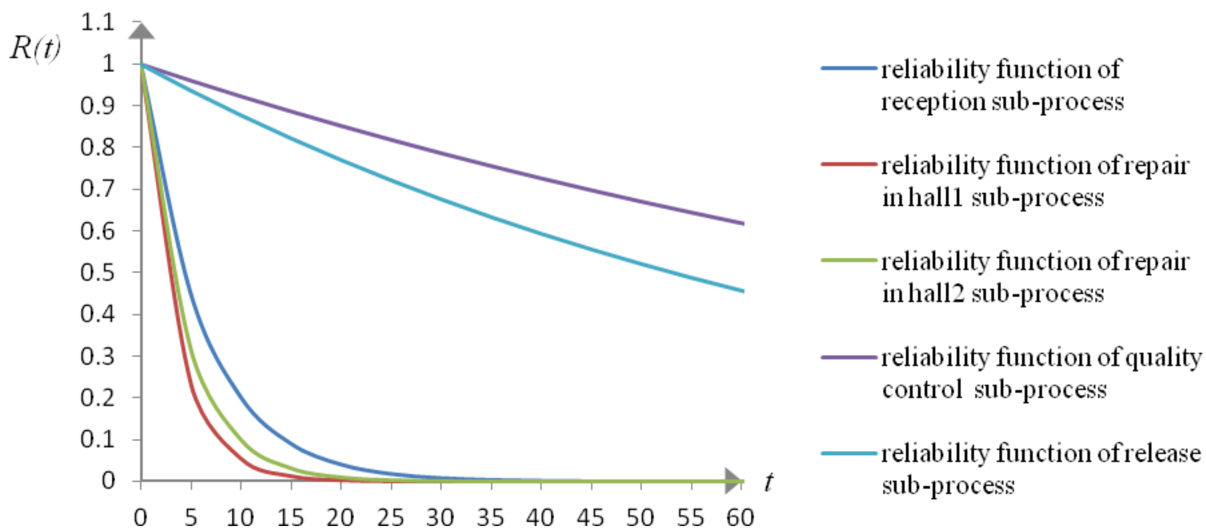


**Figure 3.** comparison of sub-processes reliability in central repair shop.

failure rates, so, as shown in Figure 3, they have lower reliability functions respectively. Therefore, these two sub-processes need more attention in decreasing their failure rates.

Fault tree diagram corresponding to the reliability of the central shop is shown by Figure 4. As it shows, the top-event of the system which means inability of central shop to provide promised service occurs when each of independent sub process fails. Therefore, these four sub-processes act as a series configuration.

The total system reliability possibly achieve by the product of their relevant reliability functions as:

$$R_p(t) = R_{p_1}(t).R_{p_2}(t).R_{p_3}(t).R_{p_4}(t)$$

where

$$R_{p_2}(t) = R_{p_{2-1}}(t).R_{p_{2-2}}(t) = e^{-0.29t}.e^{-0.23t} = e^{-(0.29+0.23)t} = e^{-0.52t}$$

so,

$$R_p(t) = e^{-0.16t}.e^{-0.52t}.e^{-0.008t}.e^{-0.013} = e^{-(0.16+0.52+0.008+0.013)t} = e^{-0.681t} \cong e^{-0.70t} \quad ;t \geq 0$$

Hence, the reliability of the central shop, for one month task is equal to $R_p(1) = e^{-(0.7\times 1)} \cong o.5$.

It means that the probability which repair shop survives one month is only 50%. By substituting the reliability function with 0.95, one with 95% confidence level can infer that this system will survive only 0.07 month (12 h):

$$e^{-0.7t} = o.95 \Rightarrow \ t \cong 0.07$$

By using Equations 4, 6 and 7, the present system sigma level attained 1.63 which is too far from world class level. In order to promote the system reliability, we aggregate the reacceptance duties in each repairing halls at first scenario. So, system configuration changed as shown in Figure 5.

Applying the first proposed plan, the system reliability

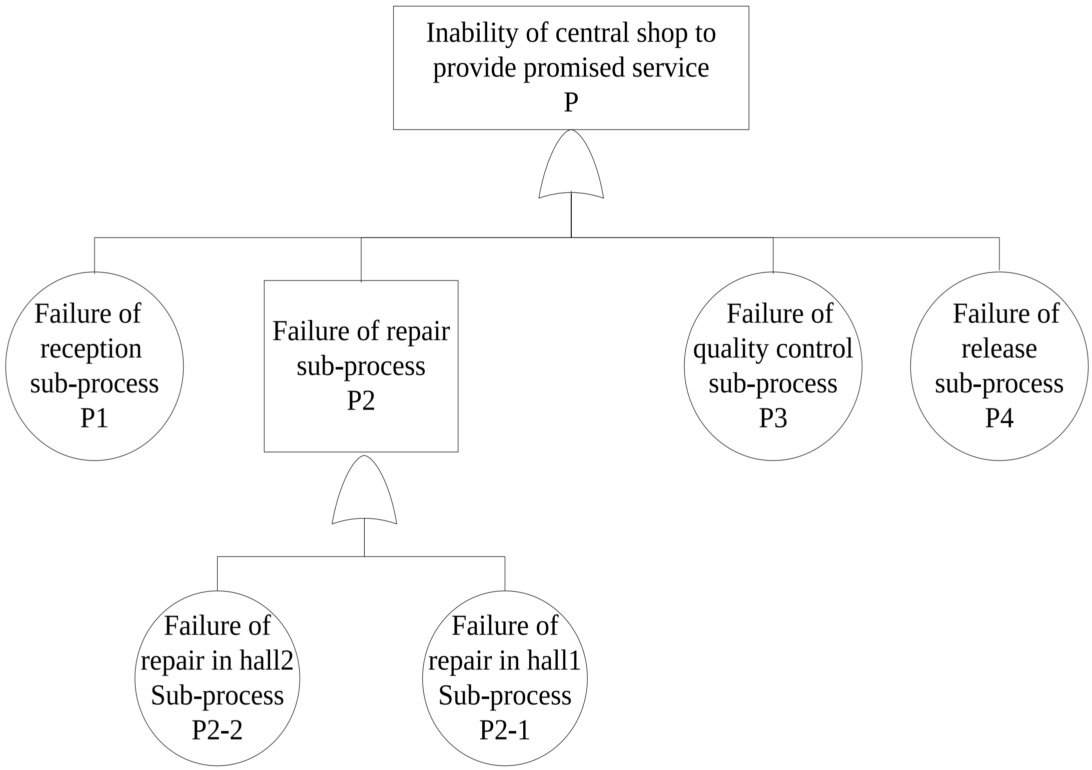


**Figure 4.** Fault tree of the repairing center shop.

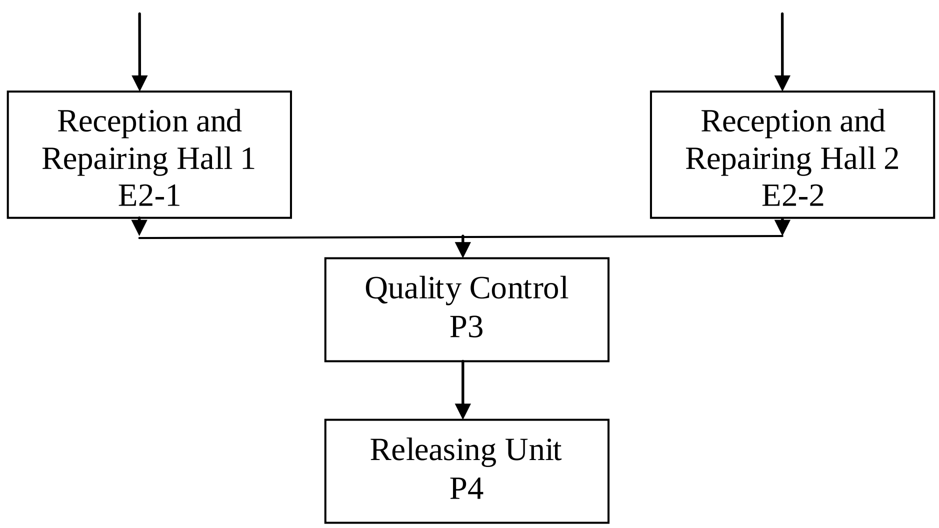


**Figure 5.** Reconfiguration of the repairing central shop based on the proposed promoting plan.

could be estimated by Equation 13:

$$R_s(t) = [1 - (1 - R_{E2-1}(t)).(1 - R_{E2-2}(t))].R_{P3}(t).R_{P4}(t) \quad ; \quad t \geq 0$$

$$R_s(t) = [1 - (1 - e^{-0.29t}).(1 - e^{-0.23t})].e^{-0.008t}.e^{-0.013}$$

By substituting *t=1*, total system reliability promoted to 0.92857 which shows about 86% improvement rate. In such circumstance, the sigma level advances to 3.6 which demonstrate 58% improvement in sigma level. We also expect to run into more progress after carrying out a standard six sigma project.

## Conclusions

In this paper, we addressed the issue of variation in service reliability with time and thus proposed a systematic method for measuring reliability function of multi-stage services using failure rate analysis in a six sigma DMAIC methodology.

The originality of this research is that it considers the issue of variation in service reliability as a function of time, unlike previous researches, and based on the six sigma approach it provides a solution to promote total system survivor function in a given multi-stage service system.

High rates of improvement in the sigma stage and system reliability at the last case study was illustrated showing the advantages of using the proposed approach in a selected multi-stage service system.

## ACKNOWLEDGEMENTS

The authors are very grateful to the editor and the referees for numerous suggestions that greatly improved the paper. This research was supported by deputy of research in the modeling and optimization research center in engineering and industrial engineering section of Islamic Azad University, South Tehran Branch.

## REFERENCES

Berry LL, Parasuraman A, Zeithmal VA (1994). Improving service quality in America:Lessons learned. Acad. Manag. Exec., 8(2): 33-35.

Gunawardane G (2004). Measuring reliability of service systems using failure rates: variations and extensions. Int. J. Qual. Reliab., 21(5): 578-590.

Günes M, Deveci I (2002). Reliability of service systems and an application in student office, Int. J. Qual. Reliab., 19(2): 206-211.

Johnson MD, Nilsson L (2003). The Importance of Reliability and Customization from Goods to Services. Qual. Manag. J., 8(1): 8-19.

Karbasian M, Tabatabayi L (2009). Introduction to Reliability. Esfahan. Pillar of science Publishers.

Li JP, Thompson G (2007). Service Reliability: Concepts and Models. International Conference on Reliability. Maintainability Safety, August: 22-26.

Pham H (2003). Handbook of reliability engineering. Springer-Verlag London. ISBN 1852334533: 532-534

Rausand M, Hoyland A (2004). System Reliability Theory: Models, Statistical Methods, and Applications. 2nd ed. John Wiley publication.

Tortorella M (2005). Service reliability theory and engineering, I: Foundations, Quality technology & Quantitative Management. 2(1): 1-16.