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SURVEY ON QUEUEING MODELS WITH STANDBYS SUPPORT

Sreekanth KOLLEDATH
Research Scholar, Department of Mathematics, Central University of Jammu, Rahya Suchani, Samba District, Bagla, Jammu Kashmir, India
sreekolledath@gmail.com

Kamlesh KUMAR
Department of Mathematics,Central University of Jammu, J & K, India
kamleshkum1984@gmail.com

Sarita PIPPAL
Department of Mathematics, Punjab University, Chandigarh, India
saritamath@pu.ac.in

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Abstract: This paper ia a survey article on queueing models with standbys support. Due to many real life applications of queueing models, it has become an interesting area for researchers and a lot of research work has been exerted so far. It is worthwhile to examine the performance based analysis for queueing modelling system as it provides a valuable insight to the tractability of the system and accelerates its efficiency. The provision of standbys to the queueing modelling of a real system is needed for smooth functioning in the presence of its unavoidable failures. The present survey provides a dig into the research work done, and emphasis the sequential developments on queueing models with standbys support.

Keywords: Queue, Standbys, Machine Repair Problem, Standby Switching, Warm, Cold, Hot and Mixed Standbys.

MSC: 60K25.

1. INTRODUCTION

For balancing the real time system's efficiency and availability, the queueing models with standbys support have become worth mentioning as far as the analysis of queueing modelling study is concerned. The provision of standbys and repairmen support to the queueing system maintain smooth functioning of the system. In the field of computer and communication systems, distribution and service systems, production/manufacturing systems etc., the applications of queueing models with standbys support may be noticed.

In order to achieve high reliability/availability performance of every queueing system operating in machining environment, the standby support is essential. The provision of standbys to queueing machining system provides an insight to the system designer for improving the quality and efficiency of the system. A significant loss of production and throughput is occurred while deploying operating machines, which brings an undesirable loss of revenue and goodwill in the market as far as practical industrial scenario is concerned. To some degree, this situation can be controlled by providing an efficient support of standby units and repair crews to the system. The operating machine may fail in some cases, but due to the standbys machines to queueing machining system, it remains operative and continues to perform the assigned job.

Taylor and Jackson [123] first considered the queueing modeling of machine repair problem with standbys. Reliability and availability of a single unit queueing system with standbys and multiple repair facilities under the exponential failure and repair time distributions have been studied by Natarajan [103]. Osaki [104] and Buzacott [10] were the first to assume that standbys would work with the same failure rate as the new operating one after failure of the operating unit, and used the term "as good as new". In addition to this, a priority rule for repair or use of a unit in the redundant systems had been introduced, too. Nakagawa and Osaki [102] studied a queueing system with general distributed repair time and working time to the priority unit but exponential distributed to the ordinary unit. They obtained some reliability indices to the system by using the Markov renewal theory. A system having operating unit with a general distribution, standby units with exponential distributed failure times and exponential distributed repair time was investigated by Subramanian et al. [120]. An approximate result based on the diffusion process with reflecting boundaries for Markovian multi component system were provided by Kumar and Agarwal [86], Cherian et al. [13, 14]. Gross et al. [28] studied Cost (profit) models in the queueing machine repair problem. Jain and Dhyani [48] provided a transient analysis to the finite server queueing machining with standbys which was earlier developed by Gross et al. [28].

Yearout et al. [155] examined two unit standby redundant system extensively. The finite capacity and servers queueing model with standbys was developed by Gross and Harris [27]. M/M/C repair system with standbys was studied by Berg and Posner [9]. Chang [151] has analysed a repairable parallel system with standby involving human failure and common-cause failure. Chernyak and Sztrik [15] and Sztrik [121] demonstrated the behavior of complex renewal standby queueing system under the assumption of "fast repair" (ex, the failure rate of the units are much smaller than their repair rates) to the failed units. The cost analysis of a finite server machine repair model having operating and standby units variable service rates was discussed by Wang and Sivazlian [145]. Jain [40] studied Diffusion process with reflecting boundaries for general distributed queueing modelling of machine repair problem with standbys machines. Azaron et al. [6] developed a new approach to obtain the reliability function of a class of dissimilar unit redundant systems with exponentially distributed life times by applying shortest path analysis for stochastic networks. Gupta and Melachrinoudis [31] established the complementary relationships between N-policy and F-policy finite source queueing models with standbys. The machine repair problem based on queueing models with reneging and standbys support was suggested by Jain and Premlata [56]. Wang [129] developed a steady-state analytic solution for the finite server machine repair problem with standbys. Several researchers including Al-seedy [2] investigated the queueing behavior of machine interference problem with standbys. A removable single repairmen queueing system with arbitrary standbys units has been tackled by Hsieh and Wang [38]. Wang and Chang [132] and Wang [131] did the cost and probabilistic analysis of machining system with standby components. Meg [100] proposed a general ordering relationship between four different queueing systems arising in standby redundancy enhancement in terms of their mean time between failures.

In order to improve the grade of service of the system, the provision of standby support is recommended. Sometimes due to restriction of volume/cost it is not feasible to provide the sufficient number of spares which are needed for smooth running of the system. The provision of additional repairmen is advisable to get desired reliability/availability in such cases. Queueing modeling of machine repair problem with standbys and additional repairmen is an extension of machine interference problem. Jain et al. [72] examined a finite servers and capacity queueing modeling of machine repair system with discouragement and standbys support.

The common cause failure of operating and standbys units in queueing system play a major role for the availability and reliability of the redundant reparable systems. It is observed that a simultaneous failure of some or all units of the queueing system may be caused by several environmental conditions such as variation in temperature, humidity, vibration or shock voltage fluctuation etc that prevail in many applications. Some researchers who have incorporated this concept in their works include Jain et al. [46] and Vaurio [127]. Dhillon and Yang [19] suggested two unit identical queueing system with common cause failure. As it may be noticed that the reliability of system is an important performance analysis factor for any manufacturing/production system as far as servicing is concerned. Gupta and Tyagi [32] have focused on the reliability analysis of a various complex queueing systems under different types of failure modes. For increasing the operational availability of the system, many authors have incorporated the concept of standbys in queueing models. The stochastic analysis of two unit standby queueinng systems with two modes of failure was given by Jain et al. [46], Shawky [111] and Goyal and Sharma [24]. Finite server Markovian queueing machine repair problem with standbys and three modes of failure was examined by Sharma and Sharma [109]. Jain et al. [73] and Wang and Wu [147] provided the cost analysis for the queueing modeling of Markovian machine repair problem with finite number of servers and two modes of failure.

Jain and Baghel [45] studied queueing modeling of repairable machining system with the provision of standbys. Jain [41] has taken into consideration a queueing machining system with standbys and state dependent rates. Jain et al. [63] studied the availability analysis queueing model of K-out-of-N machining system with standbys. Many researchers have developed Markov queueing models for the performance prediction of standby redundant queueing system in recent past. Dhillon and Cheng [18] have done Probabilistic analysis of a queueing repairable robot safety system composed of (n-1) standby robots, a safety unit and a switch. Wang et al. [139] discussed profit analysis for the finite server queueing model of machine repair problem with two types of standbys machines. Ke and Wang [82] also provided profit analysis of queueing modeling of Markovian machine repair problem with finite number of servers, discouragement and standby switching failures. They also employed the direct search method and the steepest descent method in order to determine global maximum values to satisfy constraints. Ke and Lin [79] considered a queueing based manufacturing system consisting of operating machines and standby machines with unpredictable breakdowns of repair facility. Wang and Xu [148] described the stability analysis for complex standby queueing system with different repairmen criteria using functional analysis method. Many researchers, during the last few decades have worked significantly on multi-component queueing machining system. Ke et al. [77] studied machine repair queueing problem for production system with standbys support.

An optimal analysis for machine interference problem based on queueing model with standbys was described by Mishra and Shukla [101]. They employed the N-R method to optimise the total cost function of the system. A machine repair problem with homogeneous machines and standbys under the assumptions that the multiple technicians are responsible for supervising these machines, was investigated by Ke et al. [84]. Jain and Preeti [55] done queueing analysis of MRP with standbys machines, server working vacation and breakdown. Ke and Wu [83] analyzed queueing characteristic of machine repair problem comprising operating and standbys machine. They used the Matrix recursive method to solve the steady state system equations and evaluate the various performance indices such as average number of failed units in the system, machine availability etc. Queueing modeling of machine repair problem with standbys using multi-threshold and synchronous vacation policy with c-servers was studied by Wu et al. [153], using the steady-state probabilities. Kumar and Jain [89] investigated a bi-level policy for machine repair problem with multiple standbys. They used Runge-Kutta's method to obtain the transient state probabilities and also established various performance indices of the system.

Moreover, some researchers have incorporated specific type of standbys for studying the realistic behavior of queueing models. Depending upon the failure rates of the standbys, standbys may be classified into three categories such as cold, hot and warm standbys respectively. The rest of the paper has been divided into six sections. The next section is focuses on the research work done on queueing models with cold standbys and section 3 presents the research work related to the queueing models with warm standbys support. Section 4 and 5 comprises of the research work done related to queueing models with hot and mixed standbys. Section 6 gives related work on the queueing model with standby switching failure. The conclusion has been drawn in the last section.

2. QUEUEING MODELS WITH COLD STANDBYS

The standby with zero failure rate is considered as cold standby, i.e., these components never fail when they are kept in standby mode. Whenever a primary component fails, a standby component switches over to replace the primary component and then its characteristic is the same as that of the primary component. Toft and Boothroyd [124] first obtained analytic solutions for a Markovian queueing model of machine repair problem with cold standbys. Barlow and Proshan [8] have discussed (M+S) units with S cold standby, where the failure and repair time distributions are exponential, with multiple repair facilities. Srinivasan and Gopalan [117] examined the availability and the reliability of a two-unit cold standby queueing system with a single repair facility. Lureaue [96], Gross et al. [28], Gross D, [25]. Gross et al. [26] have given some significant works in the study of Markovian queueing model of machine repair problem with standbys. All these models deal with cold standby in which standby units were not subject to failure. While Hilliard [37] has studied a cost (profit) model for cold standbys queueing system. The cost analysis of a two units cold standby queueing system with two types of operation and repair was provided by Goel et al. [23]. The general machine interference problem with cold standby machines via diffusion approximation techniques was investigated by Jain and Sharma [62]. Wang [129] researched upon a queueing model with cold standbys and two modes of failure. The reliability and availability of K operating machines and S cold standbys with multiple repair facilities and multiple critical and non-critical errors when the switching mechanism is subject to failure was given by Chung [16]. Gupta and Rao [33, 34] investigated a model of general serviced machine repair problem with cold standby. Gurov and Utkin [35] have carried out the time dependent analysis of repairable and non-repairable cold standby systems with conversion switches. They established mathematical method of system using the set of integral equations. The series systems with cold standby components, where the repair time distribution of the server is assumed to be exponentially distributed have been analyzed by Galikowsky et al. [21]. It is noticed that a two-component cold standby repairable system with one repairman and priority in use is often used in practical applications. Besides a cold standby lightning system in a hospital, similar examples can be found from Lam [91]. Wang and Lee [141] developed a cost-analysis of cold standby finite sever Markovian queueing model with multiple modes of failure. Zhang [162] studied the geometric process repair model to a two-component cold standby repairable system with one repairman.

Sing and Jain [113] researched upon the reliability of repairable multi-component redundant system. Coit [17] formulated a solution methodology to establish optimal design configurations for non-repairable system with cold standbys, non-constant hazard functions, and imperfect switching. Jain and Maheswari [50] studied the time dependent analysis of machining system with cold standbys and repairmen. Vanderperre [126] has taken into account the reliability analysis of a renewable multiple cold standby system. A non-Markov process model has extended by Zhang and Wang [163] to a generalized Markov process model by using the supplementary method. Azaron et al. [7] have used a generic algorithm approach to solve a multi objective discrete reliability for optimization problem in a dissimilar-unit non-repairable cold-standby redundant queueing system. A cold standby repairable system with two different components and one repairman assuming that the repairman can take multiple vacations has been studied by Yuan and Xu [157]. By using the Vector Markov process and Laplace transform, Wu and Wu [154] analysed the reliability of a cold standby queueing system consisting of two repairable units. Two dissimilar components of machine repair problem with the support of cold standbys and one repairman were considered by Zhang and Wang [164]. The reliability of K-out-of-n cold standby systems has been studied by Amari [4]. He examined the system reliability by using the Gamma distribution function. Ruiz-Castro [106] proposed a preventive policy for a complex cold standby queueing system subject to internal failures and external shocks with loss of units.

3. QUEUEING MODELS WITH WARM STANDBYS

The warm standbys components can have lower failure rate than the failure rate of the primary components. The reliability of a two unit warm standby system with an exponential failure time distribution and two types of general repair time distributions of the operating unit and of the standbys has been studied by Srinivasan and Gopalan [118]. Kumagi [85] considered reliability analysis for single server queueing system with n-type of warm standby. Subramanian, et al.[120] investigated a queueing system one-on-line unit (operating machine) with general lifetime distribution, S warm standbys with exponential failure time distribution and with exponential repair time distributions based on only one assumption, namely, the system fails when standbys are not available to replace the failed operating machine. Albright [1], and Sivazlian and Wang [116] have studied a cost(profit) model for warm standby queueing system. Sivazlian and Wang

[115] considered queueing analysis for the machine repair problem with warm standby system and introduced analytic solutions to the queueing system. Wang et al. [139] developed Sivazlian and Wang's model to the warm standby queueing modeling of machining system with discouragement and standby switching failures. Chelst et al. [11] have studied a cost (profit) model in the machine repair problem having warm standbys. Kalpakam and Hameed [75] investigated a queueing redundant system with N-warm standbys and carried out an analysis of availability and reliability of queueing system. The reliability analysis of two standby units queueing having general probability distributions was developed by Vanderperre [125].

Hsieh and Wang [38] have incorporated the reliability indices of queueing repairable system operating as well as warm standbys machines and single removable repairman in the service facility. Further, Jain and Maheswari [58] extended this model to analyze the repairable system in transient state under reneging constraint of the failed units. Gupta [29] studied a machine interference model with warm standbys machines. Several different system configurations of series queue with warm standby components have been investigated by Wang and Sivazlin [146]. The reliability and availability analysis of 2-unit warm standby queueing system with self-reset function and a single maintenance facility were examined by Tan [122]. By using queue size distribution, Jain [42] studied a finite server Markovian machine repair problem with warm standbys and additional repairmen. Gupta [30] considered a finite source queueing model with warm standbys under N-policy.

Arulmozhi [5] provided a closed form solution for the system reliability of a warm standby queueing system with R repairmen. Jain et al. [64] have examined a general serviced machine repair problems incorporating warm standbys and additional repairmen. Ke and Wang [80, 81] examined the reliability analysis of queueing model of repairable system with warm standbys. The series queueing system with warm standby component, where the repair time distribution of the server is assumed to be exponentially distributed was analyzed by Wang and Pearn [144]. Wang and Pearn's [144] paper to investigate the cost benefit analysis of series system with warm standby components and general repair times has been extended by Wang et al. [142]. The bilevel control policy of degraded queueing machining system with warm standbys was discussed by Jain et al. [57]. Jain and Singh [71] considered a machine repair problem with warm standbys, set up and vacation from the standpoint of the queueing theory and they have also regarded bi-level switch-over policy for the two repairman. The cost-benefit analysis of series systems with warm standby components and general repair time has been proposed by Wang et al. [142]. (Four different system configurations with warm standby components involving standby switching failures has never been investigated). Wang et al. [135] did sensitivity analysis for queueing repairable system with warm standbys. Perez-Ocon and Montoro-Cazorla [105] employed matrix analytic method to study the analysis of a system with warm standbys. An availability and reliability of K-out-of- $(M + N)$:G warm standby systems were established by Zhang et al. [161]. A three-unit system consisting of a single unit working online and two warm standby units was proposed by Srinivasan and Subramanian [119]. Wang and Chiu [133] have studied a queueing systems with warm standby units and imperfect coverage. Jain et al. [66] have considered a machine repair system with warm standby and switching failure. Wang et al. [134] compared the reliability and availability of four different system configurations with warm standby components and standby switching failures. El-Damcese [20] investigated the performance indices of warm standby queueing systems subject to common-cause failures with time varying failure and repair rates.

Jain et al. [51] proposed a queueing model of machine repair problem with multiple types of warm standbys. A generic case of warm standby redundancy and reliability optimisation techniques in several dimensions including the non-constant component hazard functions warm standby components including cold and hot standby situations, imperfect switches, K-out-of-N redundancy structures, multiple component choices was considered by Amari and Dill [3]. Maheswari et al. [98] employed a matrix recursive method for solving the state dependent system governing equations of queueing machining system with warm standbys and multiple server vacations. The reliability analysis of a warm standby repairable system was addressed by Yuan and Meng [156]. The cost benefit analysis of a machining system with warm standby components and variable server by incorporating the concept of balking was provided by Wang et al. [137]. Zang and Liu [160] studied a reliable machine interference problem with warm standbys, vacations balking and reneging. They obtained various performance measures using Matrix theory and inverse Laplace transform to solve the differential difference system governing equations. A queueing model with warm standbys along with vacation of a repairman from the view point of queueing and reliability characterization has been analyzed by Sharma [108]. Wang et al. [149] , Yue et al. [159] have considered a queueing machining model with heterogeneous repairmen and warm standbys. They investigated both queueing and reliability analysis. Jain et al. [70] analyzed the performance of primary and secondary unreliable servers in a multi component machinery system with warm standbys and switching failure. MRP with warm standbys, discouragement and unreliable multi-repairmen following a vacation policy was investigated by Singh and Maheswari [114]. Jain and Rani [60] have presented the availability prediction for a repairable queueing system with warm standbys.

Kumar and Jain [88] have studied threshold F-policy and N-policy models of a multi component machine repair problem with warm standbys. Using recursive method to solve the steady state system governing equation they obtained the queue size distributions. They also evaluated various performance indices such as the probability that the server is idle, the expected number of failed units in the system etc. A comparative analysis using Quasi-Newton method with the

PSO algorithm has been demonstrated by Wang et al. [136] for the study of MRP with warm-standbys by considering the service pressure condition and concept of balking and reneging. Ke et al. [76] considered a multi-repairmen problem comprising with warm standbys and they obtained global optimal system parameters for cost analysis by using Quasi-Newton method and probabilistic global search Lausanne method. Jain and Gupta [49] analysed the availability measurement for a redundant system with warm standby components under the care of single repair facility. The N-policy investigations in the article of Jain et al. [69] aimed at predicting the transient performance measures of a MRP with multi types of warm standbys, reboot and imperfect coverage with a single unreliable server. Wang et al. [143] studied a multiple vacation MRP with warm standbys and an unreliable repairman. They first employed a matrix-analytic method to obtain the steady-state probabilities and then computed various performances indices to facilitate the sensitivity analysis. They also used optimization algorithm to determine the optimal number of warm standbys and service rate. A MRP model with warm standbys and synchronous server vacations was studied by Wu and Ke [152]. Wells [150] analysed the reliability for queueing system with warm standbys under the assumption of repairable and non repairable failures. The reliability analysis of non-coherent warm standby systems with reworking was done by Levitin et al. [92]. They determined system performance indices using queue size distribution and matrix equations. Jain et al. [68] provided transient analysis for machine repair problem with multi types of warm standbys. Liou [94] examined a MRP with warm standbys support under the assumptions of multiple vacations and working breakdowns and he also obtained the steady-state probabilities with the help of Matrix analytic method. Yen et al. [158] used Matrix analytic method for the cost optimization of N-policy MRP operating under the server working breakdown policy. They developed the study-state probabilities of the number of failed machines in the system as well as several other performance measures using the matrix-analytic method. The reliability and sensitivity analysis of a MRP with warm standbys and an unreliable server having provision of multiple-vacations has been emphasized in the recent article of Chen et al. [12].

4. QUEUEING MODELS WITH HOT STANDBYS

The hot standby components in the queueing system are described with the same failure characteristics as that of the primary operating component. The failure characteristic of one component is not affected by other components either they are performing or non-performing. Hence, the components are statistically independent. Shree et al. [112] considered a queueing model for machine repair system with hot standbys and having repairmen under the partial server vacation policy.

5. QUEUEING MODELS WITH MIXED STANDBYS

In order to use mixed standbys instead of a single type due to some techno-economic constraints is sometimes advantageous. It can be noticed that the provision of cold or warm standby components is common in real time systems for smooth running of machining system, but in many cases, it is recommended to facilitate mixed (cold and warm) standby component. The mixed standbys are incorporated to the system as cost of cold and warm standbys are different and sometimes required quantity of one type of standbys is not available. The mixed standbys to the machining system are also provided for the smooth and improved functioning to the system. Gnedenko et al. [22] first proposed the mixed standby model with identical repair rate of the M/M/R machine repair problem. Wang and Sivazlin [145] studied a queueing model for MRP with the provision of cold and warm standby. Wang [128] investigated a queueing model for M/M/R machine repair problem consisting of M-operating machines with a specified number of cold and warm standbys machines. The cost strategy of series queueing system with mixed standbys was suggested by Wang and Kuo [140]. Sharma et al. [110] presented a characteristic analysis for machining system .

Jain and Saxena [61] examined a queueing model for machining system with mixed standbys machines. The trade-off between the repairman staffing level and the magnitude of machine interference has become a significant issue and has drawn attention of many queueing theorists who considered the machine interference problem as finite source queueing model because of cost and technical constraints. The contributions of Jain et al. [67] and many more are worth-mentioning in this regard in recent past years. A multi-unit repairable queueing system with state dependent rates was studied by Jain et al. [65]. Jain and Bhargawa [47] focused on an unreliable M/G/1 queueing system with set-up time under K-phase of optional repair and they have also obtained the queueing and reliability indices to predict the queueing behaviour of the system. Jain and Preeti [53] have incorporated the concept of controllable rates to a multi-component machining system. The reliability and availability of MRP with both warm and cold types of standby provisioning along with common cause of failure has been investigated by Hajeesh [36]. Sharma [107] investigated the MRP with mixed standbys (cold, warm and hot) along with two modes of failure under steady state conditions using Runge-Kutta method. Jain [43] employed the Runge-Kutta's method and neuro-fuzzy inference approach to study the transient analysis for MRP with mixed standbys and unreliable server. MRP with mixed standbys and discouragement has been studied by Maheswari and Ali [97]. An availability analysis of software rejuvenation in active/standby cluster system has been analyzed by Jain and Preeti [54]. The reliability analysis for a retrial queueing system with mixed standby has been presented by Kuo et al. [90]. The performance analysis of a multi component MRP under threshold policy and the provision of mixed (cold and warm) standbys has been suggested by Jain et al. [74]. They considered failure and repair rates to be interdependent and controllable. They used a threshold policy to turn on the removable additional repairman by using a product type technique to derive formulae for the steady-state probabilities and other performance measures. Jain et al. [52] used the SOR method for obtaining the steady state queue size distribution of the average number of failed units for multi-component machining system with common cause failure and mixed standbys.

6. QUEUEING MODELS WITH STANDBY SWITCHING FAILURE

The most repairable systems are deteriorative because of the ageing effect and the accumulative wear in practice. It is very often to assume that as soon as any operating system fails in any queueuing modelling of machine repair problem with standby provision, it is immediately replaced by standbys units without any delay. The operating units are duplicated in every aspect by the presence of this standby machine in operating system. This type of switchover of standbys in the main system in place of operating unit may be unsuccessful and is called the switching failure of the standbys. Until switching is successful or all the standbys have failed switch over, all the available standbys in the system try to switch over into an operating system one by one. The Switching failure of standby system and reboot delay have been fascinated by many queueing theorists in last decade. Lewis [93] first introduced the notion of the standby switching failures in the reliability for queueing system. Wang et al. [138] analysed a cost profit model for queueing model of machine repair problem with standby switching failures. Kee et al. [78] investigated a model for reliability and sensitivity analysis for queueing repairable system with standby switching failures. The reliability characteristics of multi-component repairable redundant system with coverage factor and reboot delay has been developed by Jain and Rani [59]. The availability analysis of a queueing system with reboot delay, standby switching failures and unreliable repair facility has been examined statistically by Hsu et al. [39]. Liu et al. [95] have discussed the availability behaviour of a repairable system in which the standby switched to the primary unit subject to breakdowns. Kumar and Jain [87] have considered the provision of two heterogeneous servers and vacation for the (M,m) machine repair problem with standbys and switching failure. Jain and Preeti [54] used the supplementary variable technique corresponding to remaining repair time and using recursive approach. An availability analysis for machine repair problem with multi-type standby system under standby switching failure and reboot delay in crisp environment has been studied by Jain et al. [44].

7. CONCLUSION

In this paper, we have provided an insight into the extensive work done on queueing modelling with standbys provision over past few decades. To analyse queueing behavior of a machining/manufacturing system with standbys support, various system performance indices are established to pay attention towards the real time congestion problems. Therefore, we have given a survey for the performance analysis of queueing models with standbys support. This investigation can be helpful for the operations research analyst, system designers, researchers, and manufacturers to study queueing modelling of machine repair problem with standbys. It may also be noticed that detailed literature has been covered and the related references have been provided. Further, this survey paper can be extended by including server vacations and server unreliability issues to study queueing models with standbys.

REFERENCES

[1] Albright, S. C., "Optimal Maintenance-Repair Policies for the Machine Repair Problem", *Naval Research Logistics Quaterly,* 27 (1980) 17-27.

[2] Al-Seedy, R. O., "The truncated queue: M/M/2/m/m+Y with balking spares,machine interference and an additional server for longer queues (Krishnamoorthi discipline)", *Microelectronics Reliability*, 35 (1995) 1423-1427.

[3] Amari, S. V., and Dill, G., "Redundancy optimization problem with warm-standby redundancy", in: Reliability and Maintainability Symposium (RAMS), *Proceedings-Annual*, 2010, 1-6.

[4] Amari, S. V., "Reliability of k-out-of-n standby systems with gamma distributions", in: Reliability Maintainability Symposium (RAMS), *Proceedings-Annual*, 2012, 1-6.

[5] Arullnozhi, G., "Reliability of an M-out of-N warm standby system with R repair facilities", *Operations Research*, 39 (2002) 77-87.

[6] Azaron, A. Katagiri, H. Sakawa, M Modarres, M., "Reliability function of a class of time dependent systems with standby redundancy", *European Journal of Operational Research*, 164 (2005) 378-386.

[7] Azaron, A., Perkgoz, C., Katagiri, H., Kato, K., and Sakawa, M., "Multi-objective reliability optimization for dissimilar-unit cold-standby systems using a genetic algorithm", *Computers and Operations Research*, 36 (2009) 1562-1571.

[8] Barlow, R. E., and Proshan, F., *Mathematical Theory of Reliability*, John Willey New York, 1965.

[9] Berg, M., and Posner, M. J. M., "Customer Delays in M/M/C Repair System with Spares", *Naval Research Logistics Quarterly*, 32 (1985) 287-299.

[10] Buzacott, J. A., "Availability of priority standby redundant systems", *IEEE Transactions of Reliability*, 20 (1971) 60-63.

[11] Chelst, K., Tilles, A. Z., and Pipis, J. S., "A coal unloader: a finite queueing system with breakdowns",*Interfaces*, 11 (1981) 12-25.

[12] Chen, W. L., Wang, C. H., and Chen, Z. H., "System reliability of a machine repair system with a multiple-vacation and unreliable server", *Journal of Testing and Evaluation*, 44 (2016) 1-11.

[13] Cherian, J., Jain, M., and Sharma, G. C., "Reliability of a standby system with repair", *Indian Journal of Pure and Applied Mathematics*, 18 (1987) 1061-1068.

[14] Cherian, J., Jain, M., and Sharma, G. C., "A diffusion approximation for a multi-component system with repair providing spare components", *Journal of MACT.*, 21 (1988) 79-90.

[15] Chernyak, A. I., and Sztrik, J., "Asymptotic behaviour of a complex renewable standby system with fast repair", *Problems of Control and Information Theory*, 20(1991) 37-44.

[16] Chung , W. K., "Reliability of imperfect switching of cold standby systems with multiple non-critical and critical errors", *Microelectronics Reliability*, 35 (1995) 1479-1482.

[17] Coit, D. W., "Cold-standby redundancy optimization for non-repairable systems", *IIE Transactions*, 33 (2003) 471-478.

[18] Dhillon, B. S., and Cheng, S., "Probabilistic analysis of a repairable robot-safety system composed of (n-1) standby robots, a safety unit, and a switch", *Journal of Quality in Maintenance Engineering*, 14 (2008) 306-323.

[19] Dhillon, B. S., and Yang, N., "Stochastic analysis of standby systems with common-cause failures and human errors", *Microelectronic Reliability*, 12 (1992) 1699-1712.

[20] El-Damcese, M. A., "Analysis of warm standby systems subject to common-cause failures with time varying failure and repair rates", *Applied Mathematical Sciences*, 3 (2009) 853-860.

[21] Galikowsky, C., Sivazlian, B. D., and Chaovalitwongse, P., "Optimal redundancies for reliability and availability of series systems", *Microelectronics Reliability*, 36(1996) 1537-1546

[22] Gnedenko, B. V., Belyayev, Y. K., and Solovyev, A. D., *Mathematical methods of reliability theory*, Academic Press, New York, 1969.

[23] Goel, L. R., Gupta, R., and Singh S. K., "Cost analysis of a two units cold standby system with two types of operation and repair", *Journal of Microelectronics and Reliability*, 25 (1985) 71-75.

[24] Goel, L. R., and Sharma, G. C., "Stochastic analysis of a two unit standby system with two failures and slow switch", *Microelectronics and Reliability*, 29 (1980) 493-498.

[25] Gross, D., "A spare and server provisioning model", *Computers and Operations Research*, 8 (1981) 197-207.

[26] Gross, D., Miller, D. R., nd Soland, R. M., "A closed queueing network model for multi-electron repairable item provisioning", *IIE Transactions*, 15 (1983) 344-352.

[27] Gross, D., and Harris, C. M., *Fundamentals of queuing theory, Second Edition*, John Wiley and Sons, New York, 1985.

[28] Gross, D., Kahn, H. D., and Marsh, J. D., "Queuing models for spares provisioning", *Naval Research Logistics Quarterly*, 24 (1977) 521-536.

[29] Gupta, S. M., "Machine interference problem with warm spares, server vacations and exhaustive service", *Performance Evaluation*, 29 (1997) 195-211.

[30] Gupta, S. M., "N-policy queueing system with finite source and warm spares", *Operations Research*, 36 (1999) 189-217.

[31] Gupta, S. M., and Melachrinoudis, E., "Complementarity and equivalence in finite source queueing models with spares", *Computers and Operations Research*, 21 (1994) 289-296.

[32] Gupta, P. P., and Lokesh T., "MTTF and availability evaluation of two unit two state, standby redundant coplex system with constant human failure", *Microelectronic Reliability*, 26 (1986) 647-650.

[33] Gupta, U. C., and Srinivas, Rao, T. S. S., "M/G/1 machine interference problem with spares", *Performance Evaluation*, 24 (1996) 265-275.

[34] Gupta, U. C., and Srinivasa Rao, T. S. S., "On the machine interference model with spares", *European Journal of Operational Research*, 89 (1996) 164-171.

[35] Gurov, S. V., and Utkin, L. V., "Cold standby systems with imperfect and noninstantaneous switchover mechanism", *Microelectronic Reliability*, 36 (1996) 1425-1438.

[36] Hajeeh, M. A., "Reliability and availability of a standby system with common cause failure", *International Journal of Operational Research*, 11 (2011) 343-363.

[37] Hilliard, J. E., "An approach to cost analysis of maintenance float system", *AIIE Transactions*, 8 (1976) 128-133.

[38] Hsieh, Y. C., and Wang, K. H., "Reliability of a repairable system with spares and a removable repairman", *Microelectronics and Reliability*, 35 (1995) 197-208.

[39] Hsu, Y. L., Ke, J. C., and Liu, T. H., "Standby system with general repair, reboot delay, switching failure and unreliable repair facility-A statistical standpoint", *Mathematics and Computers in Simulation*, 81 (2011) 2400-2413.

[40] Jain, M., "Diffusion approximations for G*/G/m machine interference problem with spare machines", *Microelectronic Reliability*, 33 (1993) 1415- 1418.

[41] Jain, M., "An (m, M) machine repair problem with spares and state dependent rates: a diffusion process approach", *Microelectronic Reliability*, 37 (1997) 929-933

[42] Jain, M., "M/M/R machine repair problem with spares and additional server", *Indian Journal of Pure and Applied Mathematics*, 29 (1998) 517-524.

[43] Jain, M., "Transient analysis of machining systems with service interruption, mixed standbys and priority", *International Journal of Mathematics in Operational Research*, 5 (2013) 604-625.

[44] Jain, M., Agrawal, S. C., and Preeti, "Fuzzy reliability evaluation of a repairable system with imperfect coverage, reboot and common cause shock failure", *International Journal of Engineering, Transaction C: Basics*, 25 (2012) 231-238.

[45] Jain, M., and Baghel, K. P. S., "A repairable system with spares, state dependent rates and additional repairman", *Journal of Rajasthan Academy of Physical Sciences*, 2 (2003) 181-190.

[46] Jain, M., Baghel, K. P. S., and Shekhar, C., "M/G/1 system with standbys and common cause

failure", *Journal of Rajasthan Academy of Physical Sciences*, 2 (2003) 239-250.
[47] Jain, M., and Bhargava, C., "N-policy machine repair system with mixed standbys and unreliable server", *Quality Technology and Quantitative Management*, 6(2009) 171-184.
[48] Jain, M., and Dhyani, I., "Transient analysis of M/M/C machine repair roblem with spares", *Agra University Journal of Sciences*, 2 (1999) 16-42.
[49] Jain, M., and Gupta, R., "Availability analysis of repairable redundant system with three types of failures subject to common cause failure", *International Journal of Mathematics in Operational Research*, 6 (2014) 271-296.
[50] Jain, M., and Maheshwari, S., "Transient analysis of redundant system with additional repairmen", *American Journal of Mathematical and Management Science*, 23 (2003) 347-382.
[51] Jain, M., Maheshwari, S., and Sharma, P., "Machine repair problem with k-type warm spares, multiple vacations for repairmen and reneging", *International Journal of Engineering and Technology*, 2 (2010) 252-258.
[52] Jain, M., Mittal, R., and Kumari, R., "(m, M) Machining system with two unreliable servers, mixed spares and common-cause failure", *Journal of Industrial Engineering International*, 11 (2015) 171-178.
[53] Jain, M., and Preeti, "Machine repair problem with mixed standbys, common cause failure interdependent and controllable rate", *Mathematics Today*, 25 (2009) 9-30.
[54] Jain, M., and Preeti, "Performance analysis of a repairable robot safety system with standby, imperfect coverage and reboot delay", *International Journal of Engineering, Transaction C: Aspects*, 26 (2013) 1077-1088.
[55] Jain, M., and Preeti, "Cost analysis of a machine repair problem with standby, working vacation and server breakdown", *International Journal of Mathematics in Operational Research*, 6 (2014) 437-451.
[56] Jain, M., and Premlata, "M/M/R machine repair problem with reneging and spares", *Engineering and Applied Sciences*, 13 (1994) 139-143.
[57] Jain, M., Rakhee, and Singh, M., "Bi-level control of degraded machining system problem with warm standbys, setup and vacation", *Applied Mathematical Modelling*, 28 (2004) 1015-1026.
[58] Jain, M., Rakhee, and Maheshwari, S., "N-policy for a machine repair system with spares and reneging", *Applied Mathematical Modelling*, 28 (2004) 513-531.
[59] Jain, M., and Rani, S., "Availability of hardware - software systems with standbys, switching failures and reboot delay", *Mathematics Today*, 27 (2011) 100-116.
[60] Jain, M., and Rani, S., "Availability analysis for repairable system with warm standby, switching failure and reboot delay", *International Journal of Mathematics in Operational Research*, 5 (2013) 19-39.
[61] Jain, M., and Saxena, N. K., "Performance analysis of state dependent machining system with mixed standby", *International Journal of Information and Computer Science*, 9 (2006) 38-45.
[62] Jain, M., and Sharma, G. C., "A diffusion approximation for the G/G/r machine interference problem with spare machines", *Indian Journal of Technology*, 24 (1986) 568-572.
[63] Jain, M., Sharma, G. C., and Pundir, R. S., "Reliability analysis of k-out-of-N machining system with spares and imperfect coverage", *International Journal of Information and Computing Science*, 9 (2006) 1-8.
[64] Jain, M., Sharma, G. C., and Singh, M., "G/G/r machine repair problem with spares and additional repairman", *International Journal of Engineering*, 15 (2002) 57-62.
[65] Jain, M., Sharma, G. C., and Singh, N., "Performance analysis of double ended Markovian queue for machining system with spares", *International Journal of Information and Computer Sciences*, 11 (2008) 7-16.
[66] Jain, M., Sharma, G. C., and Sharma, R., "Machine repair system with warm standby, additional repairmen, discouragement and switching failure", *Jnanabha*, 36 (2006) 157-168.
[67] Jain, M., Sharma, G. C., and Sharma, R., "Performance modeling of state dependent system with mixed standbys and two modes of failure", *Applied Mathematical Modelling*, 32 (2008) 712-724.
[68] Jain, M., Sharma, G. C., and Rani, V., "Performance prediction of machine repair problem with spares and two modes of failure", *International Journal of Operational Research*, 22 (2015) 167-193.
[69] Jain, M., Shekhar, C., and Rani, V., "N-policy for a multi-component machining system with imperfect coverage, reboot and unreliable server", *Production and Manufacturing Research: An Open Access Journal*, 2 (2014) 457-476.

[70] Jain, M., Shekhar, C., and Shukla, S., "Queueing analysis of two unreliable servers machining system with switching and common cause failure",*International Journal of Mathematics in Operational Research*, 5(2013) 508-526.
[71] Jain, M., and Singh, M., "Bi-level Control of Degraded Machining System with Warm Standbys, Setup and Vacation", *Applied Mathematical Modelling*, 28(2004) 1015-1026.
[72] Jain, M., Singh, M., and Baghel, K. P. S., "M/M/C/K/N Machine Repair Problem with Balking, Reneging", *Spares and Additional Repairmen, GSR*, 26/27 (2000) 49-60.
[73] Jain, M., Singh, M. and Baghel, K. P. S., "Machine repair problem with spares, reneging, additional repairman and two modes of failure", *Journal of MACT*, 33(2000) 69-79.
[74] Jain, M., Rani, V., and Kumari, R., "Threshold switch over policy for multi component machining system with controllable rates", *International Journal of Industrial and System Engineering*, 20 (2015) 397-414.
[75] Kalpakam, S., and Hameed, M. A. S., "Availability and reliability of an n-unit warm standby redundant system", *Journal of Mathematical and Physical Sciences*, 18 (1984) 41-50.
[76] Ke, J. C., Hsu, Y. L., Liu, T. H., and Zhang, Z. G., "Computational analysis of machine repair problem with unreliable multi-repairmen", *Computers and Operations Research*, 40 (2013) 848-855.
[77] Ke, J. C., Lee, S. L., and Liou, C. H., "Machine repair problem in production systems with spares and server vacations", *RAIRO-Operations Research*, 43 (2009) 35-54.
[78] Ke, J. C., Lee, W. C., and Wang, K. H., "Reliability and sensitivity analysis of a system with multiple unreliable service stations and standby switching failures", *Physica A: Statistical Mechanics and its Applications*, 380 (2007) 455-469.
[79] Ke, J. C., and Lin, C. H., "Sensitivity analysis of machine repair problems in manufacturing systems with service interruptions", *Applied Mathematical Modelling*, 32 (2008) 2087-2105.
[80] Ke, J. C., and Wang, K. H., "The reliability analysis of balking and reneging in repairable system with warm standby", *Quality and Reliability Engineering International*, 18 (2002) 467-478.
[81] Ke, J. C., and Wang, K. H., "Probability analysis of a repairable system with warm standbys plus balking and reneging", *Applied Mathematical Modelling*, 27 (2003) 327-336.
[82] Ke, J. C., and Wang, K. H., "Vacation policies for machine repair problem with two type spares", *Applied Mathematical Modelling*, 31 (2007) 880-894.
[83] Ke, J. C., and Wu, C. H., "Multi-server machine repair model with standbys and synchronous multiple vacation", *Computers and Industrial Engineering*, 62 (2012) 296-305
[84] Ke, J. C., Wu, C. H., Liou, C. H., and Wang, T. Y., "Cost analysis of a vacation machine repair model", *Procedia-Social and Behavioral Sciences*, 25 (2011) 246-256.
[85] Kumagi, M., "Reliability analysis of n-spare system with single repair facility", *Operations Research Quarterly*, 26 (1975) 629-640.
[86] Kumar, A., and Agarwal, M., "A review of standby systems", *IEEE Transactions on Reliability*, 29 (1980) 290-294.
[87] Kumar, K., and Jain, M., "Threshold N-policy for (M, m) degraded machining system with heterogeneous servers, standby switching failure and multiple vacation", *International Journal of Mathematics in Operational Research*, 5 (2013) 423-445.
[88] Kumar, K., and Jain, M., "Threshold F-policy and N-policy for multi-component machining system withwarm standbys", *Journal of Industril Engineering International,(Springer)*, 29 (2013).
[89] Kumar, K., and Jain, M., "Bi-level control of degraded machining system with two unreliable servers, multiple standbys, startup and vacation", *International Journal of Operational Research*, 21 (2014) 123-142.
[90] Kuo, C. C., Sheu, S. H., Ke, J. C., and Zhang, Z. G., "Reliability-based measures for a retrial system with mixed standby components", *Applied Mathematical Modelling*, 38 (2014) 4640-4651.
[91] Lam, Y., "A maintenance model for two-unit redundant system", *Microelectronics Reliability*, 37 (1997) 497-504.
[92] Levitin, G., Xing, L., and Dai, Y., "Reliability of non-coherent warm standby systems with reworking", *IEEE Transactions on Reliability*, 64 (2015) 444-453.
[93] Lewis, E. E., *Introduction to Reliability Engineering*, second ed., John Wiley and Sons, New York, 1996.
[94] Liou, C. D., "Optimization analysis of the machine repair problem with multiple vacations and working breakdowns", *Journal of Industrial and Management Optimization*, 11 (2015) 83-104.
[95] Liu, T. H., Ke, J. C., Hsu, Y. L., and Hsu, Y. L., "Bootstrapping computation of availability for

a repairable system with standby subject to imperfect switching", *Communications in Statistics Simulation and Computation*, 40 (2011) 469-483.

[96] Lureau, F., "A queueing theoretic analysis of logistics repair models with spare units", *Technical Report 55, Department of Operational Research, Stanford University, Stanford, California*, 1974.

[97] Maheshwari, S., and Ali, S., "Machine repair problem with mixed spares, balking and reneging", *International Journal of Theoretical and Applied Sciences*, 5 (2013) 75-83.

[98] Maheshwari, S., Sharma, P., and Jain, M., "Machine repair problem with K - type warm spares, multiple vacations for repairmen and reneging", *International Journal of Engineering Science and Technology*, 2 (2010) 252-258.

[99] Mahmoud, M. A. W, and Moshref, M. E., "On a two-unit cold standby system considering hardware, human error failures and preventive maintenance", *Mathematical and Computer Modelling*, 51 (2010) 736-45.

[100] Meng, F. C., "Comparing the MTBF of Four Systems with Standby Components", *Microelectronic Reliability*, 35 (1995) 1031-1035.

[101] Mishra, S. S., and Shukla, D. C., "Optimality analysis of machine interference model with spares less than servers", *Contemporary Engineering Sciences*, 3 (2010) 371-372.

[102] Nakagawa, T., and Osaki, S., "Stochastic behaviour of a two-unit priority standby redundant system with repair", *Microelectronics Reliability*, 14 (1975) 309-313.

[103] Natarajan, R., "A reliability problem with spares and multiple repair facilities", *Operations Research*, 16 (1968) 1041-1057.

[104] Osaki, S., "Reliability analysis of a two-unit standby redundant system with priority", *Canadian Journal of Operations Research Society*, 8 (1970) 60-62.

[105] Perez-Ocon, R., and Montoro-Cazorla, D., "A multiple warm standby system with operation and repair times following phase-type distributions", *European Journal of Operational Research*, 169 (2006) 178-188.

[106] Ruiz-Castro, J. E., "A preventive maintenance policy for a standby system subject to internal failures and external shocks with loss of units", *International Journal of Systems Science*, 46 (2015) 1600-1613.

[107] Sharma, D. C., "Non-perfect M/M/R Machine repair problem with spares and two modes of failure", *International Journal of Scientific and Engineering Research*, 2 (2011) 1-5.

[108] Sharma, D. C., "Machine repair problem with spares and N-policy vacation", *Research Journal of Recent Sciences*, 1 (2012) 72-78.

[109] Sharma, D. C., and Sharma, G. C., "M/M/R machine repair problem with spare and three modes of failures", *Ganita Sandesh*, 11 (1997) 51-56.

[110] Sharma, G. C., Jain, M., and Baghel, K. P. S., "Performance modeling of machining system with mixed standby component balking reneging", *International Journal of Engineering*, 17 (2004) 169-180.

[111] Shawky, A. I., "The machine interference model: M/M/C/K/N with balking reneging and spare", *Operations Research*, 36 (2000) 25-35.

[112] Shree, L., Singh, P., Sharma, D. C., and Jharotia, P., "Mathematical modeling and performance analysis of machine repairable system with hot spares", *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences*, 85 (2015) 127-135.

[113] Singh, C. J., and Jain, M., "Reliability of repairable multi-component redundant system", *International Journal of Engineering*, 13 (2000) 17-22.

[114] Singh, P. N., and Maheshwari, S., "Machine repair model with standbys, discouragement with vacationing unreliable repairmen", *International Journal of Engineering Science*, 5 (2013) 1889-1897.

[115] Sivazlian, B. D., and Wang, K. H., "Economic analysis of the M/M/R machine repair problem with warm standbys", *Microelectronics Reliability*, 29 (1989) 25-35.

[116] Sivazlian, B. D., and Wang, K. H., "System characteristics and economic analysis of the G/G/R machine repair problem with warm standbys using diffusion approximation", *Microelectronic Reliability*, 29 (1989) 829-848.

[117] Srinivasan, S. K., and Gopalan, M. N., "Probabilistic Analysis of a 2- Unit Cold Standby System with a Single Repair Facility", *IEE Transactions on Reliability*, 22 (1973) 252-254.

[118] Srinivasan, S. K., and Gopalan, M. N., "Probabilistic analysis of a two-unit system with a warm standby and a single repair facility", *Operations Research*, 21 (1973) 748-754.

[119] Srinivasan, S. K., and Subramanian, R., "Reliability analysis of a three unit warm standby

redundant system with repair", *Annals of Operations Research, Springer*, 143 (2006) 227-235.

[120] Subramanian, R., Venkatakrishnan, K. S., and Kistner, K. P., "Reliability of a repairable system with standby failure", *Operations Research*, 24 (1976) 169-176.

[121] Sztrik, J., "Asymptotic analysis of the reliability of a complex renewable standby system with fast repair", *Theory of Probability and its Applications*, 37 (1993) 101-104.

[122] Tan, Z. B., "Reliability and availability analysis of two-unit warm standby microcomputer systems with self-reset function and repair facility", *Microelectronics and Reliability*, 37 (1997) 1251-1253.

[123] Taylor, J., and Jackson, R. R. P., "An application of the birth and death process to the provision of spare machines", *Operations Research Quarterly*, 5 (1954) 95-108.

[124] Toft, J. F., and Boothroyed, H., "A queueing model for spare coal faces", *Operations Research Quarterly*, 10 (1959) 245-251.

[125] Vanderperre, E. J., "Reliability analysis of a warm standby system with general distributions", *Microelectronics and Reliability*, 30 (1990) 487-490.

[126] Vanderperre, E. J., "Reliability analysis of a renewable multiple cold standby system", *Operations Research Letters*, 32 (2004) 288-292.

[127] Vaurio, J. K., "Common cause failure probabilities in standby safety system fault tree analysis with testing-scheme and timing dependencies", *Reliability Engineering and System Safety*, 79 (2003) 43-57.

[128] Wang, K. H., "Cost analysis of the M/M/R machine repair problem with mixed standby spares", *Microelectronics Reliability*, 33 (1993) 1293-1301.

[129] Wang, K. H., "Profit analysis of the machine repair problem with cold standby and two modes of failure", *Microelectronics Reliability*, 30 (1994) 1635-1640.

[130] Wang, K. H., "Profit analysis of the M/M/R machine repair problem with spares and server breakdowns", *Journal of the Operational Research Society*, 45 (1994) 539-548.

[131] Wang, K. H., "An approach to cost analysis of the machine repair problem with two types of spares and service rates", *Microelectronics Reliability*, 35 (1995) 1433-1436.

[132] Wang, K. H., and Chang, Y. C., "Cost analysis of a finite M/M/R queueing systemwith balking, reneging and server breakdowns", *Mathematical Methods of Operations Research*, 56 (2002) 169-180.

[133] Wang, K. H., and Chiu, L. W., "Cost benefits analysis of availability systems with warm standbys units and imperfect coverage", *Applied Mathematics and Computation*, 172 (2006) 1239-1256.

[134] Wang, K. H., Dong, W. L., and Ke, J. B., "Comparison of reliability and the availability between four systems with warm standby components and standby switching failures", *Applied Mathematics and Computation*, 183 (2006) 1310-1322.

[135] Wang, K. H., Hsieh, C. H., and Liou, C. H., "Cost benefit analysis of series systems with cold standby components, a repairable service station", *Quality Technology and Quantitative Management*, 3 (2006) 77-92.

[136] Wang, K. H., Liou, C. D., and Lin, Y. H., "Comparative analysis of the machine repair Problem with imperfect coverage and service pressure condition", *Applied Mathematical Modelling*, 37 (2013) 2870-2880.

[137] Wang, K. H., Liou, Y. C., and Yang, D. Y., "Cost optimization and sensitivity analysis of the machine repair problem with variable servers and balking, Procedia - Social and BehavioralSciences 25", *International Conference on Asia Pacific Business Innovation and Technology*, (2011) 178-188.

[138] Wang, K. Ke, J. B., and Ke, J. C., "Profit Analysis of the M/M/R Machine Repair Problem with Balking, Reneging, and Standbys Switching Failures",*Computers and operations research*, 34 (2005) 835-847.

[139] Wang, K. H., Ke, J. B., and Ke, J. C., "Profit analysis of the M/M/R machine repair problem with balking, reneging and standby switching failures", *Computers and Operations Research*, 34 (2007) 835-847.

[140] Wang, K. H., and Kuo, C. C., "Cost and probabilistic analysis of series system with mixed standby components", *Applied Mathematical Modelling*, 24 (2000) 957-967.

[141] Wang, K. H., and Lee, H. C., "Cost analysis of the cold-standby M/M/R machine repair problem with multiple modes of failure", *Microelectronics Reliability*, 38 (1998) 435-441.

[142] Wang, K. H., Liou, Y. C., and Pearn, W. L., "Cost benefit analysis of series systems with warm standby components and general repair times", *Mathematical Methods of Operations Research*, 61 (2005) 329-343.

[143] Wang, K. H., Liou, Y. C., and Wang, Y. L., "Profit optimization of the multiple-vacation machine repair problem using particle swarm optimization",*International Journal of System Science*, 58 (2014) 247-258.

[144] Wang, K. H., and Pearn, W. L., "Cost benefit analysis of series systems with warm standby components", *Mathematical Methods of Operations Research*, 58 (2003) 247-258.

[145] Wang, K. H., and Sivazlian, B. D., "Cost analysis of the M/M/R machine repair problem with spares operating under variable service rates", *Microelectronics Reliability*, 32 (1992) 1171-1183.

[146] Wang, K. H., and Sivazlian, B. D., "Life cycle cost analysis for reliability and availability of series systems with warm standby components", *Research Report, Department of Industrial and Systems Engineering, University of Florida*, 1997, 97-4.

[147] Wang, K. H., and Wu, J. D., "Cost analysis of the M/M/R machine repair problem with spares and two modes of failure", *Journal of the Operational Research Society*, 46 (1995) 783-790.

[148] Wang, W. L., and Xu, G. Q., "Stability analysis of a complex standby system with constant waiting and different repairman criteria incorporating environmental failure", *Applied Mathematical Modelling*, 33 (2009) 724-743.

[149] Wang, K. H., Yen, T. C., and Fang, Y. C., "Comparison of availability between two systems with warm standby units and different imperfect coverage", *Quality Technology and Quantitative Management*, 9 (2012) 265-282.

[150] Wells, C. E., "Reliability analysis of a single warm-standby system subject to repairable and nonrepairable failures", *European Journal of Operational Research*, 235 (2014) 180-186.

[151] Chang, W. ., "Relaibility analysis of a repairable parallel system with standby involving human failure and common-cause failures", *Microelectronics Reliability*, 27 (1987) 269-271.

[152] Wu, C. H., and Ke, J. C., "Multi-server machine repair problems under a (V, R) synchronous single vacation policy", *Applied Mathematical Modelling*, 38 (2014) 2180-2189.

[153] Wu, C. H., Ke, J. C., and Choudhury, G., "Analysis of the machine repair models with multi-threshold synchronous vacations", *Journal of Testing and Evaluation*, 41 (2013) 1-8.

[154] Wu, Q., and Wu, S., "Reliability analysis of two-unit cold standby repairable systems under Poisson shocks", *Applied Mathematics and Computation*, 218 (2011) 171-182.

[155] Yearout, R. D., Reddy, P., Grosh, D. L., "Standby redundancy in reliability-a review", *IEEE Transactions on Reliability*, R-35 (1986) 285-292.

[156] Yuan, L., and Meng, X. Y., "Reliability analysis of a warm standby repairable system with priority in use", *Applied Mathematical Modelling*, 35 (2011) 4295-4303.

[157] Yuan, L., and Xu, J., "An optimal replacement policy for a repairable system based on its repairman having vacations", *Reliability Engineering and System Safety*, 96 (2011) 868-875.

[158] Yen, T. C., Wu, H., Wang, K. H. and Chou, W. K., "Optimal control of the machine repair problem with removable repairman subject to working breakdowns", *Journal of Testing and Evaluation*, 43 (2015) 1-10.

[159] Yue, D., Yue, W., and Qi, H., "Performance analysis and optimization of a machine repair problem with warm spares and two heterogeneous repairmen", *Optimization and Engineering*, 13 (2012) 545-562.

[160] Zhang, J., and Liu, Z., "Instantaneous availability of a machine repair system with warm standbys and R repairmen under N-policy vacations", *American V-King Scientific Publishing, LTD*, 2012, 11-18.

[161] Zhang, T., Xie, M., and Horigome, M., "Availability and reliability of k-out-of-(M+N): G warm standbys systems", *Reliability Engineering and System Safety*, 91 (2006) 381-387.

[162] Zhang, Y. L., "An optimal geometric process model for a cold standby repairable system", *Reliability Engineering and Systems Safety*, 63 (1999) 107-110.

[163] Zhang, Y. L., and Wang, G. J., "A deteriorating cold standby repairable system with priority in use", *European Journal of Operational Research*, 183 (2007) 278-295.

[164] Zhang, Y. L., and Wang, G. J., "An optimal repair-replacement policy for a cold standby system with use priority", *Applied Mathematical Modelling*, 35 (2011) 1222-1230.