

SURVEY ON QUEUEING MODELS WITH STANDBYS SUPPORT

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Abstract: This paper is 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 emphasizes 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 Premata [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 repairable 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 queueing 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 Sivazlian [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 renegeing. 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 queueing 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.

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