A SURVEY ON QUEUES IN MACHINING SYSTEM: PROGRESS FROM 2010 TO 2017

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Abstract: The aim of the present article is to give a historical survey of some important research works related to queues in machining system since 2010. Queues of failed machines in machine repairing problem occur due to the failure of machines at random in the manufacturing industries, where different jobs are performed on machining stations. Machines are subject to failure what may result in significant loss of production, revenue, or goodwill. In addition to the references on queues in machining system, which is also called *'Machine Repair Problem'* (MRP) or *'Machine Interference Problem'* (MIP), a meticulous list of books and survey papers is also prepared so as to provide a detailed catalog for understanding the research in queueing domain. We have classified the relevant literature according to a year of publishing, methodological, and modeling aspects. The author(s) hope that this survey paper could be of help to learners contemplating research on queueing domain.

Keywords: Machining System, Machine Repair Problem, Queues.

1. INTRODUCTION

The random failure and systematic repair of the components of machining systems have a significant impact on the outputs and the productivity of the machining systems. Hence, a proper maintenance and repair policies are required for the continuous and smooth operation of machining system without any obstruction or interruption. The effect of a random breakdown of the machine on the performance of continuous production must also be taken into account while designing the system and studying its characteristics. A machine interference problem or machine repair problem can be sampled as an example of population model of a finite source. Congestion might occur in such systems due to the scarcity of repair facility or blocking. Hence, to prevent it, a permanent repair facility along with additional repair facility should be provided for the uninterrupted functioning of the system. The worthy option of standbys support, which automatically switches in place of the identical failed machine, is also useful to maintain the continuous functioning of the system at some additional cost. For the proper working of the machining system, the components that fail are immediately removed and replaced by the components that are in the pool of standbys, but many times this switching of components might fail due to several possibilities. Therefore, the repair facility is to be adjusted such that the machines are repaired immediately and continue the operation without much-delayed interruption.

The factors that affecting the machining systems are: running time of a machine before breakdown; machine waiting time for repair until the repair of the other broken-down machines is completed, etc. In the case of multi repairmen, if the machines are broken-down, repairmen repair these broken-down machines and the excess number of machines beyond the number of repairmen wait until repairman is available. This affects the production and results into interference loss. To provide a detailed knowledge of queues in a machining system, a meticulous list of books [1-21] and survey papers [22-30] is summarized in the bibliography, which can help the beginner level researchers to explore the concepts of queueing and related fields from basics to details.

1.1. Machine repair model

Machine repairing is a typical example of finite source queueing modeling, where the machines are calling the population of prospective customers, an arrival corresponds to a machine breakdown, and the repair crews are the servers. Let us now consider a machine repair problem (finite population) consisting of M identical working machines and R repair crews. The duration of repair timing is identically exponential random variable with mean $1/\mu$ and the time that an operating machine remains in working state follows an exponential distribution with failure rate λ. Let us assume that P_n is the steady state probability that there are n failed machines in the system. The state transition diagram for Continuous-Time

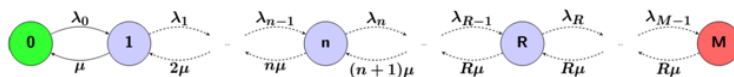Markov Chain (CTMC) involved in a machine repair model is depicted in Figure 1.

Figure 1: Machine Repair Model

The state-dependent failure and repair rates, denoted by λ_n and μ_n respectively, are given by

$$\lambda_n = \begin{cases} (M-n)\lambda, & 0 \leq n < M \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

and

$$\mu_n = \begin{cases} n\mu, & 1 \leq n < R \\ R\mu, & R \leq n \leq M \end{cases} \tag{2}$$

The steady state probability P_n is obtained for this model by solving the Chapman-Kolmogorov equations which govern the model using the transition failure and repair rates in Eq. (1) & (2). Therefore, the queue size distribution can be obtained by using product type solution as follows:

$$P_n = \begin{cases} \binom{M}{n} \rho^n P_0, & 1 \leq n < R \\ \binom{M}{n} \frac{n!}{R^{n-R} R!} \rho^n P_0, & R \leq n \leq M \end{cases} \tag{3}$$

where, $\rho = \frac{\lambda}{\mu}$, and P_0 can be determined using normalizing condition of probabilities as follows

$$P_0 = \left(1 + \sum_{n=1}^{R} \binom{M}{n} \left(\frac{\lambda}{\mu} \right)^n + \sum_{n=R+1}^{M} \binom{M}{n} \frac{n!}{R^{n-R} R!} \right)^{-1} \tag{4}$$

In order to make the system functioning smooth, the repair of the failed components has to be done efficiently and timely. Thus machine repair is a very important feature of all the machining systems. Sometimes it happens that there is overcrowding, and it takes a long to the last one to get checked up. This may lead to long queues or waiting lines and blocking in the services. However, it is quite impossible to predict correctly when and how a failed machine will arrive and

how much time it will take to get served. These decisions are often unpredicted in nature. To overcome these problems, one has to increase the service facility but at the same time, this will also lead to an increase in the service cost. On the other hand, providing less service facility would decrease the service cost but cause a long waiting line. This will cause an excessive waiting and result in loss of time of customers. In some sense, the excessive waiting is costly; it may be a social cost, loss of customer, loss of production, etc. Therefore, the main objective is to attain stability between the cost of service and the cost of waiting.

The system performance for the machining systems can be predicted using queueing theory. Most of the machining systems have stochastic elements. These measures are often random variables and are obtained using the probability distributions of queue size, busy period, and waiting time. Some important measures of performance of interest are calculated as follows:

◆ The mean number of failed machines in the system is

$$L_S = \sum_{n=0}^{M} n P_n \tag{5}$$

◆ The expected number of failed machines in the queue waiting for repair is

$$L_q = \sum_{n=R}^{M} (n - R) P_n \tag{6}$$

◆ The mean waiting time in the system is

$$W_S = \frac{L_S}{\lambda_{eff}} \tag{7}$$

where $\lambda_{eff} = \lambda (M - L_S)$

◆ The mean waiting time in the queue is

$$W_q = \frac{L_q}{\lambda_{eff}} \tag{8}$$

◆ The expected number of machines being repaired is

$$M_S = L_S - L_q = \sum_{n=0}^{R-1} n P_n + R \sum_{n=R}^{M} P_n \tag{9}$$

◆ Average server utilization is

$$U = \frac{M_S}{R} = \frac{1}{R} \left(\sum_{n=0}^{R-1} n P_n \right) + \sum_{n=R}^{M} P_n \tag{10}$$

2. SOME QUEUEING MODELS OF MACHINING SYSTEM

The machining system has got a huge importance in a wide range of everyday and industrial life with the development of the advanced and modern technology. Queueing models provide a feasible solution for improving the performance and the effectiveness of systems of machining by predicting the different parameters of the machine repair model. A queueing model is taken as a mathematical model in which a particular unit is called a customer to whom the service has to be rendered. They arrive in continuous time to get the service which is being provided by the available servers. The stochastic model of the queueing system and the detailed study of their performance measures complete the queuing theory. Machine repairing problem is a definite type of finite source queueing problem, where the population that is being called, is the machines and the arrival corresponds to a machine breakdown, and the person who repairs is the server. Some of the classical models of queueing of machine repairing under some particular conditions are being described in the sub-sections below.

2.1. Machining system with standbys

No system of machines works with full efficiency and capacity if and when the machines operating are susceptible to breakdown. This can affect the operation of the system of machines and cause a great loss of the profit of the organization that is concerned with the problem statement. The industries can avoid this loss by using a proper and organized combination of standby machines and parts. Whenever a particular machine breaks down, it is immediately replaced by a standby component that may be available in the machining system itself. As soon as the machine has been repaired, it either joins the batch of standby machines, or it goes back to the operation because of the lack of operative machines. The units of standby can be characterized broadly in three categories below:

◆ **Cold standby:**
A standby machine is referred to as cold standby if its rate of failure is zero.
◆ **Warm standby:**
A standby machine is said to be in warm standby if its rate of failure is non-zero but less than the failure rate of an operating machine.
◆ **Hot standby:**
A standby machine is said to be in hot standby if its rate of failure is the same as an operating machine.

Figure 2: State transition diagram of machining system with standbys

Figure 2 depicts the machining system with standbys consisting of M number of operating machines and S number of warm standby machines. Whenever an operating machine fails, it is quickly replaced by a standby if a standby machine is available at that instant. The failure rate denoted by λ_n, given in Eq. (1) is extended as follows

$$
\lambda_n = \begin{cases} M\lambda + S\nu, & 0 \leq n < S \\ (M + S - n)\lambda, & S \leq n < M \\ 0, & \text{otherwise} \end{cases} \tag{11}
$$

where $\nu(0 < \nu < \lambda)$ is the mean failure rate of warm standbys which follow an iid exponential distribution of inter-failure times. This can be modeled for cold standby with assumptions $\nu = 0$, and for hot standby with $\nu = \lambda$. For the mixed type standby, machining system is comprising with S_1, S_2 and S_3 standbys of type cold, warm and hot, respectively. The state dependent failure rate in Eq. (11) is changed as follows

$$
\lambda_n = \begin{cases} (M + S_3)\lambda + S_2\nu, & 0 \leq n < S_1 \\ (M + S_3)\lambda + (S_1 + S_2 - n)\nu, & S_1 \leq n < S_1 + S_2 \\ (M + S_1 + S_2 + S_3 - n)\lambda, & S_1 + S_2 \leq n < M + S_1 + S_2 + S_3 \\ 0, & \text{otherwise} \end{cases} \tag{12}
$$

The pioneer works for modeling of standby machines in machining system can be found in the contribution of the following researchers in Table 1.

Standbys	Authors
Cold Standby	Jamshidi and Esfahani [55], Liu et al. [60], Wu and Wu [131].
Warm Standby	Yen et al. [47], Huang et al. [52], Jain and Rani [79], Jain et al. [81], Wells [89], Kumar and Jain [102], Maheshwari et al. [145].
Hot Standby	Shree et al. [64].
Mixed Standby	Kuo et al. [85].
Multiple Standby	Kumar and Jain [83].

Table 1: Literature on machining system with different type of standbys

2.2. Machining system with discouragement

A lot of times, the manufacturing or the system of production having a machining system are facing situations with a lot of accumulated failed units. In such conditions, the system of machining strongly requires a well-established repair facility and some special type of caretakers. The ideal behavior of the caretaker of the failed machines for repair is that he should join the queue, wait for his turn, repair the failed component, and depart from this environment. But in real life

cases, due to various reasons, such as lack of patience, time and space, he may or may not join/continue in the queue for repair. This phenomenon is also known as discouragement. The discouragement behavior is classified mainly as

♦ **Reneging:** After spending some time in the queue, a customer may be discouraged and leave the system due to impatience or any other reasons without being served following some probability distribution. This type of queueing situation is said to be reneging.

♦ **Balking:** When a queue is so long, and a customer decides not to join the queue in a random manner and leaves the system. This type of conduct is known as Balking.

♦ **Jockeying:** Jockeying can be described as the movement of a customer from one queue to another queue in hope of receiving service more quickly.
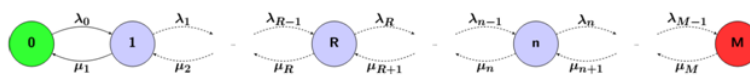

Figure 3: State transition diagram of machining system with discouragement

Considering very common and realistic behavior of customers, balking and reneging, the state dependent rate of arrival and service in Eq. (1) and (2), respectively, in machining system reduce as follows

$$\lambda_n = \begin{cases} (M-n)\,\lambda, & 0 \le n < M_1 \\ (M-n)\,\lambda\beta, & M_1 \le n < M \end{cases} \tag{13}$$

where M_1 is the threshold limit after which impatience behavior balking may start with balking probability $1 - \beta$ and

$$\mu_n = \begin{cases} n\mu, & 1 \le n < R \\ R\mu + (n-R)\,\eta, & R \le n \le M \end{cases} \tag{14}$$

with exponentially distributed time-to-wait with the reneging rate η. The major and iconic contributions in studying impatience behavior can be found in the following literature survey in Table 2.

Discouragement	Authors
Reneging	Madheswari et al. [38], Yang et al. [68], Ammar et al. [91], Jain et al. [112], Maheshwari et al. [145].
Geometric Reneging	Shekhar et al. [41], Shekhar et al. [43], Dimou and Economou [92].
Balking	Ammar et al. [91], Jain et al. [112].

Table 2: Literature on machining system with types of discouragement

2.3. Machining system with vacation

In any real time systems when there is no failed machine in the system, it is always better that the server takes a vacation to reduce the service cost. There are mainly three types of vacation defined as below:
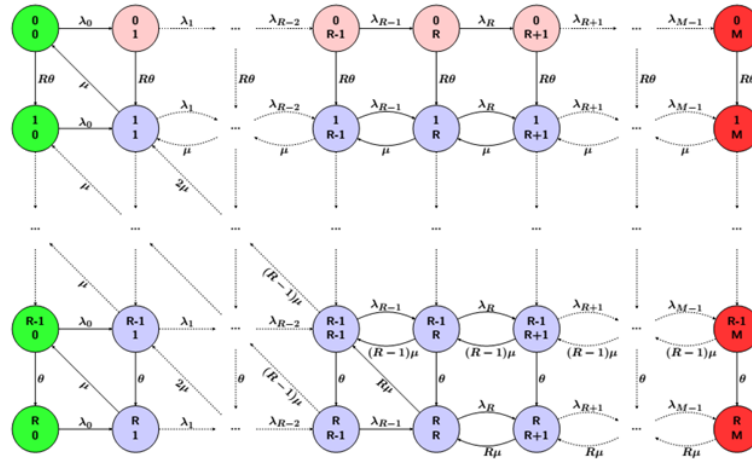

Figure 4: State transition diagram of machining system with single vacation

◆ **Single vacation:** When the server goes on vacation, it has to come back as soon as there are failed units in the system, or as soon as some threshold number of failed units is present in the queue. After coming back from the vacation, the server repairs all the failed machines present and waits for the new failed machines by waiting in the system only. Such type of vacation is known as single vacation.

◆ **Multiple vacations:** The server sometimes takes multiple vacations which mean that after returning from single vacation and completing the repair of the present failed machines if the server finds no failed machines in the queue, then, it will go for another vacation, and this process will continue till new failed machines join the queue.

◆ **Working vacation:** In many other situations, the server also works even during its vacation period, may be at a different rate. This type of vacation is known as working vacation. The working vacation will help in decreasing customers waiting time and increasing the efficiency of the system.

Time-to-being in vacation follows an exponential distribution with parameter θ. The states in quasi-birth-death (QBD) process involved in MRP with vacation is defined as a bivariate (I, J) system where I represents a number of busy servers in the system, and J denotes the number of failed machines in the system. Figures 4 and 5 represent an extension of state transition diagram of multi-server machine repair problem in Figure 1 for single and multiple vacations, respectively.
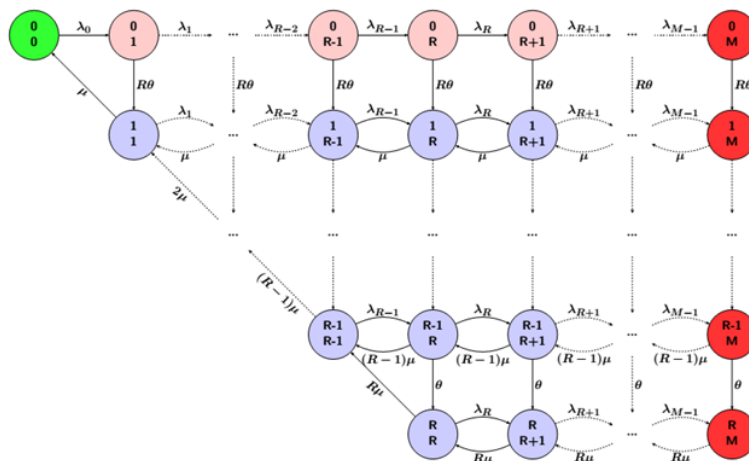
Figure 5: State transition diagram of machining system with multiple vacations

2.4. Machining system with N-policy

Yadin and Naor were the first to introduce the concept of N-policy, which can be applied to controlling the service rendered by the repairman in an optimal manner. In real life scenario, it is common that the machine fails in performing its services due to some techno-economic constraints. So, it has become evident that the repairman should be quick, prominent, economical and accurate in providing its service so that the system could function smoothly and efficiently. To achieve it, an optimal threshold policy can be implied for the functioning of the server. In some systems, the server activates at the accumulation of a threshold number of failed units (say N) in the system and stops working when there is no more failed unit waiting in the queue. This is called the N-policy.
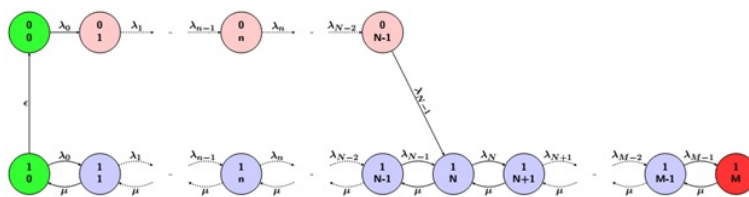
Figure 6: State transition diagram of N-policy

Figure 6 depicts state transition of the bivariate (I, J) quasi-birth-death process, where I represents the status of the server ($I = 0$ represent accumulation or vacation state and $I = 1$ defines busy state), and J denotes the number of failed machines in the system. We now present the Markovian model for machining system under N-policy. The repairman turns on whenever N or more failed units are

accumulated in the system and turns off as soon as the system becomes empty. After accumulation of N failed units, the repairman may take random setup time before starting the repair of the first failed unit. The repairman goes to vacation with a rate ϵ as soon as all failed units are repaired. Hence, the state dependent service rate of the server in Eq. (2), which is extended on the status of the server, is given by

$$\mu_n = \begin{cases} 0, & \text{server is in vacation} \\ \mu, & \text{server is busy} \end{cases} \tag{15}$$

The extensive research on vacation and its kind have been done in past due to the advances in socio-economic issues involved in machining system. In Table 3, some keynote works of pioneer researchers, mathematicians, etc, are tabulated to enrich the present literature.

Vacation	Authors
Working Vacation	Jain et al. [34], Luo et al. [37], Gao and Wang [50], Lee and Kim [58], Liu [60], Yang and Wu [67], Gao and Yao [71], Gao et al. [72], Gao et al. [73], Jain and Preeti [77], Gao and Liu [95], Gao and Wang [96], Gao and Yin [97], Gao et al. [98], Liu and Song [114], Jain and Upadhyaya [119], Jain et al. [121], Goswami and Selvaraju [136].
Optional Vacation	Yang et al. [46], Arivudainambi and Godhandaraman [107].
Modified Vacation	Haridass and Arumuganathan [51].
Bernoulli Vacation	Jain et al. [54], Rajadurai et al. [63], Singh et al. [65], Shrivastava and Mishra [88], Tao et al. [104], Choudhury and Deka [108], Jain et al. [111].
Multiple Vacation	Gao and Wang [49], Liou [59], Maurya [86], Yu et al. [106], Ke and Wu [113], Samanta and Zhang [116], Yuan [117], Maheshwari et al. [145].
Repairman Vacation	Zhang and Guo [69].
Single Vacation	Wu and Ke [90], Mary et al. [127], Yang et al. [155].
Server Vacation	Jain and Meena [33], Thangaraj and Vanitha [151].
N-policy	Jain et al. [35], Shekhar et al. [42], Haridass and Arumuganathan [51], Yang and Wu [67], Jain et al. [80], Kumar and Jain [102], Yang and Wang [105], Jain et al. [110], Jain et al. [112], Kuo et al. [124], Wang et al. [130], Sharma [149].

Table 3: Literature on machining system with different types of vacation

2.5. Machining system with F-policy

In order to avoid the congestion situation at the service center where machines are sent for repair and to make it economically viable, the provision of controlling the arrival of failed machines is made under F-policy. According to this policy, after the accumulation of $K (< M)$ failed machine in the queue, no more customers

with failed machine will be allowed to enter the queue until there are only F failed machines remain in the system to be repaired. In this way, it helps in reducing the congestion on the server at a service station. The state dependent controllable arrival rate, given in Eq. (1), is changed as follows

$$\lambda_n = \begin{cases} (M - n)\,\lambda, & 0 \leq n < K, \quad \text{customers are allowed} \\ 0, & \text{customers are not allowed} \end{cases} \tag{16}$$

The bivariate quasi-birth-death process is defined as (I, J) I representing the status of the customer whether allowed or not allowed to enter in the system ($I = 0$ represents not allowed and $I = 1$ defines the state when customers are allowed to enter in the system) and J denotes the number of failed machines in the system.
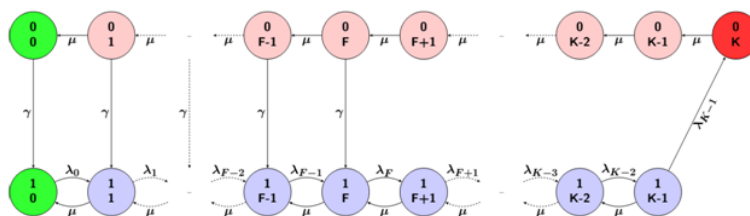

Figure 7: State transition diagram of F-policy

The state transition diagram for MRP with F-policy is drawn in Figure 7. The literature survey on F-policy is summarized in Table 4.

F-policy	Shekhar et al. [42], Jain and Bhagat [53], Chang et al. [70], Kumar and Jain [102], Yang and Wang [105], Jain et al. [110], Kuo et al. [124].

Table 4: Literature on machining system with F-policy

3. FAILURE ISSUES

In practice, different types of failures can significantly decrease the system reliability. Failure issues are important to the step when analyzing the system reliability and ensuring good performance. The failure of the machining systems may result in poor and hindered performance, loss of time and money, etc. Thus the study of the failures is very important to have reliable and efficient machining systems. One of the major things to keep in mind while doing reliability analysis, involved with redundant systems, is the requirement of additional hardware to combine the individual components into a well-functioning redundant configuration at an additional cost. Even when the components can be directly coupled

without extra hardware, failure modes of one component (major leakage, short-circuit) could represent a load, even big enough, for the redundant components to handle, thus leading to system failure. Both the extra hardware and overload failures represent failure possibilities that can be accounted for by a virtual series component. Some of the common types of failures seen in the machining systems are the common-cause failures, switching failure, degraded failure, and multi modes failure, etc. It is worthwhile to discuss such concepts as these are included in many models.

3.1. Switching failure

In order to maintain the reliability and efficiency in many redundant machining systems with standbys, a standby machine automatically becomes operational as soon as any failure of operating machines occurs. But this is possible only if the standby units switch over to the main system successfully and efficiently. If the standby units fail in their switching process, then the system may not be able to replace the failed units. While installing the standbys in any machining system, it has to be ensured that the standby units have switched over to the main system in place of failed units successfully for the uninterrupted functioning of the system. But due to some reasons like poor automation and mishandling, sometimes it has been noticed that the switching fails with a probability q, which is called the switching failure of the standbys. This process continues for all available standby until successful switching or exhaust of all available standbys in the pool.
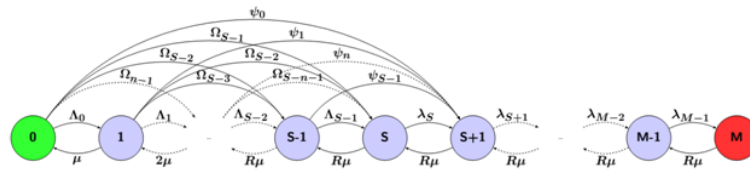

Figure 8: State transition diagram of switching failure

The state transition diagram in Figure 2 for warm standby is changed in the following structure as in the Figure 8 where

$$
\begin{aligned}
\Omega_n &= M\lambda\bar{q}q^n \\
\psi_n &= M\lambda q^{S-n} \\
\Lambda_n &= M\lambda\bar{q} + (S-n)\nu
\end{aligned}
\qquad , \tag{17}
$$

3.2. Degraded failure

In some environments, components might not always fail fully, but can degrade with time, overload and usage. All systems are subject to degradation and more

likely prone to frequent failure. This degradation can result in high production costs and inferior product quality. So, to maintain low product costs and pre-specified quality of the product, the provision of repair facility and maintenance policy are recommended, which also ensures the smooth and long run functioning of the system. Degraded failure is also an important factor to be considered while designing the system as it affects its reliability and performance. The state dependent failure rates λ_n in Eq. (11) are given, as follows, in terms of independent and identically distributed exponential distributed time to failure with parameter λ_d

$$\lambda_n = \begin{cases} M\lambda + S\nu, & 0 \leq n < S \\ (M + S - n)\,\lambda_d, & S \leq n < M \\ 0, & \text{otherwise} \end{cases} \tag{18}$$

3.3. Common cause failure

In some cases, the system fails due to the simultaneous failure of one or more machines due to common factors. These types of failures which occur because of some common reasons are called the common cause failures, and they result in heavy economic loss. Common cause failures may arise due to the failure of common power supply, environmental conditions (e.g., earthquake, flood, humidity, etc.), common maintenance problems, etc. Such types of failures are rarely encountered in almost any machining systems including manufacturing systems, transportation system, communication networks, etc, but cause heavy losses. The state transition diagram for machine repair model in which each unit may fail individually with a failure rate λ, as well as due to common cause with failure rate λ_c , is shown in Figure 9.
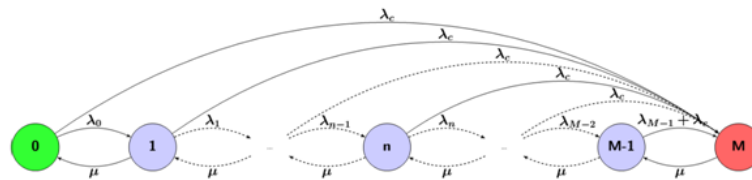

Figure 9: Machining system with common cause failure

The major work done on switching failure, degraded failure, and common cause failure is compiled in Table 5. Researchers had discussed important failure issues related to the performance of machining system under regime to various repair and maintenance policies in their pioneer works.

Failures	Authors
Switching Failure	Kuo and Ke [36], Shekhar et al. [43], Hsu et al. [75], Jain and Preeti [78], Jain and Rani [79], Jain et al. [81], Jain et al. [100], Jain et al. [112], Ke et al. [122], Jain et al. [139].
Common Cause Failure	Mechri et al. [61], Jain and Gupta [76], Dimou and Economou [92], Jain [99], Jain et al. [100], Jain and Gupta [109], Jain et al. [139], Maheshwari et al. [146].
Degraded Failure	El-Damcese and Sharma [94].

Table 5: Literature on machining system with different type of failures

4. CLASSICAL QUEUEING MODELS IN MACHINING SYSTEM

Queueing models provide a powerful tool for designing and evaluating the performance of machining systems. In Table 6, we have summarized some important and classical queueing models used for investigating the queues in machining system with some standard Kendall notations like Markovian queues, non-Markovian queues, Erlangian queues, bulk queues, general queues etc.

Models	Authors
$M/M/1$	Sharma and Kumar [87], Ammar et al. [91], Jain et al. [120], Ayyappan et al. [134], Kim and Kim [57].
$M/M/c$	Gomez-Corral and Garcia [74].
$M/E_K/1$	Yu et al. [133].
$M/G/1$	Lee and Kim [58], Gao et al. [73], Gao and Liu [95], Dimitriou and Langaris [135], Ramanath and Kalidass [147], Thangaraj and Vanitha [150], Thangaraj and Vanitha [151], Wang et al. [153].
$M^{[X]}/G/1$	Rajadurai et al. [63], Singh et al. [65], Gao and Yao [71], Choudhury and Deka [108], Wang and Li [152].
$M/PH/1$	Kim and Kim [101].
$M/G/1/K$	Kuo et al. [124].
$M^X/H_2/1$	Sharma [149].
$MAP/PH/1$	Goswami and Selvaraju [136].
$M^X/(G_1, G_2)/1$	Arivudainambi and Godhandaraman [107], Mary et al. [127].
$M(t)/M/c/c$	Tirdad et al. [44].
$PH/PH/1/K$	Hanbali [118].
$G/M/1$	Mohit et al. [39].
$Geo/Geo/1$	Lin et al. [143], Gao and Wang [49].
$Geo_1, Geo_2^X/G_1, G_2/1$	Liu and Gao [126].
$Geo^X/G/1/N$	Luo et al. [37].
$Geo^X/G/1$	Gao and Wang [96], Gao and Yin [97].
$GI/D-MSP/1$	Samanta and Zhang [116].
$GI/Geo/1$	Tao et al. [104].
$GI^X/Geo/1/N$	Gao et al. [98], Gao et al. [72].
$GI^X/Geo/1/N\text{-}G$	Gao and Wang [50].
$K\text{-out-of-}N:G$	Grover [32], Kumar and Bajaj [82], Kumar and Bajaj [84], Jain and Gupta [109], Yuan [117], Ruiz-Castro and Li [128].
$D\text{-}BMAP/PH/1/N$	Lenin et al. [142].

Table 6: Literature on machining system using different models

5. METHODOLOGY USED FOR QUEUES IN MACHINING SYSTEM

In many overcrowding situations, it is hard to analyze the performance analysis of the queueing system. Therefore, a wide range of numerical techniques and

approximation are used for providing the solution of queueing problems in term of queue size distribution analytically or numerically. In Table 7, we have summarized some important classical techniques used by prominent researchers for investigating the queues in machining system. These techniques are useful to determine the steady state or transient state queue size distribution and state probabilities. Some given techniques are important for determining optimal threshold or rate in minimizing the total designing cost and performing sensitivity analysis with respect to governing parameters.

Techniques	Authors
Matrix Method/ Matrix Geometric Method	Jain et al. [34], Yen et al. [47], Liou [59], Liu et al. [60], Phung-Duc [62], Vijaya and Soujanya [66], Yang and Wu [67], Gomez-Corral and Garcia [74], Jain and Preeti [77], Jain and Rani [79], Jain et al. [80], Kuo et al. [85], Sharma and Kumar [87], Shrivastava and Mishra [88], Wells [89], Wu and Ke [90], Do et al. [93], Gao and Liu [95], Jain et al. [100], Singh and Maheshwari [103], Tao et al. [104], Yu et al. [106], Jain et al. [110], Ke and Wu [113], Liu and Song [114], Samanta and Zhang [116], Hanbali [118], Ke et al. [123], Lin and Ke [125], Ruiz-Castro and Li [128], Yang et al. [132], Yu et al. [133], Ayyappan et al. [134], Goswami and Selvaraju [136], Lenin et al. [142], Lv et al. [144], Maheshwari et al. [145], Sharma and Sirohi [148], Wu and Ke [154].
Recursive Method	Jain et al. [35], Shekhar et al. [42], Shree et al. [64], Kumar and Jain [102], Yang and Wang [105], Kuo et al. [124], Ke and Lin [140], Ke et al. [141].
Supplementary Variable Method	Kuo and Ke [36], Luo et al. [37], Yang et al. [46], Gao [48], Gao and Wang [50], Haridass and Arumuganathan [51], Jain et al. [54], Rajadurai et al. [63], Singh et al. [65], Yang et al. [68], Gao and Yao [71], Gao et al. [72], Gao et al. [73], Gao and Liu [95], Gao and Wang [96], Gao and Yin [97], Gao et al. [98], Jain [99], Arivudainambi and Godhandaraman [107], Choudhury and Deka [108], Jain et al. [111], Kuo et al. [124], Liu and Gao [126], Mary et al. [127], Singh et al. [129], Wu and Wu [131], Hu et al. [138], Dimitriou and Langaris [135], Ke and Lin [140], Wang and Li [152].
Generating Function	Madheswari et al. [38], Upadhyaya [45], Jain et al. [54], Ammar et al. [91], Dimou and Economou [92], Nourelfath et al. [115], Jain et al. [120], Jain et al. [121], Ramanath and Kalidass [147], Sharma [149], Thangaraj and Vanitha [150], Thangaraj and Vanitha [151], Wang and Li [152].
Runge−Kutta Method	Jain and Meena [33], Rawat et al. [40], Shekhar et al. [41], Shekhar et al. [43], Tirdad et al. [44], Jain and Bhagat [53], Hsu et al. [75], Jain and Gupta [76], Jain and Preeti [78], Jain et al. [81], Kumar and Jain [83], Yuan [117], Jain and Upadhyaya [119], Maheshwari et al. [146].
Quasi-Newton Method	Ke et al. [56], Chang et al. [70], Ke et al. [123], Lin and Ke [125], Lin et al. [143], Wu and Ke [154], Yang et al. [155].
C_0-semigroup Theory	Guo et al. [137].

Table 7: Literature on machining system using different techniques

6. CONCLUSIONS

In this survey article, we have reviewed the literature in the field of queues in machining system since 2010 with a wide range of classical texts and surveys. The queues in machining system have found wide applications in the analysis and modeling of manufacturing and industrial systems, where different jobs are performed on machining stations. The main aim of the present work is to suggest a unified structure for analyzing the machine repair models via queue-theoretic approach. The machine repair models with the combination of different concepts have been cited. Queueing models in machining system with different repair or maintenance policies are helpful for resolving the problem of blocking and delay in the manufacturing industrial systems. Author(s) hope that present survey article will be of immense help to learners who are eyeing on research in queueing modeling with a specialized focus on machine repair problem. In future, this survey can be extended for some specific issues, more standard and classical queues, different maintenance policies, solution and optimization techniques etc.

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