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RECENT DEVELOPMENTS IN QUEUEING MODELS UNDER N-POLICY: A SHORT SURVEY

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ABSTRACT

Queueing system under N-Policy has been studied extensively since the late 1963's. A considerable number of works in this area were completed in the early 90's. As an extension for the classical queueing system, the N-policy (ie., a server is turned on when the number of customers in the queue size reaches a certain number N and turned him off when the system is empty) makes the model more applicable in a variety of system including optimal management policy, computer processing, manufacturing and transportation system. Motivated by these applications more studies on queueing models under N-Policy have been done during the late 90's and 2000's. This paper intends to provide a brief summary of the most recent research works on queueing models under N-Policy in the past 15 years.

Keywords: *N-policy, server's vacations, working vacations, server startup, server breakdowns, Maximum Entropy approach.*

AMS Subject Classification code: *60K25.*

1. INTRODUCTION

The queueing models under N-Policy has been studied in the past three decades and successfully applied in many areas such as computer network administration, telecommunication system, inventory control process, production process etc., This policy is very useful to control the expected total cost of the system. Excellent surveys on the earlier works of these models have been reported by Baker [5], Medhi and Templeton [40]. In this paper we briefly survey the studies on optimal control model for the past decades. We only focus on reporting the types of models used in this studies conducted over the past 15 years. For technical detail of these models, again we refer the readers to the specific papers. This paper is organized as follows: Section (2) reviews the models dealing with server's start up and breakdown under N-policy. Section (3) presents the recent models with more complex arrival process under N-policy. Section (4) is focused on variants of vacation models under N-policy. Section (5) reviews the models dealing with interdependent loss and delay under N-policy. Section (6) presents the Discrete time Queueing models under N-policy. Section (7) reviews Maximum entropy approach under N-policy. Finally section (8) concludes with some possible future research direction.

2. QUEUEING MODELS DEALING WITH SERVER'S STARTUP AND BREAKDOWN UNDER N-POLICY

The concept of N-policy was first introduced by Yadin and Naor [70]. It means that the server does not start to provide service until there are N units waiting in the system. Past work regarding queueing system under N-policy may be divided into two categories. i) the case of server startup ii) the case of server breakdown. In the case of server startup Baker [5] first proposed the N-policy M/M/1 queueing system with the exponential startup. Borthakur [8] extended Baker's result to the general startup. Wang [62] analyzed Optimal control of a removable and non reliable server in an M/M/1 queueing system with exponential startup time. This paper differs from previous works in that it studies the N-policy M/M/1 queueing system with non reliable server plus exponential startup time and it generalizes the N-policy M/M/1 queueing system with reliable server, non reliable server or reliable server plus exponential startup. A cost model is developed to determine the optimal operating policy at minimum cost. M/G/1 queuing system with startup time was first studied by Minh [41] and was investigated by several other researchers. Hur and Paik [20] examined the operating characteristics of M/G/1 queueing system under N-policy with server startup and explained how the systems optimal policy and cost parameters behave for various arrival rate. Tagaki [51] have analyzed M/G/1/k queue

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with N-Policy and setup times. Krishna Reddy *et al.* [34] have analyzed a bulk arrival queueing model and multiple vacations with setup time.

The performance of any machinery system is highly influenced by server breakdowns which may also affect the system reliability indices. This problem may be realized in the area of computer, communication, transportation system etc. Production system may also not operate during the period of breakdowns and may lead to a loss of production. Many researchers have studied the problem of unreliable server in different frameworks and suggested ways to tackle such situations. In order to have maximum profit with maximum possible efficiency of any system, the reliability of the system has to be increased.

According to N-policy system, the server is turned on when there are N or more failed units in the system and turned off when there are no failed units present in the system. For cases with server breakdowns, Wang [63] first proposed a management policy for Markovian queueing systems under the N policy with server breakdowns. Wang [65] and Wang *et al.* [67, 66] extended the model proposed by Wang [63] to $M/E_K/1$, $M/H_2/1$ and $M/H_k/1$ queueing systems, respectively. They developed the analytic closed form solutions and provided a sensitivity analysis. Jayachitra and James Albert [23] analyzed $M/E_k/1$ queueing model with server breakdowns and multiple vacations under N-policy. This paper provides a minimum expected cost for production system.

3. QUEUEING MODELS WITH VARIANTS OF ARRIVAL PROCESS UNDER N-POLICY

Queueing models with server breakdowns and vacations accommodate the real-world situations more closely. There are many applications in which the arrival rate of the input units depending on the arrival time, system's state or server's status. Therefore, it would be practical to consider the management policy for M/M/1 queueing service system with heterogeneous arrivals under the N policy, in which the server is characterized by breakdowns and vacations. A practical problem related to a manufacturing system is presented for illustrative purpose. We consider an assembly line where a worker may have some idle time between subsequent jobs. To utilize the time effectively, managers can assign secondary jobs to the worker. However it is important that the worker must return to do his primary jobs when he completes the secondary jobs and finds that the primary jobs have been accumulated to N or more units in the system.

Extensive studies were conducted on the vacation models with batch arrival under N-policy. Batch arrival queues with N policy was first studied by Lee and Srinivasan [37]. Later Lee [38] concentrated on the interpretation of the system characteristics of the $M^{[x]}/G/1$ queueing system with server startup and two vacation types. Lea and Chae [39] analyzed a batch arrival queue with N-policy and single vacation and also they obtained the analytical closed form solutions. Wang [65] analyzed Optimal control of an $M^{[x]}/Ek/1$ queueing system with a removable service station subject to servers breakdown. Wang *et al.* [64] also analyzed an M/Ek/1 queueing system with a removable service station under N-policy.

Ke and Wang [30] analyzed the heterogeneous batch arrival queue with server startup and breakdowns under N-policy. This paper provides a minimum expected cost and optimal operating policy for production system. Choudhary and Paul [15, 12] analyzed a batch arrival queue with an additional service channel under N-policy and a batch arrival queue with a second optional service under N-policy respectively. Arumuganathan and Jayakumar [2] presented the steady state analysis of $M^{[x]}/G$ (a, b)/1 queueing system with multiple vacations, closedown times and setup time with N-policy. Haridas and Aramuganathan[19] presented the optimal characteristic of an $M^{[x]}/G/1$ queueing system with unreliable server and single vacation. Ananthalakshmi and Afthab Begum [1] analyzed an optimal strategy analysis of an N-policy $M^{[x]}/M/1$ queueing system with a removable and non reliable server. Ke and Pearn[29] have analyzed an optimum management policy for heterogeneous arrival queueing system with server breakdowns and vacations. Also they provided sensitivity analysis.

3.1. Two phase queueing model under N-policy

Queueing models with two phase of service in many areas such as computer network administration and telecommunication systems where the messages are processed in two phase by a single server. In inventory control processes, due date, quantity and quality are analyzed initially in batch mode followed by individual service of the batch. The case of manufacturing bulk drugs in pharmaceutical industry is another classical example where the production cannot start until the ordered quantity reaches specific requirement. Once the specific requirement condition is met, the drug manufactured in the first phase and then it is tested to the specification in the second phase well before it is released to the customer.

Serveral attempts have been made by many investigators to provide a valid and meaningful solution so as to estimate the optimal control policy. Krishna and Lee [35], Dhoshi[16] studied distributed system where all customers arrive batch service in first phase followed by an individual service in second phase. Selvam and Sivasankaran[45] introduced two phase queueing system with server vacation. Kim and Chae[32] analyzed the two phase queueing system with N-policy. Choudhury, *et.al* [13] analyzed the N-policy for an unreliable server with delaying repair and two phase of service. Choudhary and Tadj analyzed an M/G/1 queue with two phases of service subject to the server breakdown and delayed repair. Vasantha Kumar and Chandan [57, 58] studied Cost analysis of a Two-Phase M/M/1 queueing system with N-policy and Gating and Two-Phase $M^{[X]}/E_K/1$ Queueing System with N-policy respectively. Vasantha Kumar and Chandan [55, 56, 54] also presented the optimal strategy analysis of two phase M/Ek/1 queueing system with server breakdowns and gating, optimal control policy of two phase $M^{[x]}/E_k/1$ queueing system with N-policy and the optimal strategy analysis of two phase $M/E_k/1$ queueing system with N-policy server startup and breakdown respectively. Also they obtained the total expected cost function for the system and determine the optimal value of the control parameter N. Vasasntha kumar and Srinivasa Rao[59] presented Optimal control of an N-policy two phase $M^x/M/1$ Queueing system with server start up subject to breakdowns and delayed repair. This paper investigates the economic behavior of the system. There may be delay in repair due to non availability of the repairing facility. The mean queue length waiting time by heuristic interpretation of the reliability indices of this model are also derived. The total expected cost function per unit time is developed to determine the optimal threshold of N at a minimum cost.

4. VARIANTS OF VACATION MODELS UNDER N-POLICY

Chae and Lee [9] have analyzed $M^x/G/1$ vacation models with N-Policy and determine the waiting time. Ke [24] studied the control policy of an $M^X/G/I$ queueing system with server startup and two vacation types. Also Ke [25] presented Optimal strategy policy in batch arrival queue with server breakdowns and multiple vacations. Choudhary and Madan [11] further investigated the system with a modified Bernoulli vacation and N-policy. Tedj *et al* [50] studied a bulk service queueing system with random setup time under the Bernoulli vacation policy and N-policy. They developed an algorithm to determine the optimal policy.

In (d, N) policy, service resources can be better allotted to both primary and secondary users to improve the operational economy of a multi server queueing system. Furthermore allowing servers to take vacations in this fashion makes the multi server queueing model more realistic in characterizing the dynamical behavior of many real stochastic service system. Fast food restaurant, supermarket, bank tellers and telephone service operators are usually multi task employers. Some of them (not all) might not perform other secondary jobs when they are not busy and come to serve waiting customers again when the queue becomes long again. Tian and Zhang[53] considered a multi server queueing system with a threshold type (d, N) vacation policy under which d idle servers keep taking multiple synchronous vacation until the number of customers reaches or exceeds a threshold N. Xu and Zhang [69] investigated the two threshold policy in a multi server vacation model. Ke *et. al.* [28] studied the optimal threshold policies in a finite buffer multi server vacation model with unreliable servers. Ke *et.al* [31] present a multi server queue with multi threshold vacation policy and server breakdowns. This model is not only applicable to a practical production and inventory system but also generalizes the multi server vacation model with threshold policies. In this paper a cost model is constructed to determine the optimal vacation policy and the optimal service rate of each server.

Queueing systems in which arriving customers who find all servers and waiting positions (if any) occupied may retry for service after a period of time are called Retrial queues. Ayyappan *et.al.* [3] analyzed M/M/1 Retrial Queueing System with N-Policy Multiple Vacation under Non-Preemtive Priority Service by Matrix Geometric Method. Numerical studies have been done for analysis of mean number of low priority customers in the orbit, mean number of high priority customers in the queue, probability of server free and probabilities of server busy with low, high priority customers and server in vacation for various values.

4.1. Working vacation under N-policy

The vacation queueing models have been investigated extensively in view of their application in computer system, communication networker, production managing. In a classical vacation queue, the server completely stops serving customers and may do some additional work or maintain server during a vacation. Various vacation policies provide more flexibility for optimal design and operating control of the system. Servi and Finn [46] introduced a class of semi vacation policies, the server works at a lower rate rather than completely stopping service during a vacation. Such a vacation is called a working vacation. Zhong-jum Zhang and Xiu-Li Xu [72] have analyzed M/M/1 queue with multiple Working vacation under N-policy. This policy has practical application background in managing science. When the number of customers in the system is relatively few, the system is in a lower speed operating state in order to economize operating cost and energy consumption. Meanwhile to avoid switching frequently from a speed we set a threshold N to decrease the switching cost. Stationary queue lengths have been derived using quasi birth and death process and matrix geometric solution method. It is a generalization of M/M/1 queue with multiple working vacation of Servi and Finn [46]. Vijaya lakshmi and Suchitra [60] analyzed state dependent N-policy queue with working vacation. A finite buffer renewal input N-policy queue with state dependent services and working vacations have been investigated. The amount of service demanded by a customer is conditioned by the queue length at the moment service is begun for that customer. It provides a recursive algorithm using the supplementary variable technique to compute the stationary queue length distribution of the system. Vijaya Lakshmi *et.al.* [61] analyzed Optimization of balking reneging queue with vacation interruption under N-policy. This paper analyzes a finite buffer multiple working vacations queue with balking, reneging, and vacation interruption under N–policy. Using Markov process and recursive technique, it is derived the stationary system length distributions at arbitrary epoch. Various performance measures and some special models of the system are presented. Cost analysis is carried out using particle swarm optimization and quadratic fit search method.

5. QUEUEING MODELS WITH INTERDEPENDENT LOSS AND DELAY UNDER N-POLICY

A queueing model in which arrivals and services are correlated, is known as interdependent queueing model. Borst and Combe [7] analyzed the busy period of a correlated queue with exponential demand and service. Gray *et al.* have studied an M/G/1 type queueing model with service times depending on queue length. The M/M/1 interdependent queueing model with controllable arrival rates were studied by Rao *et al.* [49]. They observed that the mean dependence rate between the arrival and service processes can reduce the congestion in queues and delays in transmission. Begum and Maheswari [4] developed the M/M/c interdependent queueing model with controllable arrival rates, which was the extended work of Rao *et al.* [49]. The M/M(a, b)/C interdependent queueing model with controllable arrival rates were discussed by Sitrarasu *et al.* [47]. Estimation comparison on busy period for a controllable M/G/1 system with bicriterion policy was analyzed by Ke *et al*. [26]. Yang *et al.* [71] developed optimization and sensitivity analysis of controlling arrivals in the queueing system with single working vacation. The loss and delay phenomena of the customers in the system is likely to bring about the understanding, that either the customers may like to wait in the queue to get service or may be lost when all the servers are busy. Jain *et al.* [21] developed loss and delay queueing model for time-shared system with additional service positions and no passing. Performance indices of Markovian loss and delay queueing model with no passing and removable additional servers was studied by Jain and Singh [22]. User optimal state dependent routing in parallel tandom queues with loss was made by Spicer and Ziedins [48]. Fan [18] developed a queueing model for mixed loss-delay systems with general inter arrival processes for wide-band calls. Kim *et al.* [33] considered Erlang loss queueing system with batch arrivals operating in a random environment. Pankaj Sharma [44] analyzed Single Unreliable Server Interdependent Loss and Delay Queueing Model with Controllable Arrival Rate under N-Policy. Queue size distribution, the expected number of customers in the system and optimal N-policy are established by using the generating function method. The expected queue length can be reduced by increasing the service rate up to a certain level. The optimal control policy for the queue length by selecting suitable parameters examined by sensitivity analysis, may be helpful to decision makers in designing appropriate service facility while reducing loss and delay of customers.

6. DISCRETE TIME QUEUEING MODELS UNDER N-POLICY

The study of discrete time queueing system has become very important over the last few years with the advent of new technologies. The reason for this is that the discrete time systems are more appropriate than their continuous time counterparts to model computer and telecommunication systems. Takagi [52] derived the queue size and waiting time under the N-policy Geo/G/1 queue with batch arrival. Böhm and Mohanty [6] investigated N-policy for the Geo/Geo/1 queue involving batch arrival and batch service, respectively. Moreno [42] extended a modified N-policy issue, where the first customers of each consecutive service period are served together and the rest of customers are served singly. She gave detailed derivations of system characteristics for a discrete time Geo/G/1 queue and developed a cost function to search the optimal operating policy at a minimum cost. Lee and Yang [36] analyzed the N-policy of a discrete time Geo/G/1 queue with disaster and its application to wireless sensor networks. Furthermore, Moreno [43] analyzed a discrete time single server queue with a generalized N-policy and setup-closedown times. In [43], the author derived the formulae for various system performance measures, such as queue and system lengths, the expected length of the vacation, set up, busy and closedown periods, and performed a numerical investigation on the expected cost function. Wang [68] analyzed a random N-policy Geo/G/1 queue with startup and closedown times. N is newly determined every time a new cycle begins. Using the generating function and supplementary variable technique, analytic solutions of system size, lengths of state periods, and sojourn time are derived.

In the real situation, the server with startup and closedown times are a natural abstraction and the number N may vary depending on different instances of the operation of the system. For example, Streaming technique is used for compression of the audio/video files so they can be retrieved and played by remote viewers in a real time. When a user wants to play video file and activates the streaming player, the streaming player will be downloaded and stored the uncertain size of data (random N, N is newly determined every time for a new cycle beginning, depending the network bandwidth) in the buffer in advance before playing the data. The user can watch the video file before the entire video file has been downloaded. However, when the streaming player is activated for playing the video, it needs a short time to start up. It also needs a shutdown time to be closed as all received data has been played.

7. MAXIMUM ENTROPY APPROACH UNDER N-POLICY

In some cases, the classical approaches of queueing theory fail to give exact result for the queue size distribution of the congestion models in different frameworks. In some cases, the classical approaches of queueing theory fail to give exact result for the queue size distribution of the congestion models. Charan jeet Singh and Madhu jain [10] analyzed Single server queueing model with N-policy and removable server. In this paper a threshold policy has been investigated to obtain probability distribution by using maximum entropy principle. Ke and Lin [27] analyzed Maximum entropy approach for batch arrival queue under N-policy with unreliable server and single vacation. The maximum entropy principle is used to approximate the $M^{[x]}/G/1$ queueing system under N policy with an un-reliable server and single vacation. This becomes particularly useful when some system characteristics (for instance, the expected number of customers in the system, the probability that the server is busy, etc.) are known. In this article we apply the maximum entropy principles associated with basic known results to study the system characteristics of the $M^{[x]}/G/1$ queueing system under N policy with an un-reliable server and single vacation.

8. CONCLUSION

Although extensive works have been done in the area over the past three decades as surveyed in Baker [5], Yadin and Naor [70], Doshi[17] and some survey papers including this paper, there are still many open peoblem for further studies. Here we mention a few directions for future research. Most part works were focused on single server queueing system under N-policy. Multi server Queueing system with working vacation under N-policy and M/Ek/1 Queueing system with working vacation under N-policy have not been investigated. Working vacation queue is the generalization of the classical vacation queue and the analysis of this kind of model is more complicated than the previous work. It is hard to get the stochastic decomposition structure of the stationary indices in this model because the distribution expression of stationary queue length is very complicated and difficult to handle. This is the reason for past researchers not to study these topics. Developing good approximations to these working vacation models under N-policy will be a fruitful future research direction. Another direction is to analyze the working vacation models with more complex vacation policies motivated by a real system.

Queueing models with N-policy consider the most common issue of controlling arrivals and reducing the set up costs. The closed-form results in case of impatient customers with working vacations, vacation interruptions under N-policy multi server are still not available. Analysis of this kind of models will be a future research direction. This survey reviews the work done in the area of queueing models under N-policy. The ideas discussed in various papers have been synthesized. It can help statisticians, researchers, engineers and managers for using these models. A wide range of literature has been covered and proper references have been cited.

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