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A Survey on Occurrence of Critical Machines in a Manufacturing Environment

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Abstract

The modern manufacturing environment is generally expressed in terms of flowshop, where all the machines are considered equally, despite the availability of critical machines. Here, a survey was made on the manufacturing environment to identify the critical machines in it. The critical machine is identified based on processing time, operation, maintenance requirement, automation, life, breakdown, buffer or delay time, rental cost, and so on. Mostly, the scheduling was done to reduce the makespan and total completion time. These objectives are indirectly achieved by effective utilization of critical machine. The need to develop heuristics becomes vital to achieve these objectives. Though many heuristics are successful, it does not concentrate on critical machine but the role of critical machines in a flowshop becomes essential. This Study was done to analyze the maximum possibilities and effective utilization of critical machines in a flowshop. Many researchers focused on the critical machines at its first stage, but very few reports are available on its second stage and further stages. The tedious task with the critical machines can be made easier by new solution methods. This article focused on the possibility of critical machine, position of critical machine and the need of a hybrid flowshop in the modern manufacturing environment for the effective management of the critical machines.

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Keywords: Critical machine; scheduling; flowshop; hybrid flowshop; heuristic

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1. Introduction

The present Manufacturing environment involves multi-tasks to produce a quality product [1]. Here, scheduling is the vital task, which involves organizing, choosing, and timely resource to carry out all the activities necessary to produce the desired output at the desired time, while satisfying a large number of time and relationship constraints among the activities and the resources [2]. The sequencing is the solution produced by scheduling, to utilize the resources effectively. According to Rinnooy [3] and French [4], the criteria for sequencing and scheduling problems were classified according to the following measures: completion times, due dates, inventory and machine utilization. Conway et al. [5] states four types of information about the scheduling and sequencing environment,

- The jobs and operations to be processed
- The number and types of machines that comprise the shop
- The disciplines that restrict the manner in which assignment can be made, and
- The criteria by which a schedule to be evaluated.

And they classified the manufacturing environment as,

1. *Single machine shop:* One machine and N jobs to be processed.
2. *Flowshop:* There are M machines in the series and jobs can be processed in one of the following ways:
    a. *Permutational:* Jobs are processed by a series of m machines in exactly the same order
    b. *Non-permutational:* Jobs are processed by a series of m machines not in the same order.
3. *Job shop:* Each job has its flow pattern and a subset of these jobs can visit each machine twice or more often i.e., Multiple entries and exits.
4. *Hybrid job shop:* The precedence ordering of the operations of some jobs is the same.
5. *Hybrid flowshop:* Stages of operation are done in a sequence and the machine can be arranged parallel.
6. *Flexible flowshop:* The order of sequence can be changed and skipping of parallel machine also considered.
7. *Open shop:* There are m machines and there is no restriction in the routing of each job through the machines. In other words, there is no specified flow pattern for any job.
8. *Closed shop:* It is a job shop; however, all production orders are generated as a result of inventory replenishment decisions. In other words, the production is not affected by the customer order.

In all these shop floor, the inventories play a vital role. In these situations, there is always a possibility of at least once critical/special machine in it [6]. Many researchers focused on this view to identify and solve the critical situation. They considered the critical machines are rental machine, high operation cost machine, high queue length machine, maintenance required machine, high investment machine, breakdown nature machine, etc. [7]. Based on the shop floor and the situation it occurs, the purpose of the critical machine and the objective of the system will vary. The various critical machine occurring situations are studied in this survey.

Nomenclature

C	Number of critical/rental machine
C_{max}	Maximum possibility of critical/rental machines
C_s	Surrogate machine
GIA	Global Industry Analyst
LB	Lower Bound
M	Number of machines
N	Number of jobs
P_{ij}	Processing time of j^{th} job in i^{th} machine
Z	Position of critical/rental machine in a flowshop

2. Literature Survey

In many manufacturing environment the possibility of critical machine arises. To handle this situation many researchers made, their effect to normalize and solve the shop floor problem. Lageweg et al. [8] considered the M x

N permutation flowshop with the objective of minimizing the completion time, in that the M machines are considered as M critical machines/ stages. They solved this problem using branch and bound methodology.

Baker and Pyke [9] solved the job shop problem by splitting into sub-lots, which emerge from the bottleneck machine i.e. critical machine. They made the sub-lots into batches and each one with a critical machine. Jatinder [10] discussed about the application of genetic algorithm in a flowshop with M machines and N jobs. The lower bound is found, from that the critical machine is identified and it is solved by decision rule of scheduling.

Huang and Liao [11] presented an article on hybrid algorithm of ant colony optimization and tabu search technique for job shop. In this the shifting of bottleneck machines makes the way to solve the problem and considering the bottleneck machine with the maximum lateness as critical machine. Liu [12] described the multi stage manufacturing system as hybrid flowshop which can be solved my splitting up into sub lots. The maximum processing machine in each stage is the dominant machine which is called critical block/machine.

A new method to solve the multi-processor flowshop using branch and bound method was stated by Carlier et al. [13]. In this solving method a critical centre/machine was generated for fixing the inputs. Martineza et al. [14] concentrated on the objective of minimizing the makespan of the flowshop problem under new blocking constraint. The discussion is about three to five machines, complexity and encountered a parallel machine in the first stage, which will be needful in achieving the objective. The first stage single machine is critical machine (blender) which describes the effectiveness of the flowshop problem.

Farouk and Chengbin [15] approached the job shop by splitting the job and sequencing it, depending on the setup time. In this approach the parallel identical machines are considered in the first stage of the shop floor. Among these, two identical parallel machines, the one which completes the work first is the critical machine.

Anant and sheik [16] solved the flowshop problem by passing a job over another by multi-level hybrid framework approach and evolutionary techniques of scatter search. In this the job is allowed even to pass over the successive machines under special condition. The condition is may be critical operation, critical situations due to successive critical machine. This block is considered as a critical block / machine; by reducing this situation the objective can be achieved.

Watson et al. [17] redesigned the permutation flowshop in a new way with critical blocks. To optimize the random input shop floor, the critical path was described by denoting as $\pi(x)$ for each flowshop problem. In this critical path, the critical blocks which pass the job are called critical machines. Christos [18] developed a shifting bottleneck algorithm for two machine flowshop total tardiness problem. This algorithm works based on the relationship between single machine (first machine) and counterpart/machine. The maximum load among these machines is considered as critical machine and its work had been reduced to reduce the total tardiness.

Shanthikumar and Wu [19] made three decomposition techniques for permutation scheduling problems. This solving method is based on iterative decomposition approach. After decomposition the remaining set of machine with high importance is called critical machine. The job shop with huge lot size was subdivided into fixed size sub lots to obtain the global optimal results [20]. The method of reaching the lower bound (LB) through branch and bound method and the machine which attains the LB is called critical machine.

Lin and Hwang [21] a two stage differentiation flowshop with fixed sequences per job type was discussed to reduce the tardiness. The first stage machine is considered as common and second stage machine is with identical parallel machine. In this paper, the discussion made on the machine with minimum tardiness, this kind of machine is called as critical machine.

Talbi et al. [22] stated about a hybrid evolutionary approach for the flowshop to optimize the multi-criteria. Here the genetic algorithm and meta-heuristic approach are used for the flowshop with the parallel machines. In this paper, it was stated that the resources are critical and machines are also critical resources.

Grabowski et al. [23] proposed a block approach for single-machine scheduling with release dates and due dates. The single machine is considered as a bottleneck machine because of its high processing time and a model is generated to state the application of job scheduling on a critical machine. Aytug et al. [24] measured the criticality of sub problems in decomposition algorithm for scheduling. In this paper, a special case of machine was described which always occurs in a manufacturing environment. This kind of special machine is called critical machine.

Armentano and Ronconi [25] addressed the tabu search for total tardiness minimization in flowshop scheduling problems. The bottleneck machines are the tardy machines and the slowest machines are the critical machines, they both are neutralized by this search technique and branch and bound method and then the objective was achieved. The same work with a different objective of minimizing the total weighted tardiness in job shops was done by Marcos and Michael [26]. In this paper, the high bound machines are tending to be considered as critical machine.

Gur and Assaf [27] discussed about the minimum weighted number of tardy jobs on an M-machine flowshop with a critical machine. A simple environment was considered with a few machines and more jobs. In this, one of operation is common for all the jobs, and is performed on the same machine which is considered as critical machine. A pseudo-polynomial dynamic programming algorithm was introduced to solve this environment.

Enrique and Gur [28, 29] also stated the first machine in a two stage flowshop is called critical machine and second machine is called dedicated machine. The objective of this works were minimizing makespan, minimizing total load, and minimizing weighted flow time. Polynomial time dynamic programming algorithms were introduced to solve the above objectives. It was inferred that the total load was minimized by reducing the work on critical machine.

Wen et al. [30] made a note on single machine shop floor problem. In this article, the makespan was considered as the objective and it is solved using deteriorating function. For analysis, a manufacturing environment was considered with blooming mill. The blooming mill was described as critical machine because it is the special type of machine in the environment and the maintenance was required for it.

Colin and Takeshi [31] defined the critical block/machine has the machine which passes the job in a critical path of job sequence. The critical path of job passes from the first machine at first and then sequenced up to last. The optimal two-phase method was proposed by Slowinski [32]. In this method, the machines in a flowshop were described in two stages, the maximum processing machines were considered in the first stage which was called as critical machine.

By the way, a parallel machine flowshop was described in two stages by Ewa [33]. In that the first stage machines were with identical parallel machine and they were called as critical machine. This environment was solved by using a heuristic approach for obtaining minimum makespan with computational aspects.

George and Koulamas [34] studied about an open flowshop with critical machine. In this system, the jobs will perform only two operations and maximum loaded machine was defined as critical machine.

Xia and Wu [35] and Guohui et al. [36] studied the flexible job shop scheduling problem with the objective of minimizing makespan and total workload. The critical machine was considered in this environment which was a maximum work load machine. The above objectives were solved by using a hybrid particle swarm algorithm and SA. Ghasem et al. [37] solved the same objective in a flexible job shop with critical machine using hybridization of the particle swarm and local search algorithm.

Gulati et al [38] studied the bicriteria in three stage flowshop scheduling to minimize the rental cost of critical machines with minimum makespan. Deepak et al [39] discussed the two stage rental/critical machine problem; with this the processing time of jobs is associated with their respective probabilities including transportation time and the objective is to minimize the rental cost. A new approach was developed by using a new type of fuzzy arithmetic and a fuzzy ranking method to minimize the rental cost for three stages specially structured flowshop which includes transportation time [40].

Gupta et al [41] introduce the concept of specially structured flowshop scheduling to minimize the rental cost of critical machines in which processing times are associated with probabilities. This objective is achieved by minimizing the idle time of the critical machine.

Harminder [42] developed a heuristic for N x M flowshop scheduling problem with the constraint of no idle in critical machine. The application of scheduling of the criteria of minimizing rental cost for the two stage flowshop environment with probability associated jobs and considering the setup time was done by Gupta et al [43]. Adiri and Pohoryles [44] studied flowshop and sum of completion times, scheduling problems, from that it was inferred the “no-idle” constraint dominates machine to make early process and effective utilization of critical machine.

The no-idle constraint arises in real-life, when machines may be rented to complete an assignment. Reduction of the rental cost of machines could be the criterion in these types of situations. The total rental cost of the machines will be at a minimum when idle times on the machines are also at a minimum. Under the no-idle constraint each machine is required to be taken on rent for the time equal to the sum of the processing times of all the jobs on it.

From this literature survey, it was inferred that the critical machine was identified in all types of shop floor. In any manufacturing environment, the critical machine occurrence was possible, but mostly it acts as an unwanted burden in the shop floor. This makes the objective to resolve the critical machine from the shop floor. In this paper, the critical machine effects and the methods to resolve it from the shop floor are discussed.

3. Occurrence of Critical Machine

The critical machine is defined as the most crucial or vital machine in a shop floor, which determines the objective and effectiveness of the shop floor. The critical machine arises in the shop floor for many reasons based on the manufacturing method, raw material, tardiness, due date, cost and so on. Based on the survey, the critical machine is identified in various shop floors and they are discussed below.

1. Automated machine
2. Blender Machine
3. Bottleneck machine
4. Breakdown nature machine
5. Buffer or delay required machine
6. Continuous processing machine
7. Critical operation performing machine
8. Dominant machine
9. First stage machine
10. High bound machines
11. High cost machine
12. High maintenance required machine
13. High operating cost machine
14. Identical machine
15. Identical parallel machine
16. Machines in critical path
17. Maximum lateness machine
18. Maximum processing machine
19. Maximum work load machine
20. Minimum tardiness machine
21. Minimum weighted machine
22. Parallel machine
23. Pivoted machine
24. Rental machine
25. Repeatedly shifting machine
26. Semi-automated machine
27. Short run machine
28. A single machine with full load, i.e., a Bottleneck machine
29. Skilled labours required machine
30. Slowest processing machines
31. Special machine

Generally, the major objective of any shop floor is minimizing the makespan. The critical machine helps for this objective, when the idle time of it is minimized. In other cases, to avoid manufacture and machine failure the critical machine requires idle time; here, the makespan is indirectly raised. By these two different views, the critical machine is classified as,

1. Idle time required machines and
2. Idle time non-required machines.

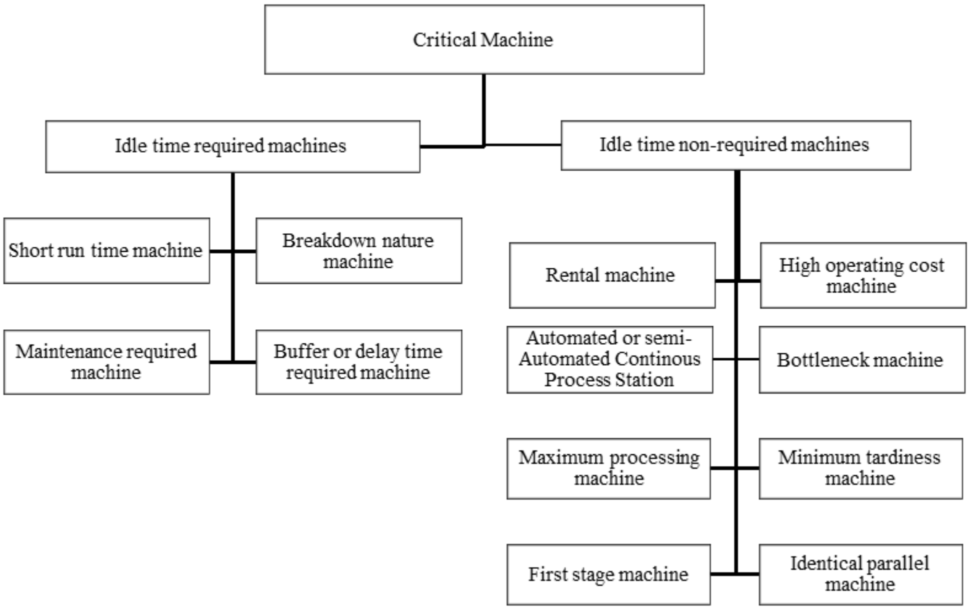

Fig. 1. A classification of critical machine's objective in a shop floor.

From Fig.1, it was inferred that the idle time of the critical machine is the vital one in most of the manufacturing environment with critical machine. Many researchers concentrated on this objective in various shop floors. A survey from 1960's to till date about the research work on critical machine was represented graphically in Fig. 2.

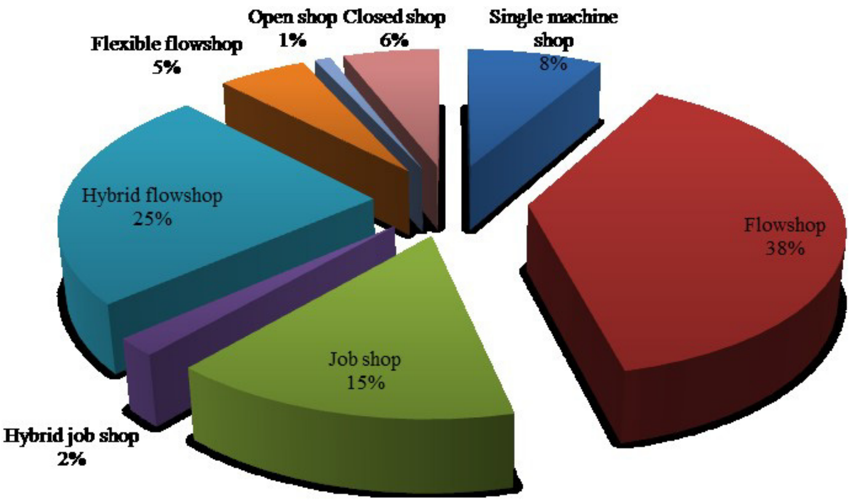

Fig. 2. Percentage of research work in various shop floors with critical machine.

From the survey represented in the Fig. 2 shows that the flowshop environment has the majority of critical machine occurring situations. The idle time reduction of critical machine in flowshop manufacturing was done by many researchers for various practical needs [45]. The analysis on the possibility of a critical machine position in a flowshop and the method to resolve the critical machine effects is becoming vital.

4. Possibilities of Critical Machines Position

There is always the possibility of having a critical machine in a flowshop. But the count of critical machines in it has to be identified [6].

Condition 1: Regarding the idle time of the first machine in any flowshop will be zero. So the necessity of considering it, in comparison is not essential. Many researchers considered the rental machine as first machine [46] but it has to be negligible.

Condition 2: Considering, minimizing the idle time of the last machine in a flowshop indirectly states optimization of makespan [47]. Many good heuristics were proposed with this objective so that, the last machine being a rental/critical machine also can be negligible.

In most of the cases, the rental/critical machine in a flowshop can be one which lies between M_2 to M_{m-1} position. But in some cases, the rental/critical machines are more than one. If they are consequent machines, then they can be added together has a single C_S, Surrogate Machine otherwise they will be placed alternately in the flowshop. The maximum possibility of rental/critical machines (C_{max}) in a flowshop is (**M**-**2**+(**M** *mod* **2**))/**2**. The ratio of number of critical machines to the number of machines is C: M.

5. Solution Methods

The idle time reduction is the major objective of the flowshop with critical machines. The idle time is reduced by many latest heuristic approaches. Even though the idle time is reduced for the critical machine, but reducing it to zero is a tedious process because of critical resources/inventories and the impact of other objectives like minimizing makespan, total completion time etc.

The flowshop is converted into hybrid flowshop by adding an identical parallel machine [48], the objectives of critical machines can be resolved. The solution methods for idle time reduction and idle time requirement are listed below.

5.1. Solution for idle time reduction of critical machine

The idle time can be reduced by continuously engaging the critical machine. To engage the critical machine continuously, the workload on it should be continued so that the identical parallel machine is added to the machine before critical machine. Thereby, the queue length is increased and makes the critical machine to work completely and effectively. The solving method for idle time reduction of critical machine is represented in Fig. 3.

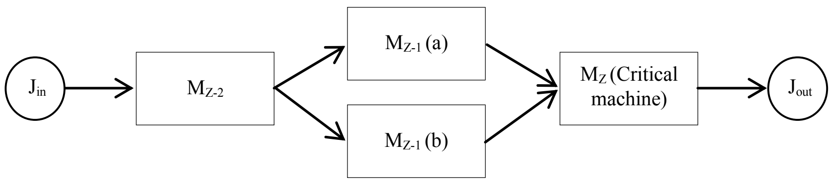

Fig. 3. Solution for idle time reduction of critical machine.

5.2. Solution for idle time required for critical machine

To avoid manufacturing or machine failure, the idle time can be generated regularly or the work has to be finished before the rest time. The work can be finished by making flowshop environment into hybrid flowshop. When the identical parallel machine is added to the critical machine position and make it as critical stage, the work will be subdivided so that the time of working gets reduced. This would help to achieve the objective to avoid failures in manufacturing and inventories. The solution method for idle time required for critical machine is represented in Fig. 4.

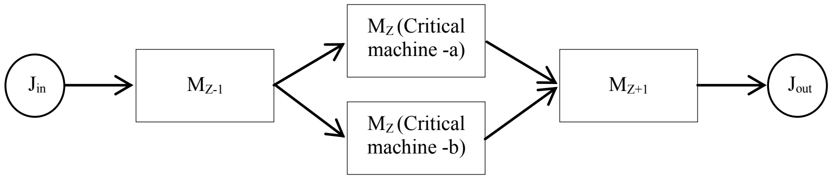

Fig. 4. Solution for idle time required for critical machine.

From the proposed two methods, the critical machine in a flowshop can be resolved. The demerit with these methods is that they are expensive, the cost of the identical machine may raise the budget of the manufacturing but when it is taken for rent, the expenditure gets reduced and also the objective can be achieved. GIA announces that the global market for inventories of rental and leasing is expected to reach $ 56 billion by the year 2017 [49]. In the method 1, the idle time is reduced so that it indirectly reduces the working time of rental machine ant it is cost effective. In method 2, the working time of the rental machine is directly reduced and the cost also reduces.

This show both the methods are very useful for the manufacturing environment with critical machine. Based on the objective of the system and the need of critical machine, the shop floor problem is solved by using these methods. The hybrid flowshop is also described as flexible flowshop [50]. Thus the solving methods and inventory utilization are effectively improved. For further improvement, the simulated annealing, genetic algorithm, particle swarm algorithm and other latest methods can be used. Among these methods, the simulation methods work well for hybrid/flexible flowshop [51, 52].

6. Conclusion

The complete study of modern manufacturing environment was carried out. The study revealed that the possibility of special machines called critical machine in the shop floor is high. The critical machine was described based on the processing time, operation, maintenance requirement, automation, life, breakdown, buffer or delay time, rental cost, and so on. The objective of the critical machine in the shop floor was determined and based on that, the critical machine was classified and resolved from the manufacturing unit. The survey of research about the critical machine was found to be predominant in flowshop environment. Research reviews revealed that the possibility of critical machine and its position could be identified in the flowshop. These newer methods are based on converting flowshop into hybrid flowshop environment by adding an identical parallel machine whenever the critical machine occurs. Thus, the proposed methods can be the permanent solution for avoiding the critical machine problems in the flowshop environment. For further improvement, the simulated annealing, genetic algorithm, particle swarm algorithm, and other latest methods can be used. Among these methods, the simulation methods work well with hybrid flowshop problems.

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