OPTIMIZATION OF JOB SHOP SYSTEM WITH PARALLEL MACHINES USING SIMULATION

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Abstract

In this paper the problem of job shop with parallel machines is discussed. Job shop system with parallel machines is one of most important and practical issues of optimization in the recent decades that has attracted many researchers. In this study, scheduling are studied in uncertain situation. In other words setup and process time for each job on each machine are uncertain. The objective is to minimize the maximum completion time (Cmax). But because of considering uncertainty, the use of exact algorithmsis met with skepticism. This is a serious challenge in these models. In such situations, simulation technique is one of the most populart techniques that can be used to investigate these problems. In this paper, the studied model is simulated using Arena software to investigate the system functionality and its weaknesses. In order to overcome these weaknesses and improve the ongoing situation the management was forced to come up with suggested solutions. Finally, in order to find the optimal solution due to the goal function, which was the average completion time of products, the optquest tool was employed.

Keywords: Job Shop Scheduling, Parallel Machines, Optimization For Simulation, Arena, OptQuest.

1. Introduction

One of the hindering obstacles for many companies is the efficiency of the production lines. So as to improve the process a variety of techniques are used, including re-engineering of the work processes, benchmarking, material handling optimization and redesigning processes, and layout. The main purposes of applying these techniques are to reduce costs and total time of the process, increase production efficiency, better use of manpower and equipment and reducing their idle time and also to establish the optimal sequence of activities. Design of production systems has long been considered as an important subject; and due to the increase of global competition and rapid expansion of technology; it has become even more so. Job Shop are one of the most common production technologies, widely used in most production systems. In order to Produce a product, a production system employs a set of work elements and consists of a number of interrelated workstations, a material handling system and an instruction on how the system works. To balance Production line is, in general, the systematic grouping of operations and work elements as workstations with respect to the restrictions, work cycle time and other special limitations in order to optimize the goals. Among methods used to do so are the exact ones in which one can reach an exact optimum solution employing mathematical programming models such linear, integer,zero-one, dynamic, goal programming, etc [1,2]. But when the number of operations and workstations increases, the problem becomes too complex to be solved in a practicable period of time. In fact, in terms of computing, assembly line balancing problem is considered NP-Hard, and for this reason, heuristic and meta-heuristic techniques are used, which do not necessarily find the optimal solution but what they do is finding an answer in a reasonable time and reasonably close to the optimal answer [2-4]. In this study, in order to analyze the production lines of the given problem, simulation technique has been used. As a matter of fact, researchers employ this popular technique for its simplicity, close to optimal answers and capability of comparing different scenarios. Mathematical analysis methods, wherever possible, are the most desirable and accurate methods for studying systems, they create calculable results for varying values of model's parameters and with high accuracy; But when analytical methods are not practical due to the model`s complexity, simulation is applied.

The target of this paper is to minimize the maximum completion time (Cmax). Therefore in this study, the production line in question has been simulated using Arena software for its function to be analyzed and its problems to be identified. To address these problems, the management of the organization was forced to come up with suggested solutions, considering the existing limitations. Finally optquest tool, which is based on heuristic methods (Tabu search and scatter search) and searches intelligently to converge to an optimal answer, was employed to find the optimal solution.

The structure of this paper is as followed: In section 2 and 3, a review of the research literature is given. In section 4, an overview of the research background is mentioned. Next the research methodology is introduced and finally, discussion and conclusions are presented in section 7.

2. An introduction to Job Shop

Job-shop production line scheduling problem has been a continuously challenging optimization problem in the field of the research on industrial engineering [1], because many practical job-shop scheduling problems can be simplified as identical parallel machine production line scheduling problems under certain conditions; therefore, the identical parallel machine production line scheduling problem has received a great deal of attention in the academic and engineering circles [6].

Job Shop are one of the most common production technologies, widely used in most production systems. The production system includes several work station in which a certain number of machines and operators are interacting with each other to make products. The Hybrid Job Shop is linked in some way to Parallel Machine Job Shop. Indeed as can seen in the Fig 1, an Hybrid Job Shop is composed of different stages which can contain one single machine or parallel machines.

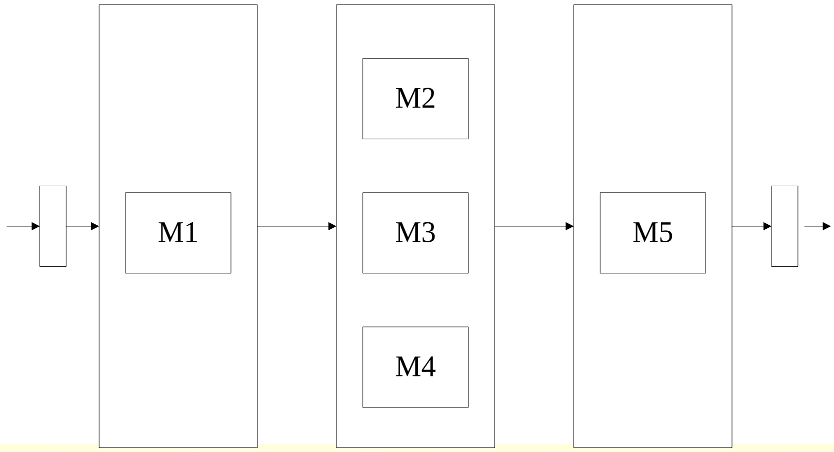

Fig 1. Example of Hybrid Job Shop

So this type of system can be described as a sequence of parallel machine problem. Moreover the Parallel Job Shop system has been widely studied especially for the minimization of the completion time.

3. Simulation

Application of simulation, as it is today, began in the late 1970s and with the arrival of computers, its value was discovered specifically. Simulation is often defined as for testing different scenarios of a real system. Banks and Carson (1996) have described it as an imitation of a real system's function during time and Shannon (1975) has defined it as the process of designing a model from a real system and make experiments with this model with the aim of recognizing the system's behavior or evaluating various strategies for the system function [7, 8]. Generally, developing a simulated model consists of the following phases: problem definition, data collection, model building, model verification and validation and finally the model implementation. Simulation using programming languages and computer software has become quite common today. One of which is Arena software, employed in this study, a high level simulator and at the same time as flexible as simulation programming language [9]. Its graphical tools have made it popular for managerial and decision problems [7]. Arena has several side – programs such as optquest. Optquest, product of opttek System Inc., intelligently searches and converges to the optimal point using heuristic methods such as Tabu and scatter searches. The optquest tool makes decisions on its own in selecting the solutions instead of relying on users. In a repetitive algorithmic process, it selects instances which lead to an optimal combination of input control values.

4. An Overview of the Research Background

Miller and Pagden (2000) have studied the evaluation and application of simulation in production system design and operation scheduling [10]. A research has been carried out in the field of artificial intelligence and simulation for production system optimization by Viharos and Monostory (2003). They evaluated the application of these two methods to improve the productivity of a wood production plant and concluded that the optimal and appropriate combination of resources and organization's facilities result in 18 percent reduction of the average total waiting time, they achieved the optimal combination of resources and facilities using genetic algorithm [11]. Ertek and Turkseven (2003) have examined the use of simulation to estimate and improve the quality and productivity in cable manufacturing plant [12]. Chang and Careen (2009), using simulation and Arena software, evaluated and improved the loading and unloading system of a production section. In order to resolve the problems of the existing system, they presented scenarios and with the aid of simulation, they selected the best solution leading to 65 percent reduction of customers' waited time [13]. Na, Chaudhuri and Shinozuka (2009) have shown the efficiency of simulation techniques in manufacturing sections and specially in planning design process and material handling systems [14]. Bard, Dar and Shtub (1992) have presented several optimization models for sequence of assembly line, considering the major specifications of the line design. By combining these specifications and the design's two objectives, minimizing the length of line and total cycle time, they also presented several optimization models [15].

For production lines balancing problems of small sizes, exact methods such as linear programming, integer programming, zero- one programming, dynamic programming, goal planning, etc. can be used to reach an optimized and exact solution and for that we can refer to the researches of Bukchin and Tzur (2000), Bukchin and Rabinowitch (2005) and Bukchin and Masin (2004) [16-18]. In many studies, since the production problems and specially assembly line balancing problems are NP-Hard, heuristic methods have been employed for the purpose of setting the cycle time and number of workstations [19, 20]. Koulamas and Kyparisis took the scheduling problem of a three-phase assembly plant with the goal of minimizing the maximum completion time and analyzed the problem using numerous innovative algorithms [21]. For the evaluation and analysis of assembly line production capacity of motorcycle bumpers, Gujarathi, Ogale and Gupta (2004) have used simulation. By providing their proposed solutions, they could increase production capacity to 435 units and the factory profit was increased 32 percent [22].

5. The Proposed Methodology

In this study, Job Shop System with Parallel Machines is analyzed employing queuing theory and simulation. This problem consists of three main elements: the machines, the operators and the material handling system. Also includes several workstations, in which the machinery and operators perform operations on the products, and the material handling between the stations is done by a forklift. In each station the product gets one step closer to the final product and eventually leaves the system. Research process is as Fig. 2.

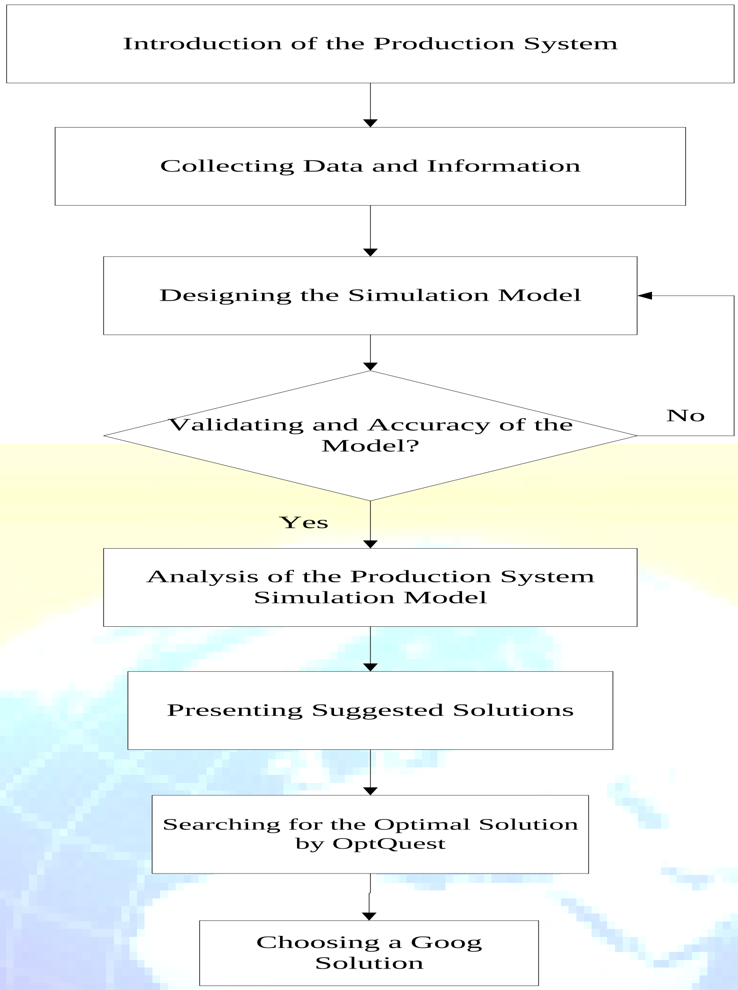

Fig2. Research Methodology for job shop system with parallel machines

5.1 Describing the Problem

The production system shown in Fig 3 produces four products simultaneously in five workstations. Each of these four products has a specific sequence of stations. Products enter the division through the loading dock; they pass their due sequence of stations in aspecific time and then go out through the unloading dock. Sequences and the possible time in each workstation are presented in Table1 for each product. In this line two products are produced one of which has three models, different in some parts and operation times. In order to simplify the problem they are considered as four different products (A, B, C and D). This division includes five workstations: electric motor assembly station (S1), the main body assembly station (S2), final electrical inspection station (S3), final mechanical inspection station (S4) and finally labeling and packaging station (S5).

All the stations except Station (S4) include a machine and an operator. Station (S4) is available four parallel machines. Products enter this division for assembly of electric motor and main body, inspection and eventually packing and labeling. For two models of the first product (B and C), the assembly of motor and body are done elsewhere in the company, due to electrical and mechanical adjustments needed. Therefore, these two enter this division with their motor and body already assembled. Whereas, for product D, motor and body are assembled elsewhere due to spatial restrictions, therefore it enters the assembly line for no more than inspections, packing and labeling.

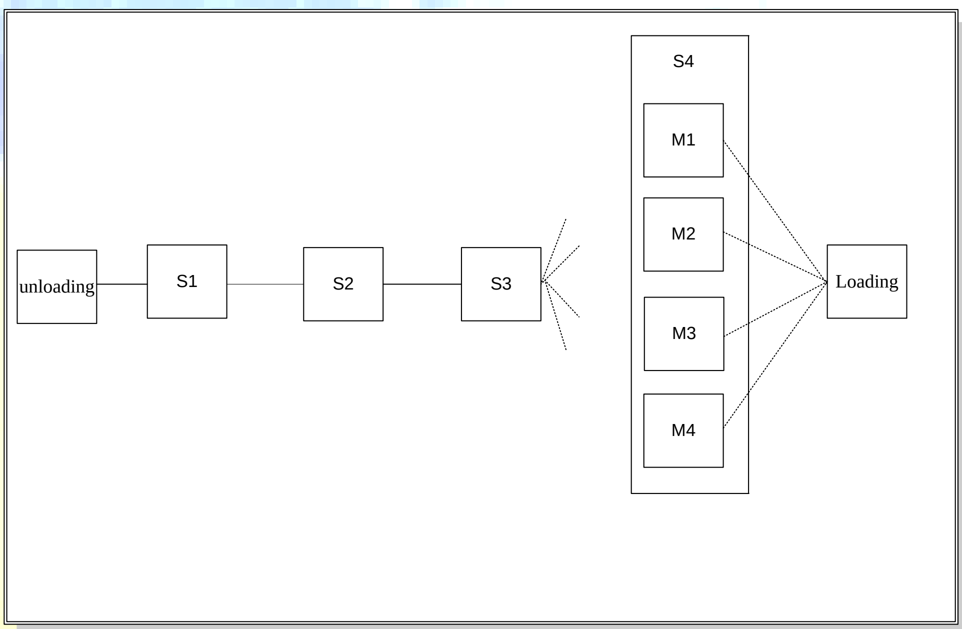

Fig. 3 Current layout of the production line

Table 1. The flow sequences between the workstations and uniform time of process (Pij) and setup (Sij) based on the product type

Product	Station1		Station2		Station3		Station4		Station5	
time	Pij	Sij	Pij	Sij	Pij	Sij	Pij	Sij	Pij	Sij
A	(3,5)	(4,5)	(2,4)	(3,5)	(2,4)	(1,5)	(3,5)	(6,8)	(2,3)	(4,6)
B	(1,4)	(5,8)	(1,5)	(2,5)	-	-	(2.4)	(5,6)	(3,5)	(5,8)
C	(5,6)	(6,9)	-	-	(2,5)	(3,7)	(1,3)	(3,5)	(2,5)	(6,9)
D	(7,9)	(6,7)	-	-	-	-	(2,4)	(1,4)	(2,4)	(3,7)

5.2 Simulation of Production System

As long as the relationships between components of a system are simple, the exact mathematical models can be used for analyzing the relationships. In this case, mathematical models are more accurate, faster and easier to use rather than simulation models. But often the real models are too complex for mathematical models to be able to solve them; especially in cases which some of system parameters are inherently random. In the studied system in this paper, most of system parameters are uncertain such as product arrival rate, process time and material handling time. In fact, simulation technique is capable of analyzing and solving complex models because of its describing power. Fig 4 simulated model of Production system Using Arena Software.

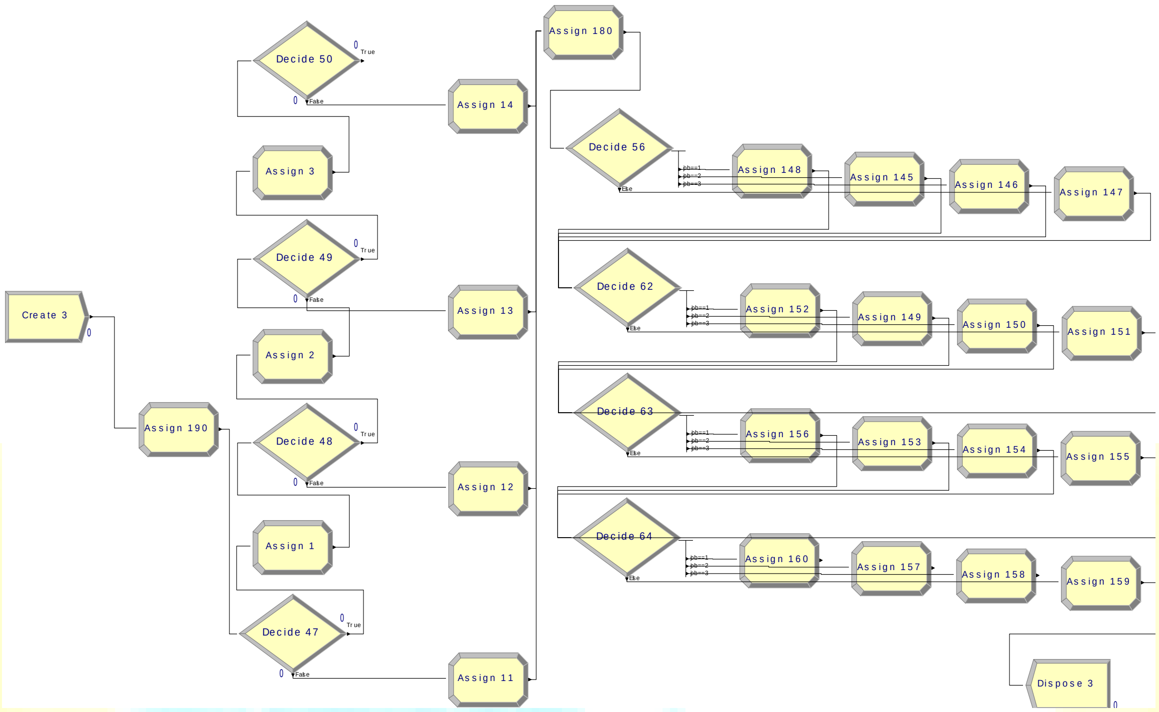

Fig 4. simulated model of Production system Using Arena Software.

5.3 Validation and Accuracy of Model Results

Validation is a process that ensures the behavior of the model is similar to the real system whereas verification is the process that ensures Arena model behaves based on the model assumptions. In other words, the model must have a reasonable reliability that its results are correct and in accordance with the existing system. Many methods have been presented for validation and improving the models reliability, one of which is comparison of models output with the real system's output. To do so, the simulation model is run for one month and according to production schedule and the result is statistically compared to that of the real system, using the paired t-test. That means the differences between each pair of observations are calculated and considered to be random variables with normal distribution, μ_D and $\sigma_D$being respectively the mean and the standard deviation and the hypothesis test is $H = \mu_D = 0$. According results the hypothesis is accepted, thus there is a %95 confidence that the simulation model's output matches with that of the real system.

Using the graphic method is yet another way to this end. Since Arena is being used, it is possible to graphically observe the system's behavior step by step in order to check if it is really correct or not? The model's behavior must also be observed in extreme conditions such as having only one product, having definite values for product arrival time or product handling time and changing these values to predict the systems behavior. This method is effectively employed to identify and remove the models errors.

Additionally, to have correct and accurate results, the bias related to models beginning conditions must be omitted.In other words, since the presumption that system is empty or idle in the beginning damages the model, a %20 warm-up period is added to the running time per day (648 minutes instead of 540).

5.4 Analysis of the Production System Simulation Model

By implementing the simulated model, the current state of the system such as the productivity coefficient of stations, the average production number, the average waiting time at station and the average completion time of products are obtained according to Table 2.

As shown, the average productivity coefficients of stations is 57% which means that these stations use only half of their potential. Moreover, the average waiting time at stations is 4.57 minutes, which are very high and could be the result of issues such as lack of operators and or handling equipment. Furthermore, the average completion time of the products in the system are not desirable.

Table2. performance criteria results for the current state

Performance criteria	Average number
productivity coefficient of stations	0.57
production number	95
waiting time at station	4.57
completion time (Cmax)	63.9

Even before running the model one of most important considerations of the management was the long completion time, which leads into delays in products delivery and therefore dissatisfaction of customers. So in order to solve these problems and to increase customers' satisfaction, and also considering spatial and financial restrictions, the management has proposed the following possible suggestions for either improving or increasing the machinery and equipment. Possible suggestions (PSs) is as Table 3.

Table 3. the five Possible Suggestions for to improve the current status

PS1	change in the arrangement of the stations to the U-shape
PS2	Increasing the working hours
PS3	Increasing the number of parallel machines
PS4	Employing a operator in the fourth station
PS5	Employing a operator in the fifth station

Change in the flow of products, or in other words change in the arrangement of the stations, which leads to change in the material handling system. Due to the aforesaid restrictions two options are available. and the other is straight line. U-shape arrangements are employed to reduce the distance between the stations and handling time. Extending the working hours in the shift could be an effective solution to reduce the number of products in the system at the end of the shift. Increasing the number of parallel machines could improve the productivity of the station which results in lower waiting time for products. Employing more operators in the stations would also decrease the waiting time of the products. Considering these five Possible Suggestions the management has proposed twenty-nine solutions (combinations of these five), seen in the Table 4.

Table 4. Evaluation of completion time results for the solutions

No	Solutions	Cmax	No	Solutions	Cmax
1	PS1	59.8	16	PS1 & PS2 & PS3	40
2	PS2	58.5	17	PS1 & PS2 & PS4	42.5
3	PS3	49.5	18	PS1 & PS2 & PS5	48.5
4	PS4	52	19	PS1 & PS3 & PS4	41.5
5	PS 5	48.5	20	PS1 & PS3 & PS5	40
6	PS1& PS2	38	21	PS1 & PS4 & PS5	38.7
7	PS1& PS3	37.5	22	PS2 & PS3 & PS4	31.9
8	PS1& PS4	39	23	PS2 & PS3 & PS5	39.1
9	PS1& PS5	45	24	PS3 & PS4 & PS5	34.2
10	PS2& PS3	41.25	25	PS1 & PS2 & PS 3 & PS4	37.9
11	PS2& PS4	48.6	26	PS1 & PS2 & PS 4 & PS5	36.
12	PS2& PS5	36.4	27	PS1 & PS3 & PS 4 & PS5	34
13	PS3& PS4	38.4	28	PS2 & PS3 & PS 4 & PS5	38
14	PS3& PS5	37.9	29	PS1 & PS2 & PS3 & PS4 & PS5	39
15	PS4& PS5	39.1			

In Table 4, the results of these solutions are cited. Making a decision to select the most suitable solution is upon the management and the criteria. In order to decide properly economic and financial aspects, humanistic and customer relationship and future conditions must be considered. But due to financial restrictions, as said earlier, all the solutions have been focused on customer satisfaction and in-time delivery of products. Therefore we must concentrate on criteria which address these purposes. Due to the fact that in-time products delivery is highly dependent on the reduction of products Completion time. Performance criteria had to be studied in each of the twenty-nine solutions is Completion time.

Results of this criteria for the solutions have been presented in Table 4. Twenty-nine different solutions due to five Possible Suggestions (change in the arrangement of the stations to U-shape, Increasing the working hours, Increasing the number of parallel machines, Employing a operator in the fourth station and Employing a operator in the fifth station) are implemented. Considering this performance criteria (Cmax), analysis of solutions are addressed. According to the table 4, the twenty-two solution shows the highest reduction in completion time. In other words, changing the production line layout to the U-shaped form, adding a parallel machine and employing two operators at stations 3 and 5, which 49.9 percent reduction in the average completion time of products A, B, C and D.

6. Searching for the Optimal Solution by OptQuest

OptQuest helps with selecting system inputs (controls and constraints) and then executes the model by running several scenarios for each set of inputs in order to achieve the desired system outputs (objective functions). The twenty-nine solutions evaluated in the previous section are only few of many states which could be studied in a search for minimizing Cmax. After choosing solution 22, the management wanted to be aware of the optimal solution, in case the company's financial problems are taken care of. Thus the five input variables (Possible Suggestions) could be considered in and five-dimensional space by determining nonnegative integers values for an five-dimensional vector to minimize the average of completion time (Cmax). Also the maximum work hours greater 12 and the increased number of parallel machines and operators not greater than 3 for each of stations.

Among the existing methods to solve this problem, one is optquest, which uses heuristic algorithms such as Tabu and scatter searching in control area, the five input variables move intelligently and converge to an optimal point. The goal of applying this software is to optimize the average of completion time due to the mentioned constraints.To run the model, a period of five months (1220 hours of work) is chosen, though it never goes this far; optquest is set to stop searching after 200 consecutive iteration of no improvement. As seen in Fig. 5, optquest has evaluated 627 scenarios and found the best in 427th iteration. Hence, the optimal of completion time converges in the number of 25.3 that is 21 percent lower than the twenty-two solution. This reduction can be achieved by some changes in the current situation such as adding a parallel machine at station 5, two operator at stations 5 in 12 working hours.

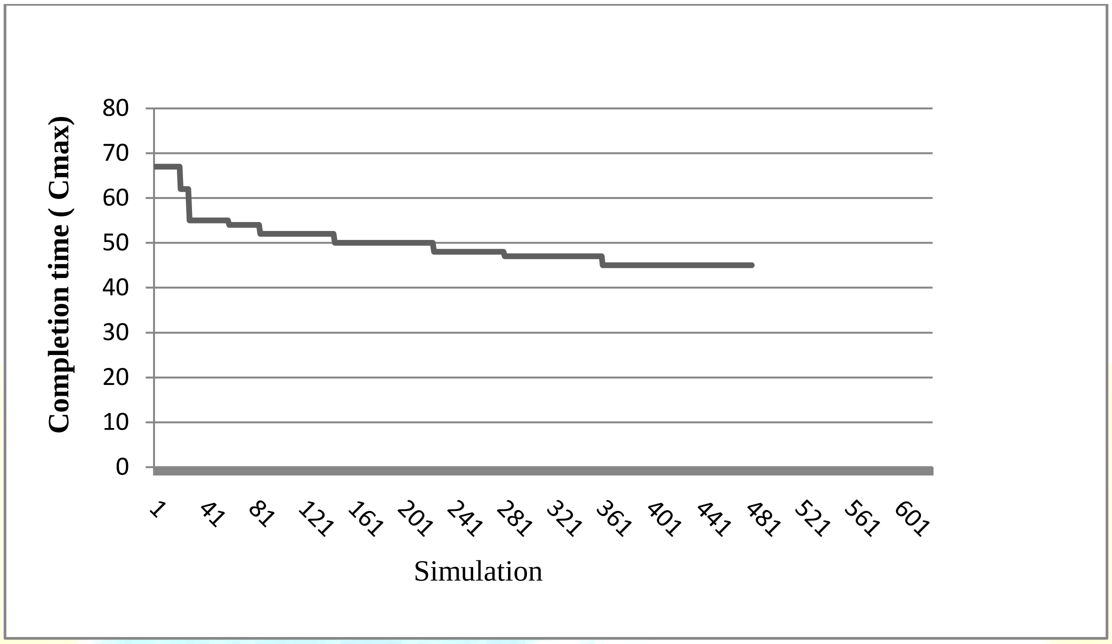

Fig.5. Optimization of completion time with evaluation of solutions in OptQuest

7. Conclusion

In this study, job shop system with parallel machines are studied in uncertain situation with the aim of minimizing completion time. There are some random and inevitable faults such asmachine failure, the lack of operator and random deviations in industrial and services systems.Therefore, considering a system in stochastic mode rather than deterministic is more realistic. In this research, setup and process time for each job on each machine are uncertain. The aim of most deterministic scheduling models is to identify the exact sequence that minimizes the completion time or scheduling length. In stochastic models, the performance evaluation criterion is the average or expected value for completion time. This is a serious challenge in these models. Because of considering uncertainty, the use of exact algorithmsis met with skepticism. In such situations, simulation technique is one of the most popular techniques that can be used to investigate these problems.

One of the effective means to improve a system is statistical simulation. It can evaluate proposed scenarios before they are actually implemented, which is an important help to decision makers who are constantly in pursuit of improving systems. In this case study, the implementation of the proposed solutions, which 52 percent reduction in the average completion time of products A, B, C and D. It should be noted that simulation is not a process of optimization, but it only gives us the system response to various operating conditions. In order to optimize the job shop system with parallel machines in this study, optquest is used to evaluate various solutions, and with respect to the constraints, select the best one, which is the minimum value of the goal function. The result was 18 percent reduction in completion time. For future researches, it is suggested that the results obtained in this study, by using simulation and optquest, be compared with simulated annealing.

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