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Flow Shop Scheduling using Simulated Annealing: A Review

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ABSTRACT

The flow shop scheduling problem (FSSP) is one of the most scientifically studied scheduling problems. In the FSSP, a set of *n* independent jobs have to be processed on a set of *m* machines. Every job requires a given fixed, non-negative processing time on every machine. Traditional flow shop scheduling problems were primarily focused on the objectives related to completion time of jobs, on the other hand, in current manufacturing tradition, on time delivery is a noteworthy criterion to stay in the rapidly growing markets. As customers expectations are to get ordered goods to be delivered on time. So industries focus has gone beyond the single objective scheduling system. The primary objective of flow shop scheduling is to obtain the best sequence, which minimizes the various objectives like makespan, flow time, idle time, work in-process and tardiness, etc. To optimize the objectives there are various method such as Tabu search, genetic algorithms and simulated annealing etc. have been developed. Among these methods, Simulated Annealing (SA) is believed to be the valuable search algorithm to accomplish the objectives. The present work is the review of simulated annealing for flow shop scheduling problems and classified based on various criteria of SA such as its parameter selection, computer resource usage, hybridization and enhancement from the past work.

Keywords: Scheduling, Flow shop, Simulated annealing, Survey, Review.

1. Introduction

A schedule is a suitable plan which generally tells the things that are made to happen; it shows us a plan for the timing of certain actions and answers the question, "When will a particular event take place". In language of industry, scheduling is a technique to order the jobs in a particular sequence. There are variety of sequencing rules which are followed in the industries such as first in first out basis, priority basis, job size basis and processing time basis etc. That sequence is adapted which gives optimal or near optimal solution. Also scheduling is concerned with allocating limited resources to tasks to optimize certain objective functions. Each task may have a certain priority level, an earliest possible starting time and a due date. In all the scheduling problems, the number of jobs and the number of machines are assumed to be finite. In flow shop production (FSP) system, jobs flow from an initial machine, through numerous intermediate machines, and at last to a final machine before completion with flow of work is unidirectional. There is a first machine that performs only the first operation of a job and the last machine that performs only the last operation of a job. In a flow shop, the work in a job is broken down into separate tasks called operations and each operation is performed at a different machine. In particular, each operation after the first has exactly one direct predecessor and each operation before the last has exactly one direct successor. The flow shop model has been divided in two parts. Firstly, in the pure flow shop

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model, where *n* different jobs consists of *m* different operations, each of which requires a different machine for processing. Secondly, in a general flow shop, jobs can require less than *m* operations. Here the initial and final operations for each job may not always occur at machines 1 and *m* and also their operations may not always require intermediate machines. However, the flow of work is still unidirectional, and it can be characterize the general case as a pure flow shop in which some of the operation times are zero.

2. Simulated Annealing

2.1 Introduction to Simulated Annealing

Since 1980s, Simulated Annealing (SA) search approach has been acknowledged after motivation from physical process of cooling fluids. The goal of the cooling process is the arrangement of atoms in the most regular possible crystalline structure. So, the cooling rate has a decisive effect on the final configuration. Only if the cooling process is sufficiently slow, an appropriate atomic alignment is possible. Otherwise, the structure will be polycrystalline or amorphous and exhibit crystal defects. The simulated annealing process lowers the temperature by slow stages until the system "freezes" and no further changes occur. At each temperature, the simulation must proceed long enough for the system to reach a steady state or equilibrium. In simulated annealing, each stage of the search as being carried out under a lower temperature than that which occurred at the previous stage. The value of the objective function is analogous to the temperature of the material being cooled. Early in the search (at high temperatures) there is some flexibility to move to a worse solution; but later in the search (at lower temperatures) less of this flexibility exists. Thus, the value of the objective function tends to fluctuate widely at the start of the search, but hardly at all toward the end of the search.

Structural elements of SA

1. Initial solution
2. Encoding scheme
3. Number of temperatures between initial and final temperatures
4. Number of neighborhood search in each temperature
5. Initial temperature
6. Cooling schedule type
7. Neighborhood search structure

Simulated annealing (SA) is a neighborhood search approach designed to obtain an optimum solution for combinatorial optimization problem. SA starts with an initial solution and iteratively moves towards other existing solutions. In order to diminish the probability of getting trapped in local optima, SA accepts moves to inferior neighboring solution under the control of randomized scheme.

The procedure of SA is as follows

Step 1: Initialization.

Step 2: Modify the schedule

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Step 3: Access the solution

Step 4: Adjust temperature

Step 5: Re-annealing

Step 6: Stop the algorithm

2.2 Literature Review

This survey is based on flow shop scheduling, done to minimize the various terms like tardiness, and makespan. The flow shop scheduling is mainly considered under NP-Hard problems. Parthasarathy and Rajendran (1997) presented a study that has been carried out in a flow shop which manufactures drill-bits. A new exponential acceptance function and a new scheme for generating the neighborhood, called the random insertion perturbation scheme (RIPS), are proposed. Tan and Narasimhan (1997) considered the problem of minimizing the tardiness in sequence-dependent setup environment. Here, the performance of SA is compared with random search. The algorithm proposed can find a good solution fairly quickly. But the algorithm is invaluable for 'on line' production scheduling and 'last minute' changes to production schedule. Younes et al. (1998) investigated the usefulness of simulated annealing (SA). Two stages are used in generating the makespans. A good initial-heuristic-seed sequence, obtained in the first stage, is improved-upon in the second stage by the SA technique. Empirical results show that the SA technique is able to generate improved Flow Shop with Multiple Processors (FSMP) makespan schedules over the first-stage makespans obtained using extant pure flow-shop heuristics. Nearchou (2004) proposed an approach which combines the characteristics of a canonical SA procedure with features borrowed from the field of GA. The final solutions obtained by this method are within less than 1% in average from the optimal solutions obtained so far. Low et al. (2004) proposed a mechanism that records the good solution's characteristics is designed and introduced into simulated annealing to make the searching procedure more robust. Gholami et al. (2009): described the incorporate the simulation into genetic algorithm approach for SDST hybrid flow shop with machines that suffer stochastic breakdown. Naderi et al. (2009) introduced a novel simulated annealing (SA) with a new concept, called "Migration mechanism", and a new operator, called "Giant leap", to bolster the competitive performance of SA through striking a compromise between the lengths of neighborhood search structures. There is another remarkable application that has been proposed by Bandyopadhyay et al. (2008) which describes a simulated annealing based multi objective optimization (MOO) algorithm that incorporates the concept of archive in order to provide a set of tradeoff solutions for the problem under consideration. Alcaide et al. (2002) proposed an approach which converts breakdowns scheduling problems into a finite sequence of without-breakdowns problems. Mazdeh Mahdavi et al. (2010) studied the parallel machines bi-criteria scheduling problem (PMBSP) in a deteriorating system. They discuss the parallel machines scheduling problem with the effects of machine and job deterioration. This deterioration is considered in terms of cost which is a function of production rate, machine's operating characteristics and the kind of work done by each machine. Manjeshwar Kumar et al. (2009) aims at minimizing the make span of two batch-processing machines in a flow shop. The processing time of a batch is the longest processing time among all the jobs in that batch. This research is motivated by a practical application observed at an electronics manufacturing facility. Chakravarthy and Rajendran (1999) dealt with the development of a heuristic for scheduling in a flow shop.

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First, they present the problem formulation, followed by a discussion on the methods for generating a good seed sequence that is given as an input to the simulated annealing heuristic. Cheng et al. (1999) presented a guided SA algorithm to schedule tasks in work orders for a manufacturing company in a job-shop environment. Laha and Chakraborty Kumar (2008) proposed a new hybrid heuristic named PSA, based on simulated annealing. The proposed hybrid heuristic uses simulated annealing in conjunction with the constructive heuristic of Nawaz et al. (1983). Naderi et al. (2009) applied a metaheuristic based on simulated annealing (SA) which makes a compromise between intensification and diversification to augment the competitive performance of our proposed SA. Mansouri Afshin (2006) proposed a multi-objective simulated annealing (MOSA) solution approach to a bi-criteria sequencing problem to coordinate required set-ups between two successive stages of a supply chain in a flow shop pattern. The MOSA approach starts with an initial set of locally non-dominated solutions generated by an initializing heuristic. The set is then iteratively updated through the annealing process in search for true Pareto optimal frontier until a stopping criterion is met. Jia et al. (2011) presented a hybrid prediction method (SA–SVM for short) using simulated annealing (SA) and SVM to predict synthesis characteristics of the hydraulic valve, where SA is used to optimize the input parameters of SVM based prediction model. SVM is a highly effective mean of system modeling for predicting. Jamili et al. (2011) proposed a hybrid algorithm named EM-SA which is based on electromagnetism-like mechanism (EM) and simulated annealing (SA) to solve periodic job shop scheduling problem (PJSSP) based on the periodic event scheduling problem (PESP). Czapinski (2010) presented a parallelizable Simulated Annealing with Genetic Enhancement (SAwGE) algorithm and applied to permutation flow shop scheduling problem (PFSSP) with total flowtime criterion. Lin et al. (2011) described an effective multi- start simulated annealing (MSA) heuristic. The use of the MSA heuristic takes advantage of the main properties of the SAs (e.g. effective convergence, small population, efficient use of memory, and easy implementation) and those of multi-start hill climbing strategies (e.g. sufficient diversification, excellent capability to escape from local optimality, and efficient sampling of the neighborhood solution space).

3. Discussions

The presented papers have taken different objectives and compared. To get a comprehensive knowledge about the different simulating annealing (SA) heuristics, three tables have been shown for this, which are as follows:

Table 1: List of research papers with multi-objectives.

Table 2: List of references opted for comparison of SA techniques in flow shop.

Table 3: Comparison of different SA algorithms.

From **Table 1;** few points can be concluded:

1. Approximately 61% of the papers cover two or more than two objectives.
2. Approximately 20% of the papers include two objectives such as minimizing makespan and total tardiness.
3. Approximately 18% of the papers include cost optimization as the objective.

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Table 2: indicates the list of references, the corresponding methodologies used, and the corresponding system specifications on which the methodologies are coded and tested. Various complex multi-objective SA's are employed such as: RIPS, HSA, PSA, GSA, MOO, AMOSA, MOSA, Stochastic scheduling, SAwGE, MSA etc. which are known as established techniques for engineering optimization problems.

Table 3: shows comparison of various methodologies in terms various parameters (initial temperature, cooling rate, probability of acceptance, final temperature, improvement by technique and run time etc.) and a good comment on the methodology used.

Now for **Table 1**, some objectives have been selected which are listed below:-

Objective 1: Minimizing makespan
Objective 2: Minimizing tardiness
Objective 3: Random breakdown of machines
Objective 4: Sequence dependent set-up times
Objective 5: Cost optimization

Table 1: List of research papers with multi objectives

S.No.	References	Year	Obj1	Obj2	Obj3	Obj4	Obj5
1	Rajendren	1995	*				*
2	Riezebos et al.	1995	*	*			
3	Ho and Chang	1995		*			
4	Parthasarathy and Rajendran	1997		*		*	
5	Tan and Narasimhan	1997		*		*	
6	Stanfield et al.	1997	*				*
7	Younes et al.	1998	*				
8	R'ios-mercado and Bard	1999		*		*	
9	Cheng Edwin et al.	2000	*	*		*	
10	Alcaide et al	2002	*	*			
11	M'Hallah et al.	2003		*			
12	Feldmann et al.	2003		*			*
13	Wang L. et. al.	2003	*				
14	Nearchou	2004	*				
15	Low et al.	2004	*				
16	Chandra et al.	2004		*			*
17	Ruiz and Stutzle	2005	*			*	

18	Ravindran et al.	2005	*				
19	Hejazi Reza and Saghafian	2005	*				
20	Zhu and Wilhelm	2006	*	*	*	*	
21	Rad Farahmand et. al.	2006	*				
22	Luo and Chu	2007		*		*	
23	Eren	2007	*	*		*	
24	Bandyopadhyay et al.	2008	*				*
25	Fakhrzad and Heydari	2008		*			*
26	Allahverdi et al.	2008				*	*
27	Laha and Chakraborty Kumar	2008	*				
28	Eren and Guner	2008	*	*			
29	Naderi et al.	2009	*	*		*	
30	Gholami et al.	2009	*		*	*	
31	Ang et al.	2009	*			*	
32	Chiang and Fu	2009	*	*		*	
33	Manjeshwar Kumar et al.	2009	*				
34	Eren	2010	*			*	
35	Mazdeh Mahdavi et al.	2010		*			*
36	Li et al.	2010	*				
37	Wang and Wang	2010	*			*	
38	Safari and Sadjadi Jafar	2010	*		*		
39	Choi et al.	2010	*				
40	Mason and Chen	2010	*				
41	Zhao and Tang	2010	*	*		*	
42	Wu and Liu	2010	*				
43	Low and Lin	2011	*				
44	Wang and Li	2011	*	*		*	
45	Wang et al.	2011	*			*	
46	Azaron et al.	2011					*
47	Wang et al.	2011		*			
48	Wang et al.	2011	*			*	
49	Yu et al.	2011	*				

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Table 2: List of references opted for comparison of SA techniques in flow shop

S. No.	Authors	Year	Algorithms	System Specifications
1	Parthasarathy and Rajendran	1997	RIPS	Heuristics are coded in C, executed on a HP-9000 series workstation
2	Tan and Narasimhan	1997	SAA	Microsoft visual basic 3.0, run on an Am5x86-P75 CPU at 133 MHz with 16 MB of RAM
3	Younes et al.	1998	Improved SA	
4	Chakravarthy and Rajendran	1999	Heuristic & SAA	
5	Cheng Edwin et al.	1999	Guided SAA	Written in C language and executed on an ordinary PC
6	Alcaide et al.	2002	Stochastic scheduling	Coded in C++ language and computational results have been obtained using a PC Pentium 133 MHz processor.
7	Nearchou	2004	Hybrid SAA	Coded in Pascal & run on Pentium3 450MHz computer
8	Low et. al.	2004	Modified SAA	Pentium II 400 MHz personal Computer
9	Mansouri Afshin	2006	MOSA	Coded in CCC and executed on a Pentium IV Intel Centrino processor at 1.7 GHz under Windows XP with 512 MB RAM
10	Bandyopadhyay et al.	2008	MOO & AMOSA	
11	Laha and Chakraborty Kumar	2008	PSA heuristic	Coded in C and run on a Pentium4, 256MB, 2.8GHz PC
12	Manjeshwar Kumar et al.	2009	Heuristic & SAA	Implemented in MATLAB 6.5. & A Pentium 3 computer with a 261MB RAM was used to run all the experiments
13	Gholami et al.	2009	Simulation is incorporated in GA	Implemented in MATLAB 7.1 and ran on a PC with an AMD 2.08-GHz processor and 1.00-GB of RAM.
14	Naderi et al.	2009	Hybrid SA	Implemented in MATLAB 7.0 and run on a PC with 2.0 GHz Intel Core 2 Duo and 1 GB of RAM
15	Naderi et al.	2009	Metaheuristic	Implement the algorithms in MATLAB 7.0 and run on a PC with 2.0 GHz Intel Core 2 Duo and 1 GB of RAM memory
16	Mazdeh Mahdavi et al.	2010	Metaheuristic algorithm	Coded in VBA & Pentium 4, 1.86 GHz 1GB RAM personal computer is for experiment.
17	Czapinski	2010	SAwGE	Coded in C++, experiments were carried out on Cranfield University's Astral cluster, having 856 Xeon 3.0 GHz processors, 2 GB memory
18	Jamili et. al.	2011	Hybrid algorithm	Coded in VB on a Laptop with Pentium IV Core 2 Duo 2.53 GHz CPU.

19	Jia et al.	2011	Hybrid prediction method	the MATLAB software is utilized to estimate the SA–SVM model.
20	Lin et al.	2011	MSA heuristics	Implemented using C language and run on a PC with an Intel Pentium 4 (2.4GHz) CPUand512 MB memory.

Table 3: Comparison of different SA algorithms

No.	Compared with	Run time/ Iteration	growth	TS	IT	CR	PoA	FT	Comment
1	Parthasarathy and Rajendran (1997)	20 min	40%	30	475	0.9	0.9	20	Heuristic algorithm based on SA
2	Tan and Narasimhan (1997)	Pilot runs	Better		High	0.995	0.5	.10	Based on subsets of those problems used by Ragatz & Rubin and Ragatz
3	Younes et al. (1998)	5 iterations	Useful	60	1000	Gradually lowered	0.9		Based on (CDS) Heuristic, Dannenbring's heuristic & Palmer's Slope Index
4	Chakravarthy and Rajendran (1999)	20 min	25%	30	475	0.9	0.9	20	Heuristic algorithm based on SA
5	Cheng Edwin et .al. (1999)	n iterations	Perform better	40	0.2				Algorithm is a modified form of SA
6	Nearchou (2004)	High	Near efficient		50	0.9	0.99	1	Combines the characteristics of canonical SA with features borrowed from GA
7	Low et al. (2004)	50-300 iterations	Near optimal	10 - 15	100 - 1000	0.9	0.9	1	The NEH algorithm was modified as an initial solution & a modified SA was proposed

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8	Mansouri Afshin (2006)	1 min	Good	10	10	0.999	0.1	1	Based on SA
9	Laha and Chakraborty Kumar (2008)	12,6,3,2 and 1 iterations	High level		1000		0.95		Based on SA
10	Manjeshwar Kumar et al. (2009)	Less than 4 min	21.17%		1500 or 2000	0.8-0.99		1	A heuristic based on Johnson's algorithm and a SA algorithm
11	Naderi et al. (2009)	Iterates at most	Better		High	Gradually lowered	0.97	1	A novel SA with a new concept, called "Migration mechanism", and a new operator, called "Giant leap",
12	Naderi et al. (2009)	3 iterations	Better	30 - 100	10-20	Linear, exponential & hyperbolic		1	Metaheuristic based on SA
13	Czapinski (2010)	Varying	Efficient		1-200	0.9-1		0.1 -1	Based on a clustering Algorithm for SA
14	Jamili et. al. (2011)	1 hour	3.5%		150	0.32- 0.79			Based on EM–SA
15	Jia et al. (2011)	200 iterations			1000	0.965		0.1	Based on SA & SVM
16	Lin et al. (2011)	Formula based	Useful	44	1000	0.90		10	Combines MSHCS & SA

4. Conclusions

This paper describes a detailed review of recent flow shop scheduling based on simulated annealing (SA). Thus, the conclusion drawn from Table 1, 2 and 3 are,

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1. Most of the SA techniques are coded and run on powerful languages and computers simultaneously. Due to their high processor speed and higher memory they can eventually reduce the computational time of the operations which further implies low computer resource investment.
2. The SA has been employed with hybridization or substantial modification due to the increasing complexities of the flow shops.
3. The Efficiency of different techniques proposed has been tested on some common test data taken from conventional and other previous techniques. Also in some comparison results are taken directly.
4. Around 75% of the research papers, they convey information about initial temperature, cooling rate, probability of acceptance of technique and final temperature.
5. Every research papers coveys the information about run time/ number of iterations of the algorithm to perform the experiments.
6. The general trend of selection range of SA parameters are, Initial temperature: 10-1000, Cooling rate: 0.8- 0.99, Probability of acceptance: 0.5- 0.9, final temperature: 1-20 and with these parameter values SA is capable of producing good solutions.

In early 90's SA became a powerful optimization technique in flow shop scheduling and a number of research papers are presented which uses these techniques. The list of papers recognized with proposed SA algorithm, which leads to the solution technique in a flow shop scheduling problems for the last two decades. Since, much research work have already performed with simple SA algorithm in multi-objective scheduling domain, hence research trend is observed in implementing major modifications in SA algorithm, which are capable to outperform simple SA algorithm in many instances and the article presented here reflects a clear trend of using these temperature based modified techniques. Also, research papers are classified based on various criteria of SA such as its parameter selection, computer resource usage, hybridization and enhancement from the past work. These days further work is being continuously performed in developing new hybrid SA algorithms by using various methods such as combination of SA with GA or other optimizing methods thus developing better results than these results are again rectified counter checked and taken best results out of many using methods like Design of Experiment (DoE) and many more, which finally identify future research scope in this widely growing area.

Abbreviations

AMOSA- Archived Multi Objective Simulated Annealing

CDS - Campbell, Dudek and Smith

CR-Cooling Rate

EM-SA- Electro Magnetism Simulated Annealing

FSMP- Flow Shop with Multiple Processors

FSP- Flow Shop Production

FSPP- Flow Shop Production Problem

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FT- Final Temperaure

GSA- Guided Simulated Annealing

HSA- Hybrid Simulated Annealing

IT- Initial Temperature

MOO- Multi Objective Optimization

MOSA- Multi-Objective Simulated Annealing

MSA- Multi Start Simulated Annealing

MSHCS- Multi-Start Hill Climbing Strategy

NEH- Nawaz, Enscore, and Ham

PESP- Periodic Event Scheduling Problem

PFSSP- Permutation Flow Shop Scheduling Problem

PJSSP- Periodic Job Shop Scheduling Problem

PMBSP- Parallel Machines Bi-Criteria Scheduling Problem

PoA- Probability of Acceptance

PSA- Proposed Simulated Annealing

RIPS- Random Insertion Perturbation Scheme

SA- Simulated Annealing

SAA-Simulated Annealing Algorithm

SAwGE- Simulated Annealing with Genetic Enhancement

SDST- Sequence Dependent Set up Time

SVM- Support Vector Machine

TS- Temperature Stages

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