A Systematic Review for Solving Flow Shop Scheduling Problem Using Differential Evolution Algorithm

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Abstract

This paper uses a systematic literature review about the resolution of the Flow Shop Scheduling problem (FSP) using a Differential Evolution (DE) algorithm, in order to define the current state of the art, and to identify possible future works in that area. Research questions were first identified, and the search strategy identified 64 studies, after getting more information from the studies and applying exclusion and inclusion selection criteria only 48 studies were selected, and considered as primary studies for this research, this process was following the guidelines proposed by Kitchengam [19]. In addition to presenting our results, there are also some suggestions for future works in the filed based on the current systematic literature review. The obtained results give information about the initial population process which is commonly generated using random processes, and the processes used to create the new individuals in each generation of the algorithm. After the review, this paper suggests the research or proposal to use heuristic algorithms to generate initial individual and start the future generation individuals based on good individual solutions, this improvement will generate better solutions and increase the performance of the algorithm.

Keywords*:* Flow shop scheduling problem, differential evolution.

1. Introduction

A flow shop is a processing system in which the task sequence of each job is fully specified, and all jobs visit the work stations in the same order [10]. Differential evolution (DE) algorithm was introduced by Storn and Price [41]. Since then, due to its effectiveness, a lot of advanced work has been conducted in order to realize the full potential of this viable approach.

This systematic literature review will follow the guidelines proposed by Kitchenham (2007) [19], so the systematic literature review process can be divided into three phases: planning, conducting and reporting the review. Research questions were first identified, the studies were analyzed based on inclusion/exclusion criterions and a discussion of the selected studies was done.

The search strategy identified 64 studies, which were catalogued as primary studies for this review. Data extraction and synthesis was performed on these studies based on these research questions, and finally only 48 studies satisfied our requirements, this systematic review is based on those selected studies.

Results have shown that there is an opportunity to do researches or proposals to use heuristic algorithms to generate initial individual and start the future generation individuals based on good individual solutions, this improvement will generate better solutions and increase the performance of the algorithm. The remaining of this paper is organised as follows: Section 2 and section 3 presents concepts of Flow Shop Scheduling and Differential Evolution algorithm respectively. Section 3 describes the steps involved in the Systematic Review process followed by the presentation of its results in Section 4. Section 5 discusses the results of the review, and suggestions for improving the current state of Differential Evolution algorithm to solve Flow Shop Scheduling problem. Section 6 concludes the paper with suggestions and comments on possible future works.

2. Flow shop sheduling

In many manufacturing and assembly facilities a number of operations have to be done on every job. Often, these operations have to be done on all jobs in the same order, which implies that the jobs have to follow the same route. The machines are assumed to be set up and the environment is referred to as flow shop [31].

The flow shop can be formatted generally by the sequencing on n jobs on m machines under the precedence condition. The general constraints that are assessed for a flow shop system is the time required to finish all jobs or makespan, minimizing of average flow time, and the maximizing the number of tardy jobs.

In a pure flow shop each job has m tasks and visits all stages. More generally, jobs may have fewer than m tasks and may skip over some stations. Still, it is assumed that a job never visits any stage i' < i after it has visited stage i [10].

3. Evolution Differential Algorithm

The differential evolution (DE) algorithm introduced by Storn and Price (1995) [41] is a novel parallel direct search method, which utilizes NP parameter vectors as a population for each generation G. DE can be categorized into a class of floating-point encoded, evolutionary optimization algorithms. Currently, there are several variants of DE. The original variant is the DE/rand/1/bin [41] scheme. Since the DE algorithm was originally designed to work with continuous variables, the optimization of continuous problems is discussed in many studies, and the way it is handling discrete variables to continue variables is an important issue in this kind of proposals.

4. Systematic Review

The formulation of the research questions is the most important part of any systematic review [19]. This paper follows the guidelines published by Kitchenham [19], so the following section details the research questions which guide this review, and the procedure followed to identify the relevant studies for this systematic literature review.

4.1. Research Questions

The formulation of the research questions is the first step in the systematic review process [19]. The approach to formulating research questions is the PICOC criteria specified by Petticrew and Roberts [30]. For this paper we don't take into account Comparison and Outcome criteria. The attributes of the research questions are shown in Table 1.

Table 1. PICOC attributes

Population	Heuristic algorithms to solve Flow shop scheduling problems
Intervention	Evolution Differential algorithm
Context	Within the domain of proposals to solve Flow shop scheduling problem using Evolution Differential algorithm

The following research questions have been considered in order to identify and evaluate all the research done on solving Flow Shop Scheduling problem using a Differential Evolution algorithm:

Question 1:
What strategies of Differential Evolution algorithms have been applied in the proposals to solve the Flow Shop Scheduling Problem?

Question 2:
What methods have been used to generate the initial population of the Differential Evolution algorithm proposed to solve the Flow Shop Scheduling Problem?

Question 3:
What Improvements or additional steps have been added to Differential Evolution algorithms proposed to solve the Flow Shop Scheduling Problem?

4.2. Search strategy

The process of identifying the primary studies has been pre-defined and updated during the review process, these are the steps:

PICOC criteria were used to identify the search terms [30], these attributed are detailed in Table 1. Synonyms and abbreviations were also considered. Search strings were constructed to be used in the search process, it was done using Boolean operators (OR, AND).

The search string used in the systematic literature review is shown as follow:

Table 2. Final search string

Differential Evolution **AND** (fsp **OR** flow shop**OR** flow-shop **OR** flowshop)

4.3. Search process

Using the search string compiled, the search process was started, it was done on 05/30/2013. The string search was customized for each primary source to be adapted to its syntaxis.

ACM Digital Library: Keywords:"Differential Evolution" AND (Keywords:"fsp" OR Keywords:"flow fhop" OR Keywords:"flow-shop" OR Keywords:"flowshop")

IEEE Xplorer: "Index Terms":"differential evolution" AND ("Index Terms":"fsp" OR "Index Terms":"flow fhop" OR "Index Terms":"flow-shop" OR "Index Terms":"flowshop")

Scopus: KEY("differential evolution") AND (KEY("fsp") OR KEY("flow shop") OR KEY("flow-shop") OR KEY("flowshop"))

Science Direct: KEYWORDS("differential evolution") AND (KEYWORDS(" fsp") OR KEYWORDS("flow shop") OR KEYWORDS("flow-shop") OR KEYWORDS("flowshop"))

The list of primary sources is given in the Table 3 including the number of results and relevant articles.

Table 3. Summary of search results

Database name	Number of search results	Number of selected articles
ACM Digital Library	22	20
IEEE Xplorer	16	16
Scopus	64	63
Science Direct	12	12

There were 2 studies which are repeated in ACM, also in Scopus there was 1 study repeated. All results from ACM Digital Library, IEEE Xplorer and ScienceDirect are inside results from Scopus, so there were in total 64 studies returned in the searches.

4.4. Study selection

Inclusion and exclusion criteria for study selection: Studies will be selected for the literature review if they meet the following inclusion criteria:

- Study looks at the proposals of Differential Evolution algorithms to solve Flow Shop Scheduling problems.
- Study describes the method to generate the initial population.
- Study describes the additional methods proposed to improve the Differential Evolution algorithm.
- About exclusion criteria, studies will be excluded if they:
- Do not focus on solve a Flow Shop Scheduling problem.
- Do not focus on a proposal of Differential Evolution algorithm.
- Only provide a schema to improve any internal step of Differential Evolution algorithm.
- Use Differential Evolution algorithm to generate values which are input for other algorithms which solve the Flow Shop Scheduling problem.

Selection process: After apply the inclusion and exclusion criteria, the quality of the primary studies selected was improved, because some articles which are not part of the objective of this systematic literature review were retired. Complete reference information was imported from the primary source and saved in some forms. For those studies which were found relevant, a digital copy of the paper was got and saved. As a next step, the digital copies attached previously were analyzed in detail. This final step was very useful for any article which has a disagreement about inclusion or exclusion criteria. After completing the final selection process, 16 studies were excluded:

4 studies use the Differential Evolution algorithm as a reference to compare their proposed algorithm.
2 studies propose new algorithm based on Differential Evolution algorithm, but they are not full compliant Differential Evolution algorithms.
2 studies do not have any relation with the purpose of this systematic review.
2 studies propose Differential Evolution algorithms, but they do not any solve Flow Shop Scheduling problem.
1 study proposes a generic algorithm, but it is not a Differential Evolution algorithm.
4 studies use a Differential Evolution algorithm to generate internal results, which will be used as input values to their proposed algorithm.
1 study provides a review and evaluation of the best-known encoding schemes to convert floating-point to integer in differential evolution for permutation flow shop scheduling, but it doesn't propose an algorithm.

The remaining 48 studies, are the approved studies for this review, a list of all these studies is provided in table 4.

Table 4. Approved studies

ID	Study
S01	A self-adaptive differential evolution heuristic for two-stage assembly scheduling problem to minimize maximum lateness with setup times [1]
S02	Flow shop scheduling using enhanced differential evolution algorithm [4]
S03	Flowshop scheduling using clustered differential evolution [6]
S04	CUDA based Enhanced Differential Evolution: A computational analysis [3]
S05	Clustered enhanced differential evolution for the blocking flow shop scheduling problem [5]
S06	A hybrid discrete differential evolution algorithm for the no-idle permutation flow shop scheduling problem with makespan criterion [7]
S07	Solving the flow shop problem with limited buffers using differential evolution [8]
S08	Optimisation of flow-shop scheduling with batch processor and limited buffer [9]
S09	DE solution for the earliness/tardiness case of Hybrid Flow-shop Scheduling problem with priority strategy [12]
S10	Cost optimization problem of hybrid flow-shop based on differential evolution algorithm [11]
S11	Multiple rules decision-based DE solution for the earliness-tardiness case of hybrid flow-shop scheduling problem [13]
S12	Hybrid PSO/DE solution for the earliness/tardiness case of hybrid flow-shop scheduling problem [14]
S13	Differential evolution method for stochastic flow shop scheduling with limited buffers [17]
S14	A hybrid differential evolution algorithm for stochastic flow shop scheduling with limited buffers [16]
S15	A differential evolution approach for NTJ-NFSSP with SDSTs and RDs [15]
S16	An improved quantum differential algorithm for stochastic flow shop scheduling problem [18]
S17	An opposition-based differential evolution algorithm for permutation flow shop scheduling based on diversity measure [20]
S18	An improved differential evolution for permutation flowshop scheduling problem with total flowtime criterion [21]
S19	A multi-objective flow shop scheduling with resource-dependent processing times: Trade-off between makespan and cost of resources [22]
S20	Scheduling flow shops using differential evolution algorithm [23]
S21	Effective heuristics based on differential evolution and variable neighborhood search for no-wait flow shop [24]
S22	Some meta-heuristics for no-wait flow shop problem [29]
S23	A discrete differential evolution algorithm for the permutation flowshop scheduling problem [25]
S24	A novel differential evolution algorithm for no-idle permutation flow-shop scheduling problems [26]
S25	A novel differential evolution algorithm for bi-criteria no-wait flow shop scheduling problems [28]
S26	An effective hybrid discrete differential evolution algorithm for the flow shop scheduling with intermediate buffers [27]
S27	A hybrid differential evolution method for permutation flow-shop scheduling [34]
S28	A DE-based approach to no-wait flow-shop scheduling [33]

S29	Rolling strategy and optimization algorithm for dynamic no-wait flow shop scheduling problem [35]
S30	An effective hybrid DE-based algorithm for multi-objective flow shop scheduling with limited buffers [36]
S31	An effective hybrid DE-based algorithm for flow shop scheduling with limited buffers [37]
S32	Hybrid differential evolution optimization for no-wait flow-shop scheduling with sequence-dependent setup times and release dates [38]
S33	A differential evolution algorithm with two speed-up methods for NFSSP with SDSTs and RDs [32]
S34	A differential evolution algorithm for lot-streaming flow shop scheduling problem [39]
S35	A discrete differential evolution algorithm for lot-streaming flow shop scheduling problems [40]
S36	A discrete differential evolution algorithm for the no-wait flowshop scheduling problem with total flowtime criterion [45]
S37	A discrete artificial bee colony algorithm for the permutation flow shop scheduling problem with total flowtime criterion [42]
S38	A discrete artificial bee colony algorithm for the total flowtime minimization in permutation flow shops [43]
S39	A differential evolution algorithm for the no-idle flowshop scheduling problem with total tardiness criterion [44]
S40	Performance evaluation of proposed differential evolution and particle swarm optimization algorithms for scheduling m-machine flow shops with lot streaming [46]
S41	Research on waiting time optimization problem of hybrid flow-shop [47]
S42	A novel hybrid discrete differential evolution algorithm for blocking flow shop scheduling problems [48]
S43	A self-adaptive differential evolution for the permutation flow shop scheduling problem [49]
S44	Differential evolution algorithm for hybrid flow-shop scheduling problems [50]
S45	A hybrid algorithm based on simplex search and differential evolution for hybrid flow-shop scheduling [51]
S46	Solving flow shop scheduling problems by quantum differential evolutionary algorithm [52]
S47	Differential evolution algorithm for the earliness/tardiness hybrid flow-shop scheduling problem [53]
S48	Optimization of flow shop scheduling problem using differential evolution and variable neighborhood search [54]

4.4. Study quality assessment

The quality assessment checklist was taken from the "Quality Assessment Checklist for Primary Studies" proposed by Azhar [2]. This checklist will provide a means to quantitatively assess the quality of the evidence presented by these studies [2]. For this checklist each question utilizes the same three point answer scale:

Yes, 1 point.
No, 0 points.
Partially, 0.5 points.

A study could thus score between 0 and 12, with the higher the overall score a study obtains, the greater the degree with which this study addresses our research questions. We selected the first quartile (i.e. 3) to act as a cutoff point, with any study scoring 3 or below being excluded form or final reference library. The first author performed the quality assessment for all X articles and none of the primary studies selected fell into this category [2].

The Table 5 details the quality assessment checklist used to evaluate the studies.

Table 5. Quality assessment checklist for studies

No	Question	Answer
1	Are the research aims clearly specified?	Yes/No/Partially
2	Was the study designed to achieve these aims?	Yes/No/Partially
3	Are the prediction techniques used clearly described and their selection justified?	Yes/No/Partially
4	Are the variables considered by the study suitably measured?	Yes/No/Partially
5	Are the data collection methods adequately detailed?	Yes/No/Partially
6	Is the data collected adequately described?	Yes/No/Partially
7	Is the purpose of the data analysis clear?	Yes/No/Partially
8	Are the statistical techniques used to analyze the data adequately described and their use justified?	Yes/No/Partially
9	Were potential confounders suitably controlled for in the analysis?	Yes/No/Partially
10	Are the study findings credible?	Yes/No/Partially
11	Are negative results (if any) presented?	Yes/No/Partially
12	Do the researchers discuss any problems with the validity/reliability of their results?	Yes/No/Partially

5. Results

The data extracted for the studies is compiled and it is addressed to each research question.

5.1. Question 1

Question 1 looks at what strategies of Differential Evolution algorithms have been applied in the proposals to solve the Flow Shop Scheduling Problem. There are 24 studies which specify the DE strategy applied, the other 24 studies do not provide that information. The most used strategy is the original **DE/rand/1/bin**. This strategy is used in pure Differential Evolution (DE) algorithms, and also some variants of this algorithm still continue using it. The second strategy most used is **DE/best/1/bin**, which uses the best individual of the population to generate the perturbation (mutation) of the new individual.

Table 6 lists the identifiers of studies which explain the strategy used in the proposal classified by type of strategy for this question.

Table 6. DE strategies used in proposals

Strategy	Studies
DE/best/1/bin	S07, S26, S34, S35, S40.
DE/rand/1/bin	S01, S06, S20, S36, S42, S43, S44, S45.
DE/best/2/bin	S04, S05.
DE/rand/2/bin	S03.
DE/rand-to-best/1/bin	S02, S33.
DE/rand-to-best/1/exp	S13, S15, S30, S32.
DE/target-to-best/1/exp	S17, S28.

5.3. Question 2

Question 2 looks at the methods used to generate the initial population of the Differential Evolution algorithms proposed to solve the Flow Shop Scheduling Problem. There are 32 studies which explain the way they are initializing the population. Detail explanations of the proposals are listed below:

Random: This proposal is the original, it creates randomly each member of the population.

2 populations (1 based on NHE Heuristic and the other randomly): This proposal generates two initial populations and start to work in the algorithm with both of them and analyze which is better in every generation.
First solution generated by NHE Heuristic: This proposal constructs the first solution using NEH heuristic, the rest of the solutions in the population are constructed randomly based in the first solution generated.

First solution generated by LSL and OSL rules: The smallest slack time on the last machine (LSL), and the smallest overall slack time (OSL) rules are commonly used to produce initial sequences for the scheduling problems with total weighted earliness and tardiness criterion, this paper applies these rules to generate three initial sequences, respectively. The other individuals are produced randomly based on the previous individuals generated.

PWQ heuristic: A study proposes a bi-objective heuristic based on the NEH and EDD heuristics, named PWQ heuristic.

NN and NHE heuristics: The initial population is constructed by two popular heuristics, namely the nearest neighbor (NN), and the NEH insertion heuristic.

Table 7 lists studies which propose a new way to initialize the population.

Table 7. Proposals on initialization of population

Method	**Studies**
Random	S09, S15, S16, S20, S27, S28, S30, S32, S33, S43, S44, S45, S46, S47.
2 populations (1 based on NHE Heuristic and the other randomly)	S18
First solution generated by NHE Heuristic	S03, S05, S06, S07, S17, S23, S26, S37, S38, S42.
First solution generated by LSL and OSL rules	S34, S35
PWQ euristic	S25
NN and NHE heuristics	S36

5.3. Question 3

The final question is directed at looking for improvements or additional steps added to Differential Evolution algorithm to solve the Flow Shop Scheduling problem. There are improvements applied in the algorithm like local search. The list below has a detail explanation of each kind of improvement:

2-opt local search: 2-opt is a simple local search algorithm, which help to the proposed algorithm to get better individuals in the generation.
2-opt local search and clustered population: Added to the 2-opt local search algorithm, this approach subdivides the population in clusters, each cluster a distinct distance from another. Population structure based on structured and random generated candidate solutions, and the application of clustering of these candidate solutions based on deviation and spread.
Local search: This search algorithm improves the performance of the Differential Evolution algorithm looking for new members locally inside the best member of the population.
LOV rule: A largest-order-value (LOV) rule is presented to convert the continuous values of individuals in Differential Evolution to job permutations.
Simplex search: A study propose simplex search to improve the results of the next generation.
VNS local search: With this local search the algorithm produces slightly better results and also improves the performance.

Table 8 lists the approved studies classified by type of improvement for this question.

Table 8. Proposals on improvements to the Differential Evolution algorithm

Improvement	**Studies**
2-opt local search	S02, S04
2-opt local search and clustered population	S03, S05
Local search	S13, S14, S24, S26, S35, S38, S42, S44
LOV rule	S15, S27, S28, S30, S31, S32, S43
Simplex search	S45
VNS local search	S21, S46, S48

6. Discussion

The results of the systematic review address three areas of developments and approaches proposed for Differential Evolution algorithms to solve Flow Shop Scheduling problem:

Differential Evolution strategy to choose is important based on the variant of the problem. Internal improvement steps in the generation of the trial individual, to improve performance and results of the algorithm. The generation of the initial population is very important; it can be the decisive step in the algorithm to generate better results in the future generations.

The analyzed studies in this systematic review can provide a general picture of the development and proposals to solve Flow Shop Scheduling problem using a Differential Evolution algorithm.\\

There are some proposals to only improve internal steps of the algorithm, and also these proposal have been validated running the algorithm and compare the results with validated algorithms like Genetic Algorithm, Tabu Search algorithm, or Particle Swarm Optimization algorithm. Also there are proposals to work in the generation of the initial population, providing some heuristic methods to generate the first individual and the other ones randomly using some minimum and maximum values extracted from the first member generated.

It is important to mention that the Differential Evolution strategy to use in the proposal is very important, because the algorithm can have different behaviors based in the selected strategy, we can choose 1 of the 10 strategies listed by Onwubolu et al. 2006 [23]. Each strategy is chosen based on the variant of the Flow Shop Scheduling problem. Also some studies which are not focus on solving Flow Shop Scheduling problem were analyzed because they were returned during the database search process, there were good proposals for solve Scheduling problems, like Task Scheduling problem or Operating Room problem, but they are not part of our systematic review. So those studies can be taken into account in a systematic review about other types of Scheduling problem solved by Differential Evolution algorithm, it can be a work for the future.

7. Conclussion

This paper presents a systematic review on the resolution of Flow Shop Scheduling problem (FSP) using Differential Evolution algorithm. The search returns in total 64 studies, of which 48 were selected. The 16 studies were excluded because of they do not refer to any proposal to a Differential Evolution algorithm to solve the FSP problem. Many of them were other Scheduling problems, which is not in the scope of this review.

About the selected studies, they do some proposals about: Improve the process of the creation of new individuals in the generations of the algorithm, others apply some heuristic methods to generate better initial individuals. Also, there are proposals which emphasise the process of the selection of the right Differential Evolution strategy. The question 2 looked for know what kind of ways or methods are used to generate the initial population in the proposals, and the results show that more of them use random process to do it. So this step needs to have more attention in the proposals because if the initial individuals have a good quality solution, the evolution of the algorithm increases exponentially.

Based on the results of this Systematic Review, this paper suggests the research or proposal to use heuristic algorithms to generate initial individual and start the future generation individuals based on good individual solutions, this improvement will generate better solutions and increase the performance of the algorithm.

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