IG-BS-LS: An Iterated Greedy Algorithm with Beam Search Reconstruction for the Permutation Flow Shop Problem

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***Abstract*—This paper proposes a hybrid metaheuristic, Iterated Greedy with Beam Search and Local Search (IG-BS-LS), for Permutation Flow Shop Problem (PFSP) with makespan minimization. The algorithm integrates an Iterated Greedy framework with a Beam Search procedure, with Limited Discrepancy Search, for solution reconstruction. We also employed effective destruction strategies and adaptive guide functions. The proposed IG-BS-LS is evaluated on standard Taillard benchmark instances, demonstrating its capability to find high-quality, near-optimal solutions. While the performed tests indicate that IG-BS-LS outperforms several state-of-the-art algorithms, achieving competitive results in terms of solution quality and computational efficiency, the algorithm's performance is very sensitive to the choice of parameters, which is a challenge especially because of the large number of parameters involved.**

***Index Terms*—Permutation Flow Shop Problem, Iterated Greedy, Beam Search, Local Search, Metaheuristic, Makespan Minimization.**

I. Introduction

The Permutation Flow Shop Problem (PFSP) is considered as a cornerstone in the field of scheduling research, primarily due to its significant practical implications in diverse manufacturing and production environments, and also for its inherent combinatorial complexity [1]. In this problem, a set of N jobs must be processed through M machines, following an identical technological sequence for all jobs.

The PFSP is known to be NP-hard for $M \geq 3$ machines [2], and the use of exact optimization methods is viable only for instances of modest scale. Consequently, a vast amount of research has focused on developing effective heuristics and metaheuristics. Early contributions included constructive heuristics such as the Palmer heuristic [3], the CDS heuristic [4], and notably, the NEH heuristic [5], which remains a widely adopted benchmark due to its efficacy.

As the field evolved, metaheuristics emerged to provide more robust solutions for larger and more complex instances. These approaches range from single-solution based methods like Simulated Annealing (SA) and Iterated Local Search (ILS) [6], to population-based techniques such as Genetic Algorithms (GA). Among these, the Iterated Greedy (IG) algorithm, introduced by Ruiz and Stützle [7], has proven to be a particularly powerful and adaptable framework for tackling permutation-based scheduling problems. IG algorithms operate by iteratively deconstructing a current solution and then reconstructing a new one, often incorporating a local search phase for intensification. Furthermore, Beam Search (BS) [8] is a tree search heuristic that explores a limited number of promising nodes at each level, and has been effectively utilized, sometimes within hybrid frameworks, for scheduling problems [9].

This paper introduces a novel hybrid metaheuristic, termed IG-BS-LS, designed to effectively solve the PFSP with makespan minimization. The core contribution of this work lies in the integration of an Iterated Greedy (IG) framework with a sophisticated Beam Search (BS) algorithm, enhanced by Limited Discrepancy Search (LDS) [10], for the solution reconstruction phase. This approach aims to effectively combine the exploratory capabilities of IG and the high-quality solution construction provided by BS-LDS, which is a departure from simpler greedy reconstruction methods often found in IG implementations. An efficient insertion-based Local Search (LS) is also employed to further intensify the search around promising solutions. The proposed IG-BS-LS algorithm is evaluated on well-known Taillard benchmark instances [11].

The remainder of this paper is organized as follows: Section II formally defines the Permutation Flow Shop Problem. Section III provides a detailed description of the proposed IG-BS-LS algorithm and its components. Section IV outlines the experimental setup, including benchmark instances and performance metrics. Section V presents and discusses the computational results. Finally, Section VI offers concluding remarks and suggests avenues for future research.

II. PROBLEM FORMULATION

The Permutation Flow Shop Problem (PFSP) under consideration addresses the scheduling of a set of N independent jobs, denoted as $J = \{J_1, J_2, \dots, J_N\}$, that must be processed on a series of M distinct machines, $Mach = \{M_1, M_2, \dots, M_M\}$. All jobs follow the same technological routing, visiting machines in the order $M_1, M_2, \dots, M_M$. The processing of job