


Chapter 8

Mathematical Modeling and Metaheuristic Optimization for Distributed No–Wait Flow Shop Scheduling in Desalination Systems

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ABSTRACT

Desalination is an innovative solution to the global water shortage; however, scheduling and resource allocation in these systems present significant challenges. To address these challenges, this paper investigates the application of metaheuristic optimization techniques to enhance the performance of distributed desalination systems. The problem is formulated as a distributed flow shop scheduling model, with the primary objective of minimizing total flow time (TFT) to ensure timely water production and operational efficiency. To solve this, three metaheuristics are proposed: Iterated Greedy, Iterative Local Search, and Variable Neighborhood

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Search. The effectiveness of these metaheuristics is enhanced using two initialization techniques: NEH and GRASP, yielding a total of six approaches. A comprehensive simulation study was conducted on a set of benchmark instances. The results show that all proposed metaheuristics provide valuable solutions for minimizing TFT and optimizing resource allocation, with varying levels of performance across different instances.

INTRODUCTION

Water scarcity is one of the most pressing global challenges of the 21st century, impacting millions of people. Population growth, urbanization, and climate change continue to intensify the pressure on freshwater resources. With 97.5% of the Earth's water being seawater and only 2.5% freshwater, 80% of which is locked in glaciers, only 0.5% of total water is readily accessible for human use (Ibrahim et al., 2017). In this context, desalination has become a crucial solution, enabling the conversion of abundant seawater into potable water and reducing dependence on traditional freshwater sources.

The global reliance on desalination has grown significantly in recent decades. As of June 2018, there were over 16,000 desalination plants in operation worldwide (Voutchkov et al., 2019), producing 87.5 million cubic meters of water per day and providing water for approximately 300 million people. Saudi Arabia is the largest producer of desalinated water (DeNicola et al., 2015; Darre et al., 2018), meeting 60% of its total water demand through desalination and holding a market share of 16.5% (Nair & Kumar, 2013). In countries like Qatar and Kuwait, desalination provides 100% of the water supply (Blanco-Marigota et al., 2017). As desalination capacity expands, the operational complexity of these systems increases, particularly in regions where multiple plants operate in a distributed manner to meet large-scale demand. Distributed Desalination Systems (DDS), characterized by multiple plants working collaboratively, offer several advantages, including localized water supply, reduced transportation costs, and enhanced resilience to disruptions. However, these systems introduce significant challenges in scheduling and resource allocation, requiring efficient coordination across multiple facilities.

The desalination process involves a sequence of stages, each requiring a specific machine to ensure efficient water treatment. A simple desalination process as illustrated in Figure 1, begins with the intake pump machine, which draws seawater into the plant system. Next, the screening machine removes large debris and marine organisms to protect the equipment. The seawater then passes through the pretreatment filtration unit, which eliminates fine particles and biological contaminants. After that, the high-pressure machine increases the water pressure, allowing it to

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