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Reviewer's opinion
on Ph.D. dissertation authored by
Jakub Wawrzyniak
entitled:
Combinatorial optimization problems in port logistics

1. Problem and its impact

In his dissertation, Jakub Wawrzyniak considers several combinatorial optimization problems emerging in port logistics. The first part is dedicated to the deterministic quay partitioning problem, where a quay has to be partitioned into berths in order to optimize the servicing of ships which arrive according to a known scenario. The goal of the next chapter is constructing portfolios of efficient heuristic algorithms for the well-known berth allocation problem, where the ships assignment to berths, and the order in which they are serviced, are optimized. Afterwards, a ship traffic model reflecting historical data from real ports is built. Finally, the stochastic quay partitioning problem is introduced. This part of the dissertation builds on the research presented in the previous chapters, as the ship traffic model represents the uncertainty of future vessel arrivals, and a portfolio of algorithms solving the berth allocation problem is used to evaluate the obtained quay partitions. All the analyzed problems are interesting from the scientific point of view, and their practical meaning is obvious.

2. Contribution

In the introduction chapter, Jakub Wawrzyniak formulates a hypothesis that *maritime container terminal performance can be improved by optimization of quay partitioning into berths*, describes the methodology used in his research, and presents the outline of the thesis. A review of related literature follows. Chapters 3 – 6 contain the main contributions related to the following problems.

A. Deterministic Quay Partitioning Problem (DQPP)

In the deterministic quay partitioning problem, a single future ship arrival scenario is assumed. For each vessel, its length, arrival time, service time, and importance (called the weight) are known. The quay length and a set of admissible berth lengths are also given. The goal is to select the number of berths and their lengths so as to minimize the mean weighted flow time (MWFT) of the vessels.

In the dissertation, two berthing schemes are analyzed. In the 1in1 scheme, at most one ship can occupy a berth at a time; in the 2in1 layout, two ships can be positioned at the opposite ends of one berth, provided that they fit together in the berth length. After presenting a formal description of the problem, the author proves that DQPP is NP-hard, both for 1in1 and 2in1 variant. Afterwards, the two versions of the problem are formulated as mixed integer linear programs (MIP). Computational experiments are conducted in order to assess the time performance of solving the MIPs and study the features of the delivered optimum or near-optimum solutions. The obtained results are presented in numerous charts. Unsurprisingly, the 2in1 layout performs better than 1in1, and hence, the author decides to use it in the following research. In the chapter summary, practical hints for terminal designers are also given.

The above results on DQPP have been published in *International Transactions in Operational Research* in 2024. Jakub Wawrzyniak is the first author of the paper.

B. Selecting Algorithms for Berth Allocation Problem (BAP)

The berth allocation problem consists in minimizing the MWFT for a given vessel arrival scenario and a fixed set of available berths. Thus, a solution to the quay partitioning problem may be a part of input for BAP, and solving an instance of BAP is required to evaluate a given solution to QPP.

Although many papers on solving different variants of BAP already exist, Jakub Wawrzyniak claims that the algorithms proposed in the literature are unsuitable for solving very large instances emerging in QPP. Moreover, a single algorithm is not capable of delivering the highest quality solutions for instances of diffferent sizes when a runtime limit has to be observed. Therefore, the candidate proposes constructing portfolios of algorithms for solving BAP, which evolve with the changing runtime limit.

Several groups of algorithms are considered as possible members of the portfolios: multiple greedy algorithms distinguished by sorting rules and control structures used, three hill climbers, six GRASP implementations, and two variants of iterated local search. Together they constitute a remarkably large set of solution methods. No explanation is given about the way in which particular metaheuristics were chosen. Was simplicity the main factor?

The algorithms are tested on four randomly generated datasets and one dataset representing real ship traffic. After the initial evaluation of the individual algorithms, two types of portfolios, i.e. cover portfolios and regret portfolios, are constructed and evaluated. It is shown that portfolios consisting of a fixed set of algorithms are not competitive for all time budgets when compared to cover portfolios evolving in time.

The contribution of this part of the dissertation is not only a collection of algorithm portfolios for solving BAP, but also a method consistently recognizing useful algorithms on the basis of their performance under a runtime limit, which can be applied to other problems.

The above results have been published in *European Journal of Operational Research* in 2020. The paper currently has 53 citations according to Google Scholar. Jakub Wawrzyniak is its first author.

C. Ship Traffic Model (STM)

Generating test data for QPP and BAP, resembling real traffic in existing ports, is yet another challenge. The thesis presents a statistical model of ship traffic, which is more advanced and detailed than the previously existing models. Historical data from eight ports of different characteristics are used. As it turns out that the differences between the traffic in these ports are significant, eight different models are actually built. The ships are divided into clusters, depending on their sizes. Each cluster has its own servicing time and arrival time statistical representation. The processing time model reflects the correlation between the ship length and its processing time. The arrival time model includes ships periodically returning to the port as well as non-returning ships. The whole STM is explainable, and recommendations on choosing the right model depending on the port characteristics are given.

The above research was published in *International Journal of Applied Mathematics and Computer Science* in 2022. Again, Jakub Wawrzyniak is the first author of the paper.

D. Stochastic Quay Partitioning Problem (SQPP)

In the stochastic quay partitioning problem, the input is the quay length with a set of admissible berth lengths, and a ship traffic model with the parameters of traffic intensity and time horizon. Thus, instead of a single vessel arrival scenario present in DQPP, a larger number of scenarios can be generated according to a given STM. In order to evaluate a given solution to SQPP, i.e. the chosen set of berth lengths, a portfolio of algorithms is executed for each generated scenario. The measure of a quay partition quality is the average MWFT value over the scenarios and algorithms.

Several algorithms for solving SQPP are proposed: brute-force enumeration, an approach based on histogram matching and integer programming, a simple Big Berths First heuristic, a hill climber and a tabu search. An algorithm producing random partitions is used as a reference. The proposed hill climber (and in consequence, also the tabu search) is not a method that can be used for any instance of the problem. For some sets of allowed berth lengths, there are no possible split or merge moves. This should be highlighted in the description of this approach.

The author studies the features of solutions obtained by brute-force enumeration, such as patterns in the chosen berth lengths, the dispersion of quality of the generated partitions, and their similarity. Afterwards, the partitioning algorithms are evaluated. As could be expected, it turns out that different algorithms achieve the best performance depending on the type of test instance solved.

I think that the metaheuristics designed for SQPP should also be used for solving DQPP, in order to compare their performance with the MIPs presented in Chapter 3. It seems that there are currently no results about heuristic approaches to DQPP, which leaves a noticeable gap in the research on this problem.

A short section on the technical aspects of solving SQPP is included at the end of Chapter 6. The candidate describes the workflow used, analyzes its scalability and reports on the possible failure types and their probability. This information is particularly interesting, because such aspects of running computational experiments are usually omitted in research papers.

3. Correctness

The presented scientific research steps follow the generally accepted standards in the field of combinatorial optimization. At the beginning, the NP-hardness of DQPP is proved, which together with the NP-hardness of BAP justifies proposing exponential exact algorithms and heuristics in the following parts of the dissertation. The mixed integer linear programming formulations are correct. The choice of heuristic algorithms and their implementation details are reasonable. The computational experiments are correctly designed; the number and diversity of test instances are more than sufficient, and the trade-off between quality of solutions and algorithm running time is taken into account. The full extent of the experiments is visible in the main part of the thesis and in Appendices C and D. The ship traffic models are built on detailed analysis of real-world data, and the choices made are clearly explained. The conclusions are well supported by the data.

The analysis of the experimental results is exemplary. The choice of various quality distribution performance metrics is convincingly justified. Statistical tests are used to confirm the significance of differences in the performance of the algorithms. The graphical representation of numerical results is also very good and helps grasp the most important findings quickly.

4. Knowledge of the candidate

I am convinced that Jakub Wawrzyniak has a very good general knowledge and understanding in the discipline of Information and Communication Technology, with a focus on combinatorial optimization and its applications in port logistics. He demonstrates it in a thorough review of related literature in Chapter 2, and the list of 106 references. He also proves his knowledge by using diverse techniques for constructing exact algorithms, heuristics and metaheuristics. Implementing the algorithms and conducting extensive computational experiments required good technical skills. The interpretation and validation of the experimental results show the candidate's competence in data analysis.

5. Other remarks

The text of the dissertation contains some minor flaws:

- In Chapters 1 and 2, the part related to Chapter 5 appears before the one concerning Chapter 4, which is rather unusual.
- On page 33, it is written that the "weighted sum of vessel completion times" is minimized. I think it should be the "weighted sum of vessel flow times".
- In some charts (Fig. 3.3, 3.5, 3.6), symbols are replaced by their descriptions (e.g., "lambda" instead of "λ"). It is not so difficult to insert proper symbols in the pictures.
- In Fig. 3.3d and 3.4d, two different lines are described as "Lc=5" (by the way, should "Lc" be "L_{max}"?).
- Table 6.1 is not referenced in the text.
- In reference [60], the authors' first names are treated as surnames and vice versa.
- In reference [89], a link is probably missing.
- In reference [94], the list of authors is incorrect.
- Some typos and grammar mistakes (like using "which" instead of "whose" on pages 20, 97 and 132) can also be found.

However, the number of such issues is small for a text of almost 150 pages (excluding appendices).

6. Conclusion

Taking into account what I have presented above and the requirements imposed by Article 187 of the A*ct of 20 July 2018 - The Law on Higher Education and Science* (with amendments)[1], my evaluation of the dissertation according to the three basic criteria is the following:

A. Does the dissertation present an original solution to a scientific problem? (the selected option is marked with **X**)

X				
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

B. After reading the dissertation, would you agree that the candidate has general theoretical knowledge and understanding of the discipline of **Information and Communication Technology**, and particularly the area of Combinatorial Optimization?

[1] http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190000276

[X]	[ ]	[ ]	[ ]	[ ]
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

C. Does the dissertation support the claim that the candidate is able to conduct scientific work?

[X]	[ ]	[ ]	[ ]	[ ]
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

Moreover, taking into account the extensiveness of the performed computational experiments, and the meticulous analysis and validation of their results, I **recommend to distinguish** the dissertation for its quality.

Signature