Modeling and Solving an Automotive Paint Shop Scheduling Problem

Felix Winter · Emir Demirović · Nysret Musliu · Christoph Mrkvicka

1 Introduction

In the paint shops of the automotive supply industry, a large number of painting jobs are processed every day. Many material pieces have to be painted in a variety of colors that can later be used as exterior systems for car manufacturing. Since the painting process causes many sequence dependent costs, like for example setup times that can lead to delays or loss of paint whenever the color has to be changed, finding an optimized schedule is of high importance for an efficient production.

In this work, we introduce a novel scheduling problem that appears in the paint shops of the automotive supply industry. Although related problems like the car sequencing problem have been studied in the past (e.g. in [3], [4]), this problem includes unique features regarding the multi-objective minimization of sequence dependent changeover times, that to the best of our knowledge have not been described before. Furthermore, we create a collection of benchmark instances and propose a heuristic approach to solve the problem.

Felix Winter and Nysret Musliu
Christian Doppler Laboratory for Artificial Intelligence and Optimization for Planning and Scheduling
DBAI, TU Wien
E-mail: {winter,musliu}@dbai.tuwien.ac.at
Emir Demirović
School of Computing and Information Systems, University of Melbourne, Australia
E-mail: edemirovic@unimelb.edu.au
Christoph Mrkvicka
MCP GmbH, Vienna, Austria
E-mail: christoph.mrkvicka@mc-partners.at

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2 Problem Description

During the process of painting, each raw material piece will be transported through the paint shop on a custom-made carrier device. There exist several physical types of such carrier devices, where each type can carry different configurations of multiple raw materials. The raw materials within a single configuration will during production pass by painting stations and therefore be simultaneously painted with the same color. Since the carriers are moved through the paint shop on a circular system of conveyor belts, the painting schedule is usually organized in rounds. Within each painting round, several carrier units will be painted one after the other in a sequence that is predetermined by the schedule. However, the number of processed carriers per round as well as the exact sequence do not necessarily have to be equal for each round. Whenever a carrier unit has passed a painting station on its way through the paint shop, the next carrier in the queue can already be processed at the now available station. Since the time it takes to apply the paint to the materials is strongly influenced by the number of color changes within the schedule, the total processing time for one round depends on the scheduled carrier sequences.

Therefore, a solution to the problem described in this work will plan painting sequences for multiple rounds of production and further determine the raw material and color configurations for the carrier units in the schedule. However, not any schedule is also technically feasible and the following constraints impose restrictions on solutions:

- *The number of carrier units per round must lie between a minimum and a maximum value.*
- *The number of consecutive carrier units of the same type must lie between a minimum and a maximum value.*
- *The total number of carrier units per round is restricted to a maximum for each carrier type.*
- *Some carrier type sequences are forbidden.*
- *Some color sequences are not allowed to appear in the schedule.*
- *All demanded material pieces must be scheduled by the associated due dates.*
- *Sufficient color supply systems must be available for all scheduled color sequences.*

Furthermore, the multi-objective minimization function includes the following optimization targets:

- *Minimize the number of color changes within the sequence:*
  Keeping the number of color changes as low as possible is motivated by the fact that each color change will require the painting utilities to be cleaned which in turn will lead to a loss of remaining color in the tubes. Additionally, switching between the color supply systems may cause idle times, because the conveyor belts may have to pause until the new color is available.

- *Minimize the number of carrier type changes between consecutive rounds:* Since scheduled rounds are processed one after the other and all carrier units within a round are moving through the paint shop simultaneously, it is often required to remove and insert carrier units from the conveyor belt system between two consecutive rounds. However, if carriers of the same type will be used in two consecutive rounds, it can be possible to keep them on the conveyor belts as long as the sequence of the kept units is compatible with the scheduled carrier sequence in the succeeding round. Since the insertion and removal of carrier units from the circular track leads to delays and can in general not be done in parallel it is desired to keep the number of such operations as low as possible.

Similar problems that have been described in the literature (e.g. [1], [2]) deal with the minimization of color changes in the schedule. However, the minimization of carrier type changes between rounds has to the best of our knowledge not been described before.

3 Solving the problem

We implemented a two-phase greedy construction heuristic to solve the problem: In the first phase the distribution of the demanded raw materials onto the carriers is determined and the selected carriers are placed into the rounds of the schedule without consideration of any sequence constraints. Afterwards, the heuristic tries to select good carrier sequences within the rounds based on the produced result of phase one. Phase two will further aim to produce sequences that are feasible regarding all of the constraints.

We created a collection of benchmark instances and conducted a series of experiments using our solver. Our method was able to produce feasible results within running times of up to 15 minutes even for large and highly constrained instances with a scheduling horizon of up to 70 rounds and 500 carrier units per round.

4 Future Work

Although the greedy heuristic approach proposed in this work is able to produce feasible solutions for the instances within reasonable running times, further improvements regarding the quality of the produced solutions are desirable. Since the method ignores the sequence constraints at first, the second phase of the heuristic will greedily repair the sequence at the cost of additional carrier and color changes and thereby increase the objective value of the solution.

For this reason, we plan to develop a local search based metaheuristic which can be used to repair and further improve given candidate solutions. We will consider different search neighborhoods for the development of this approach which will include block swaps of color assignments and carrier unit positions as well as the insertion and removal of carrier units from the schedule.

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