A Hybrid Approach for Paint Shop Scheduling in the Automotive Supply Industry

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1 Introduction

Modern day paint shops of the automotive supply industry need to manufacture a large number of products every day. As manual planning approaches can nowadays hardly cope with the growing demands of car manufacturers that are raised by the recent trend towards full automation, there is a strong need for automated scheduling techniques in this area.

One of the most important cost objectives of any automotive paint shop is to minimize the color changes that appear in the production sequence. Since the painting equipment has to be cleaned after each change, any color change will lead to a loss of valuable resources and can cause problematic delays. Minimizing the required color changes is not an easy task on its own, but several constraints that restrict technically feasible color sequences make it even more challenging to automatically create efficient schedules in practice.

In the literature, many publications exist on the topic of minimizing color changes in automotive scheduling problems (e.g. [4,3,2]) and several variants have been shown to be NP-complete [1]. However, most of the previous publications focus on problems that appear in car manufacturing, which although similar, include different constraints and objectives than the ones that are occurring in paint shops of the automotive supply industry.

Recently, we introduced a real-life paint shop scheduling problem from the automotive supply industry together with a set of 24 real-life problem instances in [6]. In [5] and [7] we further investigated exact approaches based on constraint programming for paint shop scheduling and showed that the problem is NP-hard. Experimental results revealed that exact approaches could prove

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optimal results for some of the smaller instances, but could not solve any of the larger instances in reasonable time. The empirical evaluation further showed that a simulated annealing approach can successfully produce feasible solutions for all real life instances within one hour. However, the number of required color changes in the solutions was still very high for most of the instances, resulting in schedules that have a large potential for further cost improvements in practice.

In this work, we investigate innovative solution methods that can hybridize exact and metaheuristic approaches to quickly find cost efficient schedules for real life paint shop scheduling problems. To realize an enhanced minimization of the required color changes in paint shop schedules, we propose a novel problem formulation that can be used to minimize the color changes of a given feasible solution without violating any of the problem's hard constraints.

The main idea behind the new formulation is to take a candidate solution to the paint shop scheduling problem and formulate a minimization problem based on the given solution that aims to minimize the color changes in the schedule without changing decisions on the scheduled materials and production devices. Therefore, an exact approach solving the proposed minimization problem does not need to consider the complex constraints regarding materials and production devices that appear in the original paint shop scheduling problem which caused previous exact approaches for the original problem to be impractical for large real life instances.

We provide a constraint programming model that we utilize to efficiently find optimized solutions to the new problem formulation and show that we can thereby improve feasible schedules that have been achieved with metaheuristic approaches. Furthermore, we investigate destroy and repair neighborhood operators that allow the incorporation of the proposed exact approach into metaheuristic methods within the framework of large neighborhood search. Finally, we additionally propose a novel construction heuristic that can produce cost efficient initial solutions for local search, and hence can improve the solution process for large scale real life instances.

2 Intermediate Experimental Results

We implemented a first prototype version of the proposed novel construction heuristic and large neighborhood search to produce a first set of intermediate results. All experiments have been conducted on an Intel Xeon E5345 2.33 GHz CPU with 48 GB RAM under a time limit of one hour. Table 1 summarizes the results on 24 publicly available problem instances for paint shop scheduling[1].

The left side of the table shows experimental results on the smaller instances (I1-12), while the right side shows results on the larger instances (I13-24). Columns labeled LS display results achieved with the local search approach from [6], while columns labeled CP show results produced with the

[1] `https://www.dbai.tuwien.ac.at/staff/winter/`

	LS	LNS	CP		LS	LS+CH	LNS+CH	CP
I1	851	799	775*	**I13**	116235	20060	26168	-
I2	886	853	842*	**I14**	118628	27766	35088	-
I3	995	980	961*	**I15**	180863	54077	51533	-
I4	1256	1061	918*	**I16**	262252	96744	78859	-
I5	598	607	530*	**I17**	421777	-	-	-
I6	892	872	842*	**I18**	581021	-	-	-
I7	1116	1113	1040	**I19**	555829	543264	586260	-
I8	2599	1775	1237*	**I20**	930564	629729	606886	-
I9	2198	1746	992	**I21**	917955	-	-	-
I10	1223	1243	966	**I22**	1128716	-	-	-
I11	5652	5960	-	**I23**	1889804	-	-	-
I12	5973	7348	-	**I24**	2086450	-	-	-

Table 1 Table showing the intermediate experimental results we performed using 24 real life problem instances.

state-of-the-art exact technique from [7]. Column LNS shows results achieved with the prototype for the proposed large neighborhood search, whereas columns LS+CH and LNS+CH show results achieved with the new construction heuristic together with local search and large neighborhood search respectively. Results marked with a * denote proven optimal solutions, where a - indicates that no feasible solution could be reached within the time limit.

We can see in the intermediate results that results produced with large neighborhood search lead to improved results compared to the existing local search method for the majority of the small instances. For the larger instances I13-24 the results show that the proposed construction heuristic leads to a significant improvement in solution quality for six of the instances, but is not able to produce feasible solutions for all instances within the time limit. We further observe that large neighborhood search does not always lead to improved results for the larger instances, but achieves improved results for instances 15 and 16.

The reason why the prototype of the construction heuristic can currently not produce feasible solutions for all instances is that the computation of the initial schedule is not fast enough yet for some of the instances that need to schedule a very large number of jobs. This is because the current implementation finishes execution just after the best position for each single job in the initial schedule has been calculated. We expect that the approach will be able to produce solutions for all instances in our next implementation, when we introduce limits on the time budget for the generation of initial solutions.

3 Future Work

The intermediate results for instances I13-16 and I19-I20 look promising as the first prototype implementation of the proposed techniques already was able to provide six novel improved upper bounds in our experiments. In the next steps, we plan to investigate additional variants of the destroy operator for

LNS. Afterwards, we want to utilize automated parameter configuration tools to further tune the performance of LNS, before we later conduct a systematic experimental study of the proposed techniques, where we expect to reach novel improved upper bounds for several real-life paint shop scheduling instances.

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