Proceedings of the 16th International Symposium on OPERATIONAL RESEARCH in Slovenia

SOR '21

September 22-24, 2021

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S. Drobne • L. Zadnik Stirn • M. Kljajić Borštnar • J. Povh • J. Žerovnik

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Preface

This volume, Proceedings of the 16th International Symposium on Operational Research, called SOR'21, contains papers presented at SOR'21 (https://sor.fov.um.si/), organised by Slovenian Society INFORMATIKA (SDI), Section for Operational Research (SOR), University of Maribor, Faculty of Organisational Sciences, Kranj, Slovenia (FOV), and University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia (UL FS). The SOR'21 symposium, held 22-24 September 2021, was originally planned to take place in Bled, Slovenia, but was moved online due to the situation of COVID-19 in Slovenia and beyond. The volume contains blind peer-reviewed papers or abstracts of papers presented at the symposium.

The opening address at SOR'21 was given by Prof. Dr. Lidija Zadnik Stirn, President of SOR, Mr. Niko Schlamberger, President of SDI, representatives of FOV and UL FS, Prof. Dr. Mario Jadrić, President of Croatian Operational Research Society (CRORS), Dr Sarah Fores, manager of The Association of European Operational Research Societies (EURO), and presidents/representatives of some others Operational Research Societies from abroad.

SOR'21 is the scientific event in the field of Operational Research, another in the traditional series of biennial international OR conferences organised in Slovenia by SDI-SOR. It is the continuation of fifteen previous symposia. The main objective of SOR'21 is to promote knowledge, interest and education in the field of OR in Slovenia, Europe and worldwide in order to build the intellectual and social capital essential for maintaining the identity of OR, especially at a time when interdisciplinary cooperation is proclaimed as particularly important for solving problems in today's challenging times. By joining IFORS and EURO, the SDI-SOR has also agreed to collaborate with different disciplines, i.e., to balance the depth of theoretical knowledge in OR and the understanding of theory, methods, and problems in other fields within and outside OR. We believe that SOR'21 creates the advantage of these goals, contributes to the quality and reputation of OR by presenting and sharing new developments, opinions and experiences in the theory and practise of OR.

SOR'21 was highlighted by five distinguished keynote speakers. The first part of Proceedings SOR'21 contains invited abstracts, presented by five outstanding scientists: Assist. Prof. Nikolina Ban, University of Innsbruck (UIBK), Department of Atmospheric and Cryospheric Sciences, Innsbruck, Austria, Assist. Prof. Vedran Kojić, University of Zagreb, Faculty of Economics & Business, Zagreb, Croatia, Prof. Panos Patrinos, KU Leuven, Department of Electrical Engineering (ESAT), STADIUS Center for Dynamical Systems, Signal Processing and Data Analytics, Leuven, Belgium, Prof. Suresh P. Sethi, Eugene McDermott Chair Professor of Operations Management, Director, Center of Intelligent Supply Networks, Naveen Jindal School of Management, The University of Texas at Dallas, Dallas, USA, and Prof. Jerneja Žganec Gros, Alpineon Ltd, Ljubljana, Slovenia.

The Proceedings includes 118 papers or abstracts by 240 authors. Most of the authors of the contributed papers came from Slovenia (82), then Croatia (52), Hungary (23), Portugal (23), Serbia (17), Poland (9), Czech Republic (8), Slovak Republic (7), Spain (6), Netherlands (4), Bosnia and Herzegovina (2), Austria (1), Belgium (1), France (1), Germany (1), Romania (1), Ukraine (1), United Kingdom (1), and United States of Amerika (1). The papers published in the Proceedings are divided into Plenary Lectures (5 abstracts), eleven special sessions: Application of Operational Research in Smart Cities (6 papers), Computational Mathematical Optimization (7 papers and 6 abstracts), Data Science – Methodologies and Case Studies (10 papers), Graph Theory and Algorithms (2 papers), *High-Performance Computing and Big Data (3 papers), Industry & Society 5.0: Optimization in Industrial and Human Environments (6 papers), International Projects in Operations Research (2 papers), Lessons Learned from the COVID-19 Pandemic: Applications of Statistical and OR Methods (8 papers), Logistics and Sustainability (9 papers), Operational Research in Ageing Studies and Social Innovations (5 papers), Operations Research in Agricultural Economics and Farm Management (5 papers), and eight sessions: Econometric Models and Statistics (6 papers), Environment and Social Issues (5 papers), Finance and Investments (6 papers), Location and Transport, Graphs and their Applications (5 papers), Mathematical Programming and Optimization (5 papers and 1 abstract), Multi-Criteria Decision-Making (10 papers), Theory of Games (3 papers), and Problems Approaching OR (3 papers).*

Proceedings of the previous fifteen International Symposia on Operational Research organised by the Slovenian Section on Operational Research, listed at https://www.drustvo-informatika.si/sekcije/sor/sor-publikacijepublications/, are indexed in the following secondary and tertiary publications: Current Mathematical Publications, Mathematical Review, Zentralblatt fuer Mathematik/ Mathematics Abstracts, MATH on STN International and CompactMath, INSPEC. It is expected that Proceedings SOR'21 will be covered by the same bibliographic databases.

The success of the scientific events at SOR'21 and of the present conference proceedings should be seen because of joint efforts. On behalf of the organisers, we would like to express our sincere gratitude to all those who assisted us in the preparation of the event. Without the dedicated and advice of the active members of the Slovenian Operations Research Section, we would not have been able to attract so many top-class speakers from all over the world. Many thanks to them. In addition, we would like to express our deepest gratitude to the prominent keynote speakers, the members of the Programme and Organising Committees, the reviewers who improved the quality of SOR'21 with their useful suggestions, the section chairs and all the numerous people - far too many to list individually here - who helped in organizing of the 16th International Symposium on Operational Research SOR'21 and compiling this proceedings. Finally, we thank the authors for their efforts in preparing and presenting the papers that made the 16th Symposium on Operational Research SOR'21 a success.

We would like to give special thanks to the Partnership for Advanced Computing in Europe (PRACE) for their financial support.

Ljubljana and Kranj, September 22, 2021

Samo Drobne
Lidija Zadnik Stirn
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Janez Povh
Janez Žerovnik
(Editors)

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SCHEDULING OF WASTE WOOD PROCESSING FACILITIES WITH OVERLAPPING JOBS

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Abstract: An important phase in most waste wood value chains is the processing of bulk waste from various sources, usually by means of shredding. This paper presents a method for scheduling the machines in such a waste wood processing facility, where incoming deliveries of different types of wood are processed by a series of treatment and transformation steps to produce shredded wood. A mathematical model is presented for the problem, that allows overlaps between consecutive steps to optimize resource flow through the system. The efficiency of the model is presented on randomly generated instances.

Keywords: scheduling, waste-wood processing, reverse wood value chain

1 INTRODUCTION AND MOTIVATION

The role of renewable materials and their reuse and recycling possibilities have become increasingly important with the growing significance of environmental awareness. One of the best examples for this is wood, a material that has a variety of primary uses, while also being a prime candidate for reuse and recycling. Optimization of the traditional product flows of wood is a well-researched area, with problems ranging from harvesting [14, 12] through facility-level decision-making (e.g. sawmilling [11], cutting pattern optimization [8]) to network-level modeling [13]. However, the utilization of waste wood and the reverse flows of this material are not widely studied. Waste wood can originate from a variety of sources, the two main groups being residual industrial wood (from the woodworking industry) and used wooden products (ranging from demolition waste to household items). However, similarly to other biomass residues, waste wood is mostly considered as a resource for energy production [15], and scientific studies usually concentrate on this aspect, while there might be more sustainable recycle possibilities [5].

As it was mentioned, the literature studying the optimization problems of waste wood is scarce. The two main research areas are the resource flow of waste wood for energy [6, 10] and the optimization problems of network design [2, 1, 16, 4]. While the previous studies concentrate mostly on network-level decisions, optimization problems in the nodes of waste wood logistics networks should also be studied. One important step is the processing of the collected waste, which is usually done by means of shredding, as most end-uses (e.g. energy or chipboard) require wood to be shredded to a certain size.

This paper presents the scheduling of a waste wood processing plant where the incoming wood deliveries are processed by a series of transformation steps in order to produce shredded wood. A mathematical model is formulated for the problem that allows overlapping of the automated processing steps in order to provide as continuous operation as possible. The efficiency of the proposed model is shown on instances that were randomly generated based on distributions from the literature. The presented model is a variation of our previously published work on scheduling waste wood processing facilities [3]. This previous study considered the uncertainty of the type and origin of the incoming deliveries (which is not tackled in the current paper), it did not allow any overlapping between the various processes of the facility.

2 PROBLEM DESCRIPTION

The goal of the proposed approach is to minimize the total weighted lateness of a waste wood processing plant that processes deliveries from collection centers and households. Each delivery is considered to be a job that has to go through 5 processing steps:

- inspection and sorting (`IS`)
- metal separation (`MS`)
- coating removal (`CR`)
- shredding (`SH`) and reshredding (`RS`)
- screening (`SC`)

Shredding is the main step, which is carried out by dedicated, high-throughput machines. The shredded wood needs screening, which selects large pieces for reshredding. Screening has its dedicated machines, while reshredding is executed by the same machines as the shredding step.

For metal separation, two options are available. It can either be done manually by a dedicated crew or in an automated fashion by a magnetic separator after shredding. If metal-separation is done manually, it has to precede coating removal, and succeed inspection, both carried out by their dedicated crew. Coating removal is only needed for a portion of the whole delivery.

The overall process of the plant is illustrated in Figure 1.

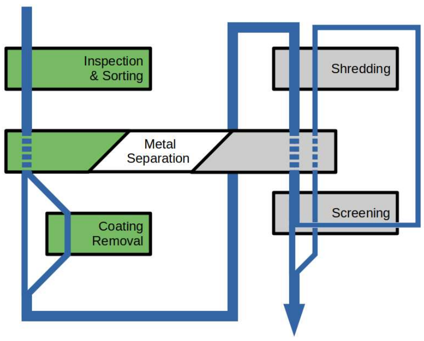

Figure 1: The possible flow of waste wood through the different transformation processes (green: manual steps, gray: machine steps).

The processing plant works in a semi-continuous fashion. Manual steps can be considered as batch subprocesses that cannot overlap or be interrupted. While the automated steps are also not interruptible, they can operate in a continuous way, so they may overlap with each other. Moreover, these steps may have an input storage/buffer that can hold shredded wood as long as needed, with sufficient capacity. Thus, fully batch operation is also available, if equipment availability would require it.

The re-entry of insufficiently shredded wood into the shredding machines forces the shredding step to envelop screening (and metal separation if done automatically) in time. Figure 2 illustrates the possible timings of these steps for both options with metal separation.

The dedicated crews for manual steps may not be split up between different jobs at the same time. However, several machines can be assigned to the same job simultaneously for the

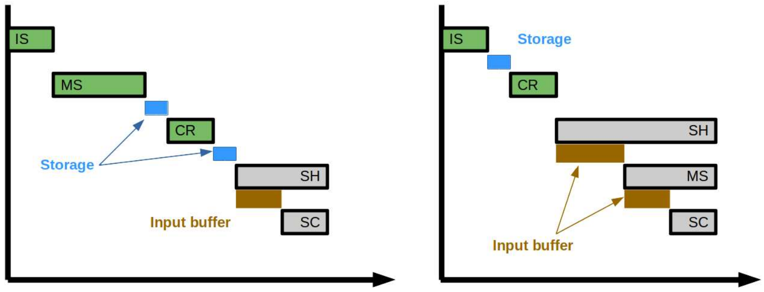

Figure 2: Possible timing of processing steps for both metal removal operations.

same step, if available. The percentage of wood / shredded wood that requires coating removal / reshredding can be estimated based on statistical data, based on the type of the delivery that can be either solid (S) or derived (D).

3 FORMAL PROBLEM DEFINITION AND THE PROPOSED MODEL

3.1 Problem data

The problem data is formally given as:

J is the finite set of jobs/deliveries.

$S = \{\texttt{IS}, \texttt{MS}, \texttt{CR}, \texttt{SH}, \texttt{SC}\}$ is the set of steps.

$d_j^a \in \mathbb{Z}^{0,+}$ is the day of arrival for the delivery of job $j \in J$. $[day]$

$d_j^s \in \mathbb{Z}^{0,+}$ is the day of shipping for the product of job $j \in J$. $[day]$

$p_j \in \mathbb{R}^{0,+}$ is the priority of job $j \in J$. $[-]$

$m_j \in \mathbb{R}^{0,+}$ is the total mass of the delivery of job $j \in J$. $[t]$

$t_j \in \{\texttt{S}, \texttt{D}\}$ is the type of job $j \in J$. $[-]$

M is the finite set of machines, partitioned to $M^{\texttt{IS}}$, $M^{\texttt{MS}}$, $M^{\texttt{CR}}$, $M^{\texttt{SH}}$, and $M^{\texttt{SC}}$.

$c_{mj} \in \mathbb{R}^{0,+}$ is the throughput capacity of a machine $m \in M$ for job $j \in J$. $[t/h]$

$s \in \mathbb{R}^{0,+}$ is the length of the shifts. $[h]$

$p_{\texttt{S}}^{\texttt{CR}}$, $p_{\texttt{D}}^{\texttt{RS}}$ $\in [0, 1]$ are the percentages requiring coating removal and re-shredding for solid (S) and derived (D) deliveries. $[-]$

From the modeling point of view, dedicated crews behave exactly as machines, thus they are considered as such later on ($M^{\texttt{IS}} = \{\texttt{IS}\}$, $M^{\texttt{CR}} = \{\texttt{CR}\}$, and $\texttt{MS} \in M^{\texttt{MS}}$)

3.2 Variables

The proposed model relies on the following variables:

t_{js}^s, $t_{j,s}^c$ non-negative continuous variables for starting and completion of step $s \in S$ for job $j \in J$.

a_{jm} binary variable that indicates if machine $m \in M$ is assigned to job $j \in J$.

q_{jm} non-negative continuous variable for the quantity of wood processed by machine $m \in M$ from job $j \in J$.

$b_{jsj'}$ binary variable that indicates if processing of job $j \in J$ precedes that of $j' \in J$ for step $s \in S$. $(j \neq j')$

3.3 Constraints

Due to space limitations, only the key parts of the mathematical model are presented here. The constraints can broadly be categorized into three groups: logical/quantity constraints, recipe timing constraints and scheduling/sequencing constraints.

A key logical constraint forbids the assignment of any magnetic metal separator to a job if a crew already performed the task:

$$a_{jm} \leq 1 - a_{j\mathtt{MS}} \qquad \forall j \in J, m \in M \setminus \{\mathtt{MS}\} \tag{1}$$

The total quantities assigned to the machines from a job must add up to the total mass of that job for each step. Depending on the step and the type of the job, this total mass may be different from m_j. The equation is the most complex for metal separation, as the total quantity is larger by the reshredded volume if automatic separation is selected:

$$\sum_{m \in M^{\mathtt{MS}}} q_{jm} = m_j + m_j \cdot p_{t_j}^{\mathtt{RS}} \cdot (1 - a_{j\mathtt{MS}}) \qquad \forall j \in J \tag{2}$$

These quantity variables can be used to provide a lower bound on processing times:

$$t_{js}^c \geq t_{js}^s + q_{jm}/c_{mj} \qquad \forall j \in J, s \in S, m \in M^s \tag{3}$$

A group of recipe timing constraints set the starting and completion times for tasks of the same job. This constraint, for example, sets the timing appropriately between manual metal separation and coating removal:

$$t_{j\mathtt{CR}}^s \geq t_{j\mathtt{MS}}^c - \mathbf{M} \cdot (1 - a_{j\mathtt{MS}}) \tag{4}$$

where $\mathbf{M}$ is a sufficiently large number.

Sequencing of tasks assigned to the same unit are tackled with the following constraint:

$$t_{j's}^s \geq t_{js}^c - \mathbf{M} \cdot (3 - a_{jm} - a_{j'm} - b_{jmj'}) \qquad \forall j, j' \in J, j \neq j', s \in S, m \in M^s \tag{5}$$

3.4 Objective

To calculate the objective, an integer helper variable l_j is introduced, which indicates the lateness. This variable is set by the following constraint:

$$t_{j\mathtt{SH}}^c \leq (d_j^s + l_j) \cdot s \qquad \forall j \in J \tag{6}$$

Then, the objective is simply expressed as:

$$\sum_{j \in J} l_j \cdot p_j \rightarrow \min \tag{7}$$

4 NUMERICAL RESULTS

As acquiring real-life datasets with varied sizes and structures is not a trivial task, testing of the model was done with the same methodology presented in [3]. Input instances were randomly generated based on available distribution data. The arrival day of the deliveries was chosen randomly over a one-week horizon for every instance. The features of the waste wood deliveries were determined based on statistics in [7], their sizes were determined using the capacities of biomass transport trucks [9] and data on real machines was used to determine throughput.

Two different instance types were created: instances with small deliveries had a mass corresponding to the payload of a small truck (6 t–15 t) and the ones with large deliveries had a mass corresponding to the payload of an average-sized biomass transport truck (31 t–49 t). The number of deliveries was a multiple of five between 5 and 30 for each instance. This resulted in 12 instance sets (one for each each pair of delivery size and delivery number, e.g. '25 large deliveries'), with 20 different random instances in each set. The model was solved for all instances using the Gurobi 9.1 solver on a PC with an Intel Core i7-5820K 3.30 GHz CPU and 32 GB RAM. A running time limit of 1800 s was introduced to all test runs.

Instances with 30 or fewer small deliveries were all solved to optimality in less than 1 s. The model was also tested for instances with 35 and 40 small deliveries, but these did not yield optimal solutions in the given time limit.

Instances with large deliveries were solvable to optimality in the case of 15 or fewer deliveries. Only half of the 20-delivery instances yielded optimal solutions within the time limit, while the suboptimal results of the remaining 10 instances had an average gap of 44.33%. A significant number of the larger instances did not provide solutions within the time limit: only 9 and 13 instances were optimal in the case of the 25- and 30-delivery sets respectively. For the remaining instances, there were either no feasible solutions found within the time limit, or only ones with extremely large optimality gaps.

5 CONCLUSIONS

This paper presented the problem of machine scheduling in a waste wood processing plant where the incoming deliveries of wood are shredded. A mixed-integer linear programming model was presented for the problem that allows overlapping of the machine processing steps so the flow of material can be as continuous throughout the facility as possible. The efficiency of the model was shown on instances that were randomly generated based on real-life statistical data. Results showed that the model is capable of scheduling a large amount of jobs over the short-term period of one week, under a short solution time. Possible extensions of this work can include an exhaustive testing of larger planning periods of several weeks, as well as the development of metaheuristic algorithms for solving instances with even larger number of deliveries. The proposed model should also be tested for real-world datasets.

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