Optimization of Direct Transportation Flows for the Removal of Construction Waste Bins with both Resource and Task Availability Interval Constraints

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Keywords: Waste Transportation, Waste Bin Removal, Parallel Machine Scheduling Problem, Multiple Availability Interval Constraints, Mixed Integer Programming.

Abstract: This study focuses on a new real-word problem encountered in the construction sector, which concerns the optimization of the removal of construction waste bins from construction sites to a massification platform, where a limited heterogeneous fleet of tipper trucks (vehicles) must perform direct trips from the platform to the construction sites to collect the waste bins. Each vehicle has a capacity of one bin, it leaves the platform with an empty bin, travels to the construction site, drops off the empty bin in the construction site, collects the full bin and returns to the platform to unload the full bin. The issue is that the vehicles and the construction sites have one or more periods of availability, and thus are not available any time. This problem is modeled as a parallel machine scheduling problem of bin removal tasks on non-identical machines (vehicles), with new constraints that concern the presence of multiple availability intervals for both vehicles and tasks. Two mixed-integer programming (MIP) models are presented and evaluated on 18 new instances derived from real industrial case study.

1 INTRODUCTION

As the construction industry develops, it generates an enormous quantity of materials and a very large quantity of waste. In France[1], the construction sector is responsible for almost 45% of national energy consumption, over 25% of greenhouse gas emissions, and generates over 42 million tons of waste per year. Legislation in France proposes a more global approach to the environmental impact of the construction sector including a better management of the construction supply chain. Thus, sorting, recycling and valorization of construction waste has become important for improving the environmental and ecological performance of the construction industry. This issue is studied in the French framework of the R&D project DILC which refers to "demonstrator innovations logistic sites", whose aim is to design an innovative platform for optimizing construction site logistics, that is adapted to multi-site ecocity construction projects. The DILC project focuses on the consolidation of transport flows and human resources through a physical platform that is modular, removable, and mobile, and the development of decision support tools to help the platform managers to optimize their logistics.

The platform must also manage the removal of waste from construction sites to the platform. The platform offers a recycling area to sort and recycle the collected waste, and a material shop for the reuse of some of this waste. Better management of waste transport flows from the sites to the platform will permit to extend the ecological efforts of the building sector to the construction phase. It should be noted that there are two types of waste: Big-bag waste and waste bin. Big-bag wastes are packed on pallets and concern wastes that are produced with small and medium quantities such as soft plastic, hard plastic, and cardboard. Waste bin concerned the wastes that are produced in large quantity like wood and metals.

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[1] https://www.optigede.ademe.fr/outils-multi-acteurs/batiments-et-travaux-publics/dechets-du-batiment/cadre-reglementaire

Abderebbi, S. and Ramdane Cherif-Khettaf, W.
Optimization of Direct Transportation Flows for the Removal of Construction Waste Bins with both Resource and Task Availability Interval Constraints.
DOI: 10.5220/0011821900003396
In *Proceedings of the 12th International Conference on Operations Research and Enterprise Systems (ICORES 2023)*, pages 221-228
ISBN: 978-989-758-627-9; ISSN: 2184-4372

The optimization of the Big-bag removal is studied in (Jaballah and Ramdane Cherif-Khettaf, 2021; Ramdane Cherif-Khettaf et al., 2022) where a new vehicle routing model called the Multi-Trip Pickup and Delivery Problem, with Split loads, Profits and Multiple Time Windows was proposed. This model allowed mutualization of material delivery with Big-Bag waste removal, using tail-lift truck fleet. In this study, we focus only on waste bin removal, which consists in performing a set of direct trips from the platform to the construction sites to satisfy construction site requests for full bins removal and their replacement by empty bins. The remainder of the paper is organized as follows. Section 2 describes the problem and related literature; two MIP models are presented in section 3. Experimental results with the definition of benchmarks are given in section 4. Finally, concluding remarks are given in section 5.

2 PROBLEM DESCRIPTION AND RELATED LITERATURE

A limited heterogeneous fleet of tipper trucks (vehicles) situated at the platform must perform multiple direct trips between the platform and the construction sites. The vehicles differ by their speed and their distance limit. Each trip consists of loading an empty bin at the platform, delivering it to a given construction site, collecting a full waste bin from this construction site, and unloading it in the recycling center located just next to the platform. Each vehicle has one or more periods of availability, which represent the time windows when the vehicles are available at the platform and so can move to the construction sites to collect waste bins, outside of these periods of availability, the vehicles can be mobilized for other tasks external to the platform and can't satisfy the request of bin removal. The platform also has a period of availability, that is given by the platform's opening hours. The construction sites have one or more types of bins depending on the specificity of the works in progress in the construction site (bin for wood, bin for metals, bin for plaster, bin for inert materials, etc.). Each site has only one bin per type, and must therefore send to the platform requests for bin removal. The platform must manage the bins waste removal with the available resources and ensure the replacement of each full bin with an empty one. The construction sites also have one or more periods of availability during which vehicles access is allowed, and thus the arrival and departure of vehicles at the construction site location must be within one of the availability time windows allowed by the construction site. We denote by a bin removal task, all operations that consists of loading the vehicle with an empty bin at the platform, travelling from the platform to the construction site, unloading the empty bin at the construction site, loading the full bin, travelling back to the platform and unloading the full bin at the platform's recycling center. Platform service time is the time required for loading and unloading the bin on the platform.

This problem can be modelled as unrelated parallel machine scheduling problem in which the vehicles can be represented as machines with multiple periods of availability and the bin removal tasks as jobs that have one or multiple periods of availability, and require a certain amount of processing time, that depends on the vehicle that is used. In addition, the constraint of availability of the tasks in our case concerns only a part of the task processing time, it is the loading and unloading part at the location of the construction site and does not concern the part of the travel to and from the site. The objective is to perform the maximum number of bin removal tasks, to determine the assignment of tasks to the availability intervals of the vehicles; and to define the sequence of satisfied tasks per available interval of each used vehicle.

In terms of computational complexity (Lenstra et al., 1977) proved that the single machine scheduling problem with only release dates, which is a special case of our problem is NP-hard. In literature, extensive studies have been conducted in the area of parallel machine scheduling with time constraints without availability constraints (Arik et al.,2022; Osorio-Valenzuela et al., 2019). In most of the research reviewed in the area of parallel machine scheduling, the availability constraints are defined on resources (Such-Jeng, 2013). Very few studies consider the availability intervals of tasks as in (Gedik et al.,2016). A survey on parallel machine scheduling under availability constraints can be found (Kaabi and Harrath, 2014).

Despite the abundant literature on parallel machine scheduling, the problem that we present here is in our knowledge a novel one and allows us to model a new constraint in unrelated parallel machine scheduling problems, that is both resource and task multiple availability interval constraint. Our contribution can be summarized in the two following issues:

- Modeling a real problem of direct transportation of bin waste in the construction sector as a parallel machine scheduling problem with a new specific constraint that is multiple periods of

availability of both resources and tasks. In addition, the period of availability of tasks in our case concerns only a part of the task processing time, it is the loading and unloading part in the construction site. The travel time which is a part of the processing time is not concerned by the task availability interval.
- Proposing of two mixed-integer programming (MIP) models, and analysis of results on 18 instances provided by our industrial partners.

3 NOTATION AND MATHEMATICAL PROGRAMMING MODELS

For a given time horizon specified by the platform's opening time window, we seek to assign n non-identical jobs (bin removal tasks) to K non-identical machines (vehicles). The objective is to provide the best sequence of bin removal tasks on each vehicle to perform a maximum of bin removal tasks. Moreover, the processing time of each bin removal tasks depends on the type of vehicle that is assigned to it. Each bin removal task has a processing time, that includes loading and unloading time in the platform, travel time from the platform to the construction site and from the construction site to the platform. Note that task service time represents only loading and unloading at the construction site. Each task has DC periods of availability intervals for its task service, and each vehicle has DV periods of availability intervals. The objective is to maximize the total number of tasks to be performed within a given time horizon.

We first define the parameters and decision variables, and then present the two proposed mathematical models.

Indices:

i, j	: task index ($1, \ldots, n$)
k	: vehicle index, $k = 1, \ldots, K$
α	: task availability interval index, $\alpha = 1,.., DC$
l	: vehicle availability interval index, $l = 1, \ldots, DV$

Parameters:

n	: total number of tasks
K	: total number of vehicles
DC	: total number of tasks' availability intervals
DV	: total number of vehicles' availability intervals
M	: a very large number
CP	: platform loading time
DP	: platform unloading time
rp	: release date of the platform's time window
dp	: due date of the platform's time window
$timePC_{ik}$	: duration between the platform and the construction site i, using vehicle k
CS_i	: site i loading time
DS_i	: site i unloading time
$timeTask_{ik}$	: processing time of task i using vehicle k, such that: $timeTask_{ik} = CP + 2\times timePC_{ik} + CS_i + DS_i + DP$
$rs_{i\alpha}$	: release date of availability interval α of task i
$ds_{i\alpha}$	: due date of availability interval α of task i
$dist_i$	: round-trip distance between the platform and the construction site i
$distmax_k$	: maximum distance of each vehicle k
$timeInter_{kl}$	: duration of availability interval l of vehicle k
rv_{kl}	: release date of availability interval l of vehicle k
dv_{kl}	: due date of availability interval l of vehicle k

Decision Variables

V_k	: 1, if vehicle k is used; 0, otherwise
$Y_{i\alpha kl}$	: 1, if task i is scheduled using its availability interval α on availability interval l of vehicle k; 0, otherwise
Z_{ij}	: 1, if task i precedes task j; 0, otherwise
T_i	: task i start time; 0 if i is not assigned to any vehicle

3.1 Mixed Integer Programming (MIP1)

The first mathematical model that will be referred to as MIP1 is given below:

$$\text{(MIP1) Maximize } \sum_{i=1}^{n}\sum_{\alpha=1}^{DC}\sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha k} \quad (1)$$

St.

$$\sum_{\alpha=1}^{DC}\sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha kl} \leq 1, \quad \forall i \quad (2)$$

$$V_k \leq \sum_{i=1}^{n}\sum_{\alpha=1}^{DC}\sum_{l=1}^{DV} Y_{i\alpha kl}, \quad \forall k \quad (3)$$

$$\sum_{i=1}^{n}\sum_{\alpha=1}^{DC}\sum_{l=1}^{DV} Y_{i\alpha kl} \leq M_4 * V_k, \forall k, M_4 = n \quad (4)$$

$$T_i + CP + timePC_{ik} - rs_{i\alpha} \geq M_5 \times (\sum_{l=1}^{DV} Y_{i\alpha kl} - 1) \quad \forall i, \alpha, k, M_5 = DP \quad (5)$$

$$T_i + CP + timePC_{ik} + CS_i + DS_i - ds_{i\alpha} \leq M_6 * (1 - \sum_{l=1}^{DV} Y_{i\alpha kl}), \quad \forall i, \alpha, k, M_6 = DP + timeTask_{ik} \quad (6)$$

$$T_i \geq rv_k + M_7 \times (\sum_{\alpha=1}^{DC} Y_{i\alpha kl} - 1), \forall i, k, l, M_7 = DP \quad (7)$$

$$T_i + timeTask_{ik} \leq dv_{kl} + M_8 \times (1 - \sum_{\alpha=1}^{DC} Y_{i\alpha kl}) \quad \forall i, k, l, M_8 = 1.5 \times DP \quad (8)$$

$$\sum_{i=1}^{n}\sum_{\alpha=1}^{DC}\sum_{l=1}^{DV} dist_i \times Y_{i\alpha kl} \leq distmax_k \times V_k, \forall k \quad (9)$$

$$\sum_{i=1}^{n}\sum_{\alpha=1}^{DC} Y_{i\alpha kl} \times timeTask_{ik} \leq timeInter_{kl}, \forall k, l \quad (10)$$

$$\sum_{\alpha=1}^{DC}\sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha kl} \leq T_i, \quad \forall i \quad (11)$$

$$T_i \leq M_{12} \times \sum_{\alpha=1}^{DC}\sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha kl}, \forall i, M_{12} = DP \quad (12)$$

$$T_i + \sum_{\alpha=1}^{DC}(Y_{i\alpha kl} \times timeTask_{ik}) \leq T_j + M_{13} \times (3 - \sum_{\alpha=1}^{DC} Y_{i\alpha kl} - \sum_{\alpha=1}^{DC} Y_{j\alpha kl} - Z_{ij}), \quad \forall i < j, k, l, M_{13} = DP \quad (13)$$

$$T_j + \sum_{\alpha=1}^{DC}(Y_{i\alpha kl} \times timeTask_{jk}) \leq T_i + M_{14} \times (2 - \sum_{\alpha=1}^{DC} Y_{i\alpha kl} - \sum_{\alpha=1}^{DC} Y_{j\alpha kl} + Z_{ij}), \quad \forall i < j, k, l, M_{14} = DP \quad (14)$$

$$V_k \in \{0,1\}, \forall k ; Y_{i\alpha kl} \in \{0,1\}, \forall i, k, l, \alpha ; Z_{ij} \in \{0,1\}, \forall i, j ; T_i \geq 0, \forall i \quad (15)$$

The objective function (1) maximizes the number of tasks. Constraint (2) guarantees that each task is scheduled at most once, fulfilling one task availability interval and one vehicle availability interval. Constraints (3) and (4) ensure the coherence between Yiαkl and Vk . Constraints (5) and (6) state that the start time of the task, which represents the beginning of the loading of an empty bin at the platform must allow the vehicle to arrive at the site i and to perform the service on the site i (unloading the empty bin and loading the full bin) while meeting one of the task availability intervals. Constraint (7) and (8) guarantee that the start time of the task must respect the release date and the due date of one of the interval availabilities of the vehicle that is selected. Constraint (9) means that each vehicle must satisfy its maximum distance. Constraint (10) ensures that the sum of the processing times of all tasks assigned to a given interval must satisfy the time duration of this interval. Constraints (11) and (12) represent coherence constraint between Ti and Yiαkl . Constraints (13) and (14) force a precedence relation between two tasks if they use the same vehicle availability period. Constraints (15) are the set constraint.

3.2 Mixed Integer Programming (MIP2)

In this section, we present another version of MIP1, in which constraints (1)-(15) are maintained except constraints (5) and (6) which will be reformulated in another way:

$$T_i + CP + \sum_{k=1}^{K}(timePC_{ik} \times \sum_{l=1}^{DV} Y_{i\alpha kl}) - rs_{i\alpha} \geq M_{5'} \times (\sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha kl} - 1), \forall i, \alpha, M_{5'} = DP \quad (5')$$

$$T_i + CP + \sum_{k=1}^{K}(timePC_{ik} \times \sum_{l=1}^{DV} Y_{i\alpha kl}) + CS_i + DS_i - ds_{i\alpha} \leq M_{6'} \times (1 - \sum_{k=1}^{K}\sum_{l=1}^{DV} Y_{i\alpha kl}), \forall i, \alpha, M_{6'} = DP \quad (6')$$

4 EXPERIMENTAL RESULTS

To solve our two models, we use Pyomo, an open-source constrained optimization library and GLPK solver. All tests were carried out on MacBookPro18,3 at 2.66 GHz, with 16 GB RAM. We conducted numerical experiments on 18 new instances which are inspired by real case studies given by our industrial partners.

In this section, we give a general description of the studied instances, we present the results that allowed us to validate our models. We first analyze the detailed results of the two models on an illustrative example, then we give a comparison of the two models and evaluate their limit on all instances.

4.1 Instance Description

The studied instances simulate a real case study provided by our industrial partners. The number of sites for the considered instances is 10. Each site can have one or several requests for bin waste removal, which gives a total number of tasks that ranges between 10 and 20. The characteristics of the instances are given in table 8a. Column1 indicates the instance, this name starts with R, followed in order by the number of sites, the instance index, the letter 'F' to indicate that the number of vehicles is fixed, then a letter (U or P) means that the vehicles have only one interval of availability (U), or multiple interval of availability (P). The last position in the instance name is a group number. Instances with the same group number have the same characteristics except the total number of tasks. i.e. the number of requests per construction site is different, which results in a different number of tasks. The two other columns give the characteristics of each instance, which are the following in column order: the number of sites (NS), the number of tasks (n), the number of vehicles (K), minimum and maximum number of availability intervals of tasks (DC), and finally the minimum and the maximum number of availability intervals of vehicles (DV).

4.2 An Illustrative Example

In this section, the instance R10_1_F_P is given to illustrate the problem environment and the solution structure. This instance considers 10 sites, and 5 vehicles. Each site has one demand for bin removal (1 task per site). The number of availability intervals per site (respectively per vehicle) is between 1 and 4 (respectively between 2 and 3). All details of this instance are given in tables 1, 2, 3, 4 and 5.

Table 1: R10_1_F_P_1 size.

K	*NS*	*n*	*[Min, Max] DC*	*[Min, Max] DV*
5	10	41	[1, 4]	[2, 3]

Table 2: R10_1_F_P_1 instance - vehicle features.

V	*Distmax (km)*	*Speed max (Km/h)*	*DV*	*TimeInter {Min(h), Max (h)}*	*Intervals*
V1	800	80	3	{3, 6}	[6, 12], [14, 17], [18, 21]
V2	600	70	2	{3,3}	[14, 17], [18, 21]
V3	600	60	3	{3, 6}	[6, 12], [14, 17], [18, 21]
V4	500	50	3	{3, 6}	[6, 12], [14, 17], [18, 21]
V5	800	80	2	{3, 6}	[6, 12], [14, 17]

Table 3: R10_1_F_P_1 instance - site features (DSP: Distance between sites and the platform, the length of intervals is equal to 1h for all sites).

Sites	*DSP (Km)*	*DC*	*CS (h)*	*DS (h)*	*Intervals*
S1	187.24	4	0.17	0.17	[7, 8], [11, 12], [14, 15], [17, 18]
S2	194.82	2	0.08	0.12	[14, 15], [17, 18]
S3	150.26	3	0.10	0.10	[7, 8], [14, 15], [17, 18]
S4	32.42	2	0.13	0.10	[7, 8], [14, 15]
S5	104.86	4	0.15	0.10	[7, 8], [11, 12], [14, 15], [17, 18]
S6	140.45	2	0.17	0.17	[14, 15], [17, 18]
S7	142.93	3	0.17	0.10	[7, 8], [11, 12], [14, 15]
S8	127.90	3	0.17	0.12	[11, 12], [14, 15], [17, 18]
S9	169.06	2	0.17	0.15	[14, 15], [17, 18]
S10	86.62	1	0.15	0.12	[11, 12]

Table 4: R10_1_F_P_1 instance-platform features.

rp	*dp*	*CP* (h)	*DP* (h)
6	21	0.10	0.13

The availability interval constraints are shown in figure 1 for the construction site 7. We can notice for site 7 and if we consider only vehicle 1, only the first availability interval of site 7 can be feasible, because the second and the third interval does not allow vehicles to perform the travel time, when respecting these vehicle availability intervals even if we start the task as soon as possible (see figure 2.a and figure 2.b for more details). If task 7 is selected in the solution, the beginning of the service of this task will be scheduled using the first availability interval of the site [7h, 8h]. The task will be assigned to the availability interval [6h, 12h] of the vehicle 1.

Table 5: R10_1_F_P_1 instance - travel time between the platform and the sites (h).

	Vehicles				
Sites	*V1*	*V2*	*V3*	*V4*	*V5*
S1	1.17	1.34	1.56	2.27	1.17
S2	1.22	1.39	2.02	2.35	1.22
S3	1.34	1.07	1.25	1.50	1.34
S4	0.20	0.23	0.27	0.32	0.20
S5	1.06	1.15	1.27	1.05	1.06
S6	1.28	1.00	1.17	1.40	1.28
S7	1.29	1.02	1.19	1.43	1.29
S8	1.20	1.31	1.07	1.28	1.20
S9	1.06	1.21	1.41	2.09	1.06
S10	0.54	1.02	1.12	1.27	1.54

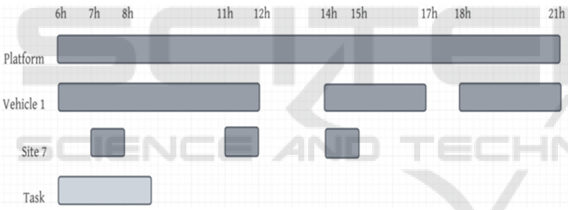

Figure 1: R10_1_F_P_1 instance – illustration of the availability interval constraints on task 7.

Table 6: R10_1_F_P_1 – comparison between MIP1 and MIP2.

Model	*Obj*	*K*	*Time (min)*
MIP1	**6**	4	3
MIP2	**6**	4	1.3

The results obtained for instance R10_1_F_P by model 1 (respectively model 2) are illustrated by a Gantt chart in figure 3 (respectively in figure 4). The results show that an optimal solution was found by both models. 6 tasks were scheduled among the 10 tasks using 4 vehicles among the 5 available. Vehicle 2 is not used in both solutions, because none of the remaining tasks is compatible with the availability intervals of this vehicle. The two solutions one interval for each selected vehicle except for vehicle 1 and vehicle 3, where a second interval was chosen only for vehicle 1 in the first solution and only for vehicle 3 in the second solution. The other selected intervals are the same for each vehicle in the two solutions. The tasks that have not been assigned in the optimal solution are tasks 2, 6, 8 and 9. We can notice that the availability intervals of these tasks are incompatible with all the remaining availability intervals of the vehicles.

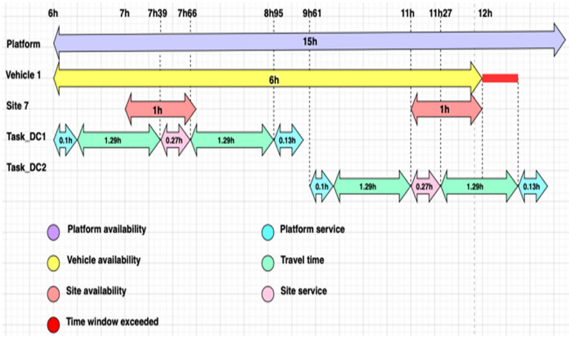

Figure 2a: R10_1_F_P_1 - compatibility of availability intervals [7h, 8h] and [11h, 12h] of task 7.

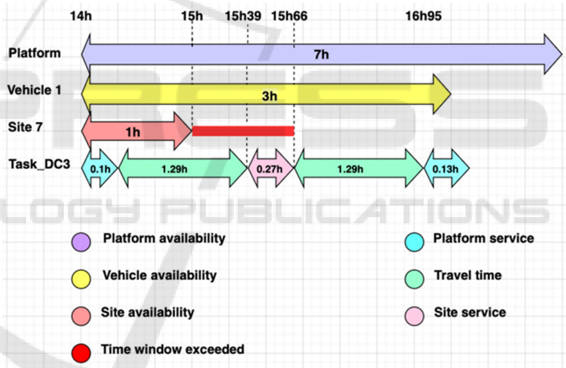

Figure 2b: R10_1_F_P_1- compatibility of availability interval [14h, 15h] of task 7.

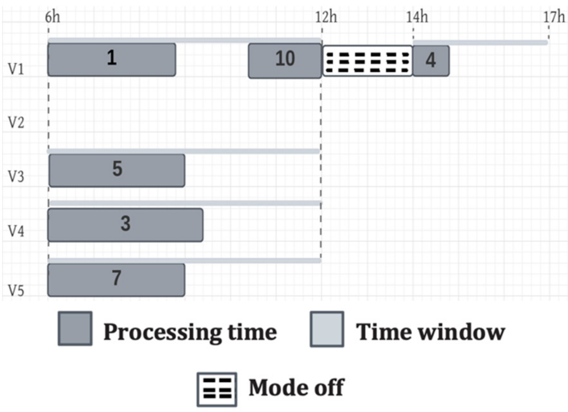

Figure 3: R10_1_F_P_1 - Gantt chart of the optimal solution obtained by MIP1.

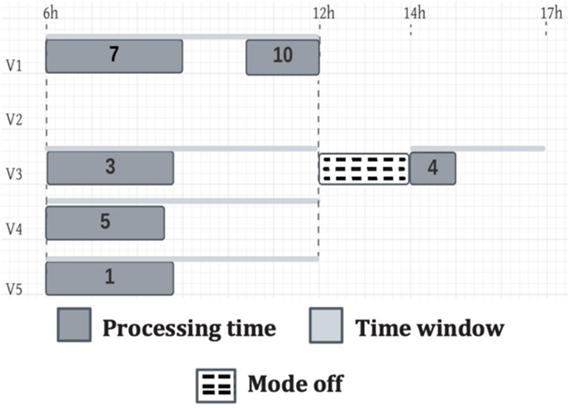

Figure 4: R10_1_F_P_1 - Gantt chart of the optimal solution obtained by MIP2.

Table 7: R10_1_F_P_1-evaluation of MIP2 limit by varying the number of tasks (NTF number of feasible tasks).

Instances	*NS-n-NTF*	*Obj*	*Time (min)*
R10_1_F_P_1	10-10-6	**6**	**1.3**
R10_1_F_P_2	10-15-10	**10**	**30**
R10_1_F_P_3	10-20-14	12	>120
R10_1_F_P_4	10-25-19	16	>120
R10_1_F_P_5	10-30-21	18	>120

Table 6 reveals that model 1 is more efficient in computational time than model 2 on the illustrative instance. We then investigated the limit of model 2 on the same instance by duplicating the number of requests of some sites to increase the number of tasks. The results are summarized in table 7. The solutions in bold are optimal, the others indicate the best feasible solutions found by the solver while limiting the computation time to 2h. We can see that model 2 can solve instances up to 15 tasks, 5 vehicles, 4 task availability intervals and 3 vehicle availability intervals. On instances with 20 tasks, the model returns a feasible solution with about 85% of completed tasks among all feasible tasks.

4.3 Comparison of MIP1 and MIP2

The purpose of this section is to study the limit of the two models on 18 instances derived from a real case study, and to compare their performance. Table 8 summarizes the obtained results. The columns MIP1-obj and MIP2-obj give the percentage of tasks performed in relation to the total number of tasks. It can be noticed that both models have the same limit, they succeed in solving optimally instances with up to 15 tasks, 10 vehicles, 4 vehicle availability intervals, and 3 task availability intervals. For instances with 20 tasks, the table illustrates the best feasible solutions found within a time limit of 2h.The results show that model 2 performs better than model 1, the computation time on instances up to 15 tasks of model 2 is on average 19% better compared to the computation time of model 1. Model 1 takes from 3 to 90 minutes of computation time, while model 2 takes from 0.7 minutes to 37 minutes.

On the instances with 15 tasks, the computation times are more important when using multiple availability intervals compared to the instances with only one vehicle availability interval. On instances with 20 tasks, model 2 is able to satisfy up to 6% more tasks compared to model 1. We can conclude that model 2 is more efficient, and allowed us to solve up to 15 tasks in a more reasonable time. We are currently analyzing the obtained results, by computing for each instance the real number of feasible tasks, this will be used to adjust the objective according to the feasible tasks, which is more representative than using the total number of tasks. These results have been validated by our industrial partner. The obtained results are important for further research which aims to solve larger instances. The results of the MIP models will allow us to evaluate heuristic approaches under development.

5 CONCLUSIONS

In this paper, we have presented a detailed study of a new real problem encountered in the construction sector on the optimization of waste bin transportation in the framework of an organization with a massification platform. The platform has a limited

Table 8a: Instances characteristics.

Instances	***NS-n-K***	*[Min,Max]* **DC, DV**
R10_1_F_P_1	10-10-5	[1, 4]-[2, 3]
R10_2_F_P_1	10-10-5	[1, 4]-[2, 3]
R10_3_F_P_1	10-10-5	[1, 4]-[2, 3]
R10_1_F_U_1	10-10-5	[1, 4]-[1, 1]
R10_2_F_U_1	10-10-5	[1, 4]-[1, 1]
R10_3_F_U_1	10-10-5	[1, 4]-[1, 1]
R10_1_F_P_2	10-15-10	[1, 4]-[2, 3]
R10_2_F_P_2	10-15-10	[1, 4]-[2, 3]
R10_3_F_P_2	10-15-10	[1, 4]-[2, 3]
R10_1_F_U_2	10-15-10	[1, 4]-[1, 1]
R10_2_F_U_2	10-15-10	[1, 4]-[1, 1]
R10_3_F_U_2	10-15-10	[1, 4]-[1, 1]
R10_1_F_P_3	10-20-10	[1, 4]-[2, 3]
R10_2_F_P_3	10-20-10	[1, 4]-[2, 3]
R10_3_F_P_3	10-20-10	[1, 4]-[2, 3]
R10_1_F_U_3	10-20-10	[1, 4]-[1, 1]
R10_2_F_U_3	10-20-10	[1, 4]-[1, 1]
R10_3_F_U_3	10-20-10	[1, 4]-[1, 1]

Table 8b: Comparison of the performance of MIP1 and MIP2.

Instances	*NS-n-K*	*MIP1 Obj.*	*MIP2 Obj.*	*MIP1 time (min.)*	*MIP2 time (min.)*
R10_1_F_P_1	10-10-5	**60%**	**60%**	3	1.3
R10_2_F_P_1	10-10-5	**50%**	**50%**	5	1.5
R10_3_F_P_1	10-10-5	**30%**	**30%**	3	1.1
R10_1_F_U_1	10-10-5	**10%**	**10%**	4	1
R10_2_F_U_1	10-10-5	**20%**	**20%**	3.5	0.7
R10_3_F_U_1	10-10-5	**20%**	**20%**	3.7	0.9
R10_1_F_P_2	10-15_10	**13%**	**13%**	90	37
R10_2_F_P_2	10-15-10	**33%**	**33%**	66	30
R10_3_F_P_2	10-15-10	**13%**	**13%**	78	32
R10_1_F_U_2	10-15-10	**7%**	**7%**	57	28
R10_2_F_U_2	10-15-10	**13%**	**13%**	43	21
R10_3_F_U_2	10-15-10	**7%**	**7%**	53	26
R10_1_F_P_3	10-20-10	-	5%	>120	>120
R10_2_F_P_3	10-20-10	-	10%	>120	>120
R10_3_F_P_3	10-20-10	5%	5%	>120	>120
R10_1_F_U_3	10-20-10	5%	10%	>120	>120
R10_2_F_U_3	10-20-10	10%	15%	>120	>120
R10_3_F_U_3	10-20-10	5%	10%	>120	>120

fleet of heterogeneous vehicles available during certain periods, the sites have a bin for each type of waste and negotiate contracts with the platform for the bin waste removal. The sites limit access to vehicles at certain time windows periods. The platform must manage the waste bin removal by replacing each full bin with an empty bin. The construction site may have multiple bin removal requests (one request per bin waste type). We modeled this problem as a scheduling problem on non-identical parallel machines with new constraints that concern the presence of multiple availability intervals for both vehicles and tasks. We presented two mathematical integer models, which we compared and evaluated using 18 instances derived from a real case study. The test results allowed us to optimally solve instances up to 15 tasks, 10 vehicles, 4 task availability intervals and 3 vehicle availability intervals. Currently, we are improving the mathematical model by integrating the interval incompatibility. The obtained results will allow us to evaluate the quality of the heuristic approaches that are under development.

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