paper seems to be the only one where IMO containers are included, but the IMO segregation rules are only applied within the stacks of the locations under consideration. However, IMO segregation rules also affect IMO containers in nearby locations. Due to this, we believe their model might lead to infeasible solutions when implemented for a real world case.

4. Computational results

We have tested our model on 304 instances, 174 contain under deck locations and 130 contain on deck locations. An overview of the instance characteristics can be found in Table 2. We are aware of the instances used in Delgado et al. (2012), but, because we define a location to be the entire on deck or under deck part of a bay, these cannot be used in our model directly. We also seem to interpret and handle the IMO rules differently, and we therefore generate our own instances from solutions for the Multi Port Master Bay Planning Problem. The MPMBP instances are randomly generated, but they have been made deliberately to correspond closely to real world stowage problems.

The purpose of the computational experiments described here is twofold: we want to ensure that our model is "correct" in the way that it produces solutions according to the problem description in Section 2, and we want to find out if problem instances of realistic size can be solved to optimality in reasonable time. Delgado et al. (2012) recommend one second as a reasonable runtime to solve the SPP. Our SPP instances correspond to two SPPs in Delgado et al. (2012), thus two seconds would be a reasonable solution time. Table 2 gives an overview of the instances used, with column headers as follows. ID identifies a set of instances, #Inst is the number of instances in the given set. The columns under Length tell if at least one instance has the given length or not. Under/On tells if the instances contain under deck or on deck locations. Reefer indicate whether at least one container in at least one instance of the given set is a reefer container. Principle 2 and 3 indicate whether at least one instance of the given set contain containers following the respective principle. The # Containers to be loaded columns give the maximum, minimum and average number of containers to be loaded in each instance, and finally # Ports gives the maximum number of ports of destination.

Table 2. Overview of instances.

ID	# Inst	Length		Under/On	Reefer	Principle		# Containers to be loaded			# Ports
		20'	40'			2	3	Max	Min	Aver	
1	47	✓	✓	Under	✓	✓		78	21	43	3
2	50	✓	✓	On		✓	✓	70	19	42.22	3
3	46	✓	✓	Under	✓			83	19	40.7	3
4	49	✓	✓	On				85	13	48.29	3
5	50	✓	✓	Under	✓			86	20	48.74	3
6	11	✓	✓	Under	✓	✓		90	26	61.27	3
7	11	✓	✓	On		✓	✓	94	34	58.45	3
8	20	✓	✓	Under	✓	✓		84	44	45.7	3
9	20	✓	✓	On		✓	✓	65	6	42.8	3

Table 3. SPP results.

ID	Runtime			# Inst solved	
	Max	Min	Aver	≤ 1 sec	> 1 sec
1	2.0	0.01	0.79	35	12
2	2.3	0.03	0.52	47	3
3	2.0	0.01	0.59	42	4
4	2.5	0.05	0.52	42	7
5	2.5	0.06	0.90	38	12
6	2.2	0.15	0.85	8	3
7	0.4	0.03	0.17	11	0
8	3.0	0.03	0.54	17	2
9	1.2	0.05	0.48	19	1

All experiments have been run on a Linux machine with Intel Core i7-5600U, CPU 2.60GHz x4 and 16 GB of memory. The model was implemented in Pyomo and solved with Gurobi 7.0, which is a state-of-the-art linear solver. Since the model is linear, all solutions are globally optimal. The results given in Table 3 show that most of the instances are solved to optimality within one second. There are a few instances in almost all sets which have a runtime between two and three seconds. This means we are very close to being able to solve realistically sized instances in reasonable time. If all SPP instances for a container vessel are solved sequentially in one operation, a runtime of between two and three seconds for some instances will not be a problem, as the average runtime is well below one second.

5. Conclusions

In this paper, we have extended known models for the Slot Planning Problem to include proper handling of IMO containers according to segregation rules for such containers. The problem has been rigorously described, and is formulated as a pure binary programming problem. Computational experiments show that the model can be solved to optimality in reasonable time using standard commercial software.

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