A TABU SEARCH METAHEURISTIC FOR ASSIGNMENT OF FLOATING CRANES

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***Abstract**: In this paper floating bulk handling cranes have been assigned to serve vessels placed in nodes within inland waterways. The software based on Tabu Search technique is developed for solving the problem. Numerical examples are solved and the results are shown to depict the possibility of the proposed algorithm.*

Keywords: *Assignment models, Tabu Search Technique, Metaheuristics.*

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1. INTRODUCTION

This paper addresses the management of floating bulk handling cranes used for gravel unloading from river vessels into unloading locations.

The entire process of gravel loading, transport and unloading by river towed fleet as well as the allocation of floating bulk handling cranes are controlled by a dispatcher. Decision of dispatcher has to satisfy the interests of all gravel distribution process participants.

The carrier tries to achieve as higher sales at minimal costs. This can be achieved by better usage and minimal hold of vessels as well as by sailing at optimal speed. Interests of handling device owners are the increase of handling device working period and downtime elimination.

In order to minimize time floating cranes spend at these locations, resulting in a higher turnover of available barges in the planning horizon as well as the maximal productivity of the entire system, the loading/unloading system handling devices have to be managed by dispatchers during the process of gravel distribution.

In the paper of Vidović and Vukadinović [7] the problem was formulated for the first time and named the Handling Devices Allocation Problem (HDAP). Handling devices are allocated to the bulk unloading locations minimizing the waiting time of loaded vessels and the execution time of unloading process at the unloading locations.

In the paper of Vidović and Vukadinović static handling devices allocation problem (SHDAP), where all tasks are already known when the scheduling plan is determined and all vessels to be unloaded are considered to be already placed at unloading locations, is studied. Also, two formulations of the problem are given and heuristics based on clustering is offered for problem solving.

Dynamic Handling Devices Allocation Problem (DHDAP) is a version of the problem where tasks service ready times are known after the beginning of the planning interval.

There are several papers in literature where the DHDAP is solved. Bjelić and Vidović [1] have applied memetic algorithm to solve the problem. Also, Bjelić et al. [2] solved the problem by the Variable neighborhood search metaheuristic.

Although the dispatcher makes real time decisions based on all available information, in this paper static problem is considered under the assumption that the vessel readiness moments for unloading and their capacity are known in advance. The SHDAP was solved by applying the Tabu search technique (TS).

So far, the proposed metaheuristic has not been used for solving the problem.

Numerical example has shown that the TS can successfully allocate floating cranes to tasks.

The paper is organized as follows. The problem description is given in the second chapter. The third chapter provides a description of TS method. The fourth chapter is devoted to the application of the TS to the assignment of floating bulk handling cranes solving. The fifth chapter describes the numerical example and gives analysis of obtained results. The conclusion is given in the sixth chapter.

2. PROBLEM DESCRIPTION

Gravel distribution is carried out within inland waterways. The process includes three main phases: loading of gravel by a suction dredger into river barges, transport of gravel to the ports or unloading locations, and unloading of gravel by handling equipment that usually consists of pontoon mounted crane and belt conveyor. Due to high costs, a number of cargo handling devices is usually relatively small, and requires consecutive relocation of handling equipment between different unloading places according to demand.

Since handling devices differ in productivity, their operational characteristics and quantity of load to be handled influence service time at nodes. Unloading time as well as handling device navigation or transfer time between unloading locations must be taken into consideration.

Providing efficient and cost effective service of loaded vessels requires appropriate allocation plan for handling cranes, which means defining sequence of unloading locations that should be served by each handling device. In order to utilize handling devices efficiently, and to minimize the waiting time, as well as the total service time of vessels, it is necessary to consider assignment of handling equipment to unloading locations and orders of servicing different unloading locations.

The problem could be introduced in the following way. For a given collection of barges a set of assignments should be found to minimize total service time including waiting for service and handling devices transfer times.

In other words, sequences of tasks assigned to each of available handling devices should be determined with objective of minimizing the total time that all barges spend on service and waiting to be served.

Waiting time of barges to be served represents the cumulative service time of all barges served by assigned handling device before observed barge. It is assumed that handling devices will serve disjoint subsets of tasks.

In this paper, the static problem (SHDAP), where all tasks are already known beforehand, is studied.

3. TABU SEARCH

Tabu search algorithm was proposed by Glover [4] and later by Hansen [5] for solving combinatorial optimization problems. The use of memory, which stores information related to the search process, represents the particular feature of tabu search.

The idea is to start from a random solution and successively move it to one of its current neighbors. Usually, the whole neighborhood is explored in a deterministic manner. When a better neighbor is found, it replaces the current solution. When a local optimum is reached, the search carries on by selecting a candidate worse than the current solution. The best solution in the neighborhood is selected as the new current solution even if it is not improving the current solution. To avoid possible cycles, TS discards the neighbors that have been previously visited. It memorizes moves recently applied, which is called the tabu list. This tabu list constitutes the short-term memory and at each iteration it is updated. Usually, the attributes of the moves are stored in the tabu list. At the beginning, the tabu list is empty and when new elements arrive, previous elements get shifted towards the end of list. When the tabu list is full, the oldest one gets removed from the list. The length of the tabu list determines the tabu tenure, i.e. the number of iterations a certain element is declared as tabu.

Depending on the length of the tabu list, the number of solutions which are unintentionally declared tabu may be very high. This effect makes it difficult for the search process to find better solutions. In such a case it may be desirable to revoke the tabu status of those elements which lead to solutions of outstanding quality. This approach is called aspiration and the most widely used criterion is the occurrence of a solution which exceeds the best solution found so far.

Tabu search incorporates aspects of both intensification and diversification (long-term memory). This is achieved by the combination of the solution choosing mechanism with the tabu list(s). Choosing the best possible neighboring solution in each step clearly aims at intensification. However, the memory has a diversifying effect on the search by disallowing moves or solutions. It may restrict the set of neighbors such that an intensification is not possible any more. This occurs when all improving solutions are marked as tabu. As soon as the search process arrives at an unexplored region of the solution space and unvisited improving solutions are available, it again performs intensification until it encounters the next local optimum [3],[6].

4. SOLVING THE ASSIGNMENT OF FLOATING CRANES BY TABU SEARCH

In this chapter the characteristics of the algorithm based on TS methodology will be introduced.

Application of Tabu search technique in software development involves a number of specific choices:

definition of neighborhood and attributes that will be remembered in tabu list, the length of tabu list, aspiration criteria, and ways of combining short-term and long-term memory.

Initial solution is randomly generated and it represents a random sequence of integers in the interval [1, N+d-1], where N is the number of nodes in the network and d is the number of handling devices (d>1).

A series of numbers 1,…, N represents network nodes while the numbers in the series N+1,…, N+d-1 are the borders between suborders of nodes assigned to individual devices.

For example, if there as a network with N=5 nodes marked with numbers 1, 2, 3, 4 and 5, served by d=2 handling devices, a possible solution is given in the Table 1.

Table 1. Solution encoding

3	4	1	6	2	5
Handling device 1				Handling device 2	

It determines two pieces of information: assignment of handling equipment to nodes and sequencing orders. Number 6 separates node subsets assigned to handling devices. The first handling device is assigned three nodes to serve by this order: 3, 4, and 1 while the second handles two nodes: 2 and 5.

The replacement of any pair nodes in the initial solution changes the orders of nodes assigned to handling devices (depending on the position the assigned subsets might be changed too). It is a neighboring solution, while the described change represents “move”. Switched pair of nodes is the attribute of move.

The set of all points in the space of admissible solutions obtained in this way is called the neighborhood of the initial solution. The number of points in the neighborhood is $\binom{N+d-1}{2}$.

The developed algorithm combines short-term memory to long-term memory, based on the frequency of memory.

A tabu list T of length L, so called the short-term memory, is introduced and it is initially empty. The tabu list memorizes switched pairs of nodes replaced in the last L moves. A pair of nodes remains on the list next L iterations and they are forbidden to change the position again.

The neighborhood of the solution expands or reduces depending on the history of the search process and represents the set of all candidates for the next search point. Due to efficiency, only a subset of K points that give the best value of the criterion function is observed. The next point is determined to be the best permitted point.

The tabu restrictions are not applied in all situations. If there is a forbidden move that leads to a better value of the best current criterion function value, the tabu status is ignored.

When all moves are forbidden and none of them gives better cost function value, the next point is determined by the move losing its tabu status through the minimal number of iterations.

The long-term memory, as an advanced mechanism, stores information, such as frequencies of moves. This type of memory is taken into account when none of possible moves from the current point reduces the value of the criterion function. Then, moves with high frequencies are penalized. Penalization is done by multiplying the frequency by a positive constant ω. This value is then added to the value of the objective function.

The next point is obtained by minimizing the value of new criteria functions on the observed set of points.

In this way, the points with the attributes of low frequencies are forced. It is the process of diversification.

In this paper a stopping criterion is given by predefined number of iterations.

5. NUMERICAL EXAMPLE

In order to demonstrate the proposed metaheuristic approach, the following examples are tested.

River and canals network, with distances (km) between network nodes is given in Figure 1. There are twenty unloading locations (nodes) with loaded vessels to be served.

There are three handling devices moving at the same speed, which is 10 km/h. Their unloading productivities are 200 tons/h, 150 tons/h and 100 tons/h, respectively. Handling devices are placed at the depot node.

Handling device preparation times before and after the unloading are considered zero. Also, all vessels to be unloaded are considered to be already placed at unloading locations.

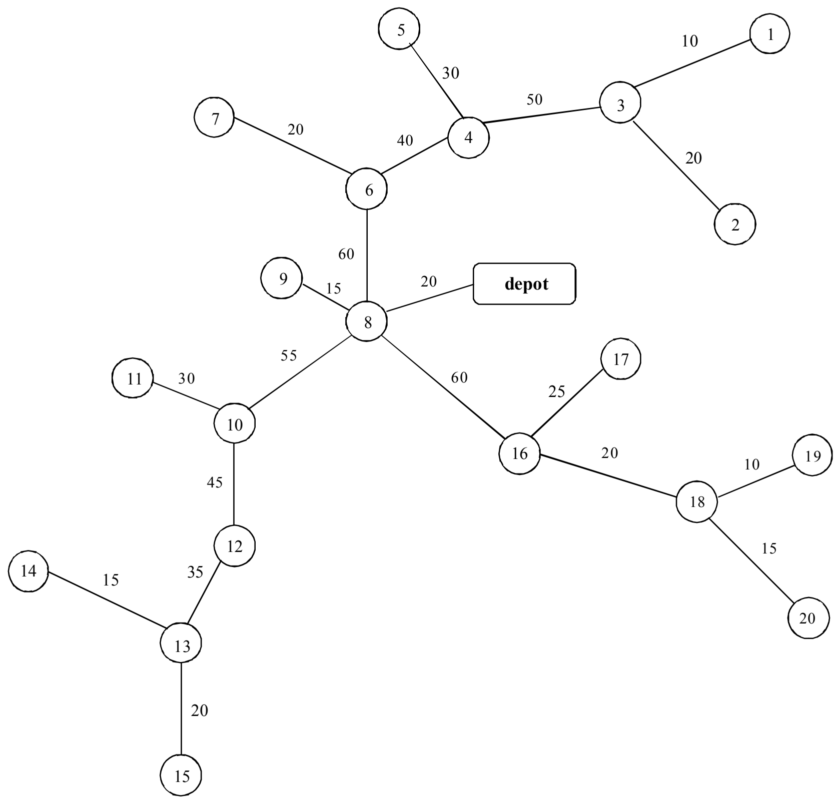

Figure 1. Transportation network

The assumption is that nodes have demand shown in Table 2.

Table 2. Node demand

Node	1	2	3	4
amount[t]	2000	6000	3000	4000
Node	5	6	7	8
amount[t]	5000	2000	3000	2000
Node	9	10	11	12
amount[t]	5000	3000	1000	2000
Node	13	14	15	16
amount[t]	6000	1000	3000	5000
Node	17	18	19	20
amount[t]	4000	3000	2000	1000

Specific choices concerning developed software were made. A tabu list of length L=3 was introduced. A subset of K=15 neighboring points that give the best value of the criterion function (as candidates for the next search point) was observed. Attributes of moves stored in the tabu list are switch pairs of nodes. Frequencies of moves were penalized by ω=5.

We composed six instances choosing the nodes from transportation network as it is shown in the first column of Table 3. The first fifteen nodes make the first numerical example etc.

All the tests were performed on AMD Athlon Dual Core computer processor with 1.90 GHz and 3 GB of RAM.

All experiments were finished after 100 iterations.

The solutions obtained by using the Tabu search technique are presented in the Table 3.

The objective function values (the total service times) and the CPU times are given in the second and the third column of the Table 3, respectively. Also, subsets of nodes and their orders served by assigned handling devices are given in the Table 3 (column 4, 5 and 6, respectively).

Table 3. Solution of numerical example

Set of nodes	Objective function value (h)	CPU time (s)	Handling device 1	Handling device 2	Handling device 3
1-15	1045.83	1.545855	6, 7, 4, 1, 3, 2	8, 11, 10, 9, 5	12, 14, 15, 13
1-16	1201.83	1.761005	6, 7, 4, 3, 1, 2, 5	8, 11, 10, 9, 16	12, 14, 15, 13
1-17	1385.00	2.034951	8, 11, 10, 9, 16, 17, 2	6, 7, 1, 3, 4, 5	12, 14, 15, 13
1-18	1519.00	2.228539	6, 7, 1, 3, 4, 5, 2	8, 10, 18, 17, 16, 9	11, 12, 14, 15, 13
1-19	1644.67	2.441825	8, 6, 7, 4, 1, 3, 2, 5, 9	10, 11, 12, 14, 15, 13	19, 18, 16, 17
1-20	1711.50	2.709223	6, 7, 4, 1, 3, 2, 5	8, 20, 19, 18, 17, 16, 9	11, 12, 14, 15, 10, 13

For example, the last instance consists of all 20 nodes. The total service time is 1711.50 h. The CPU time is 2.709223 seconds. The solution obtained by the software consists of the sequence of 22 integers. Their order is divided by numbers 21 and 22 on three parts showing the node subset and the order of serving for each handling device. It is shown in the Table 4.

Table 4. The 20-node solution obtained by the software

6	7	4	1	3	2	5	**22**	8	20	19	18	17	16	9	**21**	11	12	14	15	10	13
Handling device 1								Handling device 2								Handling device 3					

The first handling device is assigned sequence of nodes: 6, 7, 4, 1, 3, 2, 5, the second handling device is to serve: 8, 20, 19, 18, 17, 16, 9 by this order, while the sequence 11, 12, 14, 15, 10, 13 is to be handled by the third handling device. The solution of this numerical example is given in the Figure 2.

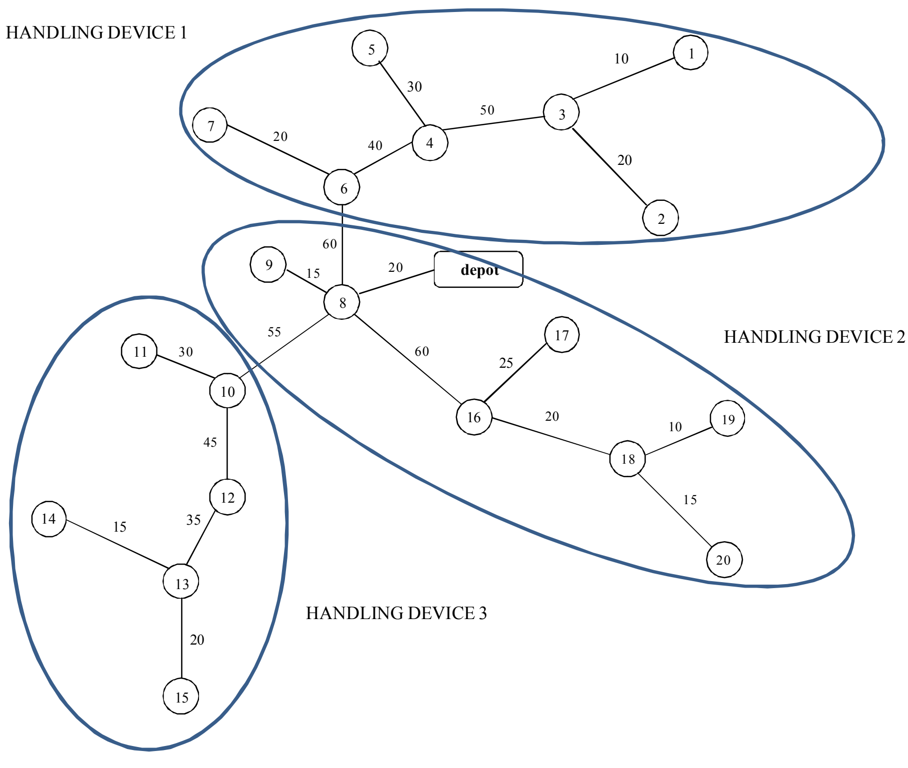

Figure 2. The solution of the 20 – node transportation network

6. CONCLUSION

This paper addressed the problem of assigning of handling devices to unloading places on inland waterways. Rational handling device allocation enables their better utilization, decreasing costs incurred due to the loaded vessel waiting.

In solving the planned tasks, dispatchers need decision-making system support to make very complex decisions. One of the possibilities for the development of decision support systems is the development of automated systems based on mathematical programming.

Another possibility for the development of decision support systems is the use of heuristic and metaheuristic algorithms that can achieve good solutions in a relatively short time.

In this paper, the approach based on the Tabu search method is offered to address the assignment of floating bulk handling cranes to unloading locations on inland waterways. Six numerical examples (river networks of 15, 16, 17, 18, 19 and 20 nodes) are considered to be served with three handling devices.

Numerical examples have shown that the problem is successfully solved by the proposed metaheuristic algorithm.

Since the computing time of the TS metaheuristic is very reasonable, it is acceptable for solving the problem in real time.

On the basis of obtained results, it could be concluded that the use of this metaheuristic method is justified in solving other resource allocation problems that might not be exclusively related to the transportation network.

Another research direction might be a development of exact algorithm and a comparison between optimal solutions with those obtained in this paper. Additional research opportunity might be the usage of a real data set.

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