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SHIP'S CARGO HANDLING OPTIMIZATION

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Abstract: *This paper proposes a new optimization model of cargo handling operations on ships which solution results in determination of the structure of resources required, along with attaining the minimum total "in-port" costs and the minimum time required for completion of cargo operations. Due to complexity of the model the solution has been sought by utilization of an adapted genetic algorithm. In the course of decision making, the ship operator can, on the basis of the proposed model and taking into consideration shipping market data, choose appropriate variation of the returned solution, which incorporates minimum costs, minimum of operational time and related cargo handling resources.*
Key words: *ship, optimization, cargo handling*

1. INTRODUCTION

In this paper general cargo ship is defined as multichannel, multiphase mass service system, where input flow of general cargo passes through four phases in the process of cargo handling (Hess & Hess, 2009). When making business decisions related to these processes (Fendick, 1989), it is essential for ship operator to achieve the minimum transhipment costs together with the minimum service time in a port.

Due to problem complexity, multiobjective optimization model is set up that consists of two objective functions (the first is minimum total cost of service and waiting and the second is minimum service time) with decision variables: number of ship cargo cranes, number of forklifts, number of workers engaged on cargo securing, and workers engaged on cargo separation and marking.

The problem solution sought in this paper is based on application of an adapted genetic optimization algorithm that is combined, for the purpose of achieving more precise solutions (Kalyanmoy, 2001), with a hybrid optimization algorithm. It should be emphasized here that the process starts with completely different assumptions in optimization modelling than the classical mathematical procedures that can be found in operating research literature (Bose, 2002).

The mathematical model has been tested on the real world example with general cargo ship with six holds and five cranes that load 10,000 cargo units by ship's cargo cranes.

2. THE PROBLEM

While planning process of cargo handling on the ship during her stay at port, the problem occurs in organization and optimal utilization of the existing port and ship resources, i.e. ship cranes, forklifts and workers, with the objective of minimizing the total operational costs (Hess & Hess, 2009).

In real life, however, the problem can be more complex if the ship operator considers those costs confronted to total earnings in the broader context of business making, in time period that extends ship stay at port. An example is related to costs and gain through complete ship voyage, from the first loading port to the last discharging port according to chartering agreement. Solution obtained for minimal total operating costs related to cargo handling in port does not have to mean that solution is also found for maximal gain on the observed voyage. This is because the minimum of the stated costs in reality can be produced by slower operations of cargo handling, especially in ports with lower port dues and high tariffs for overtime work. Effect of longer ship staying at port, on the other hand, leads to postponed signing of a next chartering agreement and in final fewer earnings in longer period of time. Hence, apart from finding solution for minimal total operating costs of cargo handling in port, it is essential at the same time to determine minimal time of ship stay at port.

The goal of this paper is to determine simultaneously minimal costs and minimal ship service time, as well as to quantify resources needed for cargo operations (ship cargo cranes, forklifts, workers). Here, for the sake of problem simplicity, the process of cargo handling is limited to the loading operations only.

3. MATHEMATICAL MODEL

As emphasized in the paper Optimization of ship's cargo handling (Hess & Hess, 2009), ship can be defined as mass servicing system where arrival rate of units, parameter λ represents the average number of general cargo units arrived alongside the ship during an observed time unit (e.g. during a year, month or day). The average number of general cargo units that can be served at ship in a time unit is service rateμ.

Model set up in the paper (Hess & Hess, 2009) for estimation of the optimal number of service places in each phase consists of one objective function minimizing sum of expected total costs:

$$\min C = \min \left\{ \begin{array}{l} \sum_{i=1}^{4} C_i S_i + \sum_{i=1}^{4} \left[C_{wi} L_i - \sum_{n=0}^{S} n \cdot p_{ni} \right] \\ -\sum_{i=1}^{4} \left[C_{wi} \dfrac{S_i^{S_i}}{(S_i - 1)!} \cdot p_{0i} \cdot \dfrac{\psi_i^{S_i+1}}{1-\psi_i} \right] \end{array} \right\} \quad (1)$$

$$\min W_{usl} = \min \beta Q \sum_{i=1}^{4} w_{usl_i} = \min \beta Q \sum_{i=1}^{4} \frac{1}{\mu_i S_i} \quad (2)$$

with constraints:

$$1 \le S_1 \le 5; 1 \le S_2 \le 6; 3 \le S_3 \le 18; 2 \le S_4 \le 12 \quad (3)$$

Input variables are: $\lambda, \mu_1, \dots, \mu_4, C_1, \dots, C_4, C_{w1}, \dots, C_{w4}$, and decision variables: $S_1, \dots, S_4$.

Due to the complexity of computational procedure (Powell, 1978), the approach taken here of finding solution, in the first part applies genetic optimization algorithm (GA) adapted to the problem setup in order to reach solution area close to the optimum in fewer number of iterations, followed by application

Stage	Stg 1	Stg 2	Stg 3	Stg 4	Stg 5
tolerance	0.02	0.02	0.02	0.01	0.02
time limit (s)	10	10	10	10	10
max num of gen.	202	136	148	20	2
number of points	23	34	30	31	31
avrg.dist.measure	0.100	0.088	0.070	0.092	0.039
spread measure	0.380	0.410	0.476	0.501	0.293

Tab. 1. GA and GHA input controls and output parameters

of hybrid optimization algorithm (GHA) that leads to the final solution area.

4. PROBLEM SOLUTION AND RESULTS ANALISIS

In order to attain practical solutions, multiobjective optimization used here will generate and select noninferior solution points since any point in Ω that is an inferior point represents a point in which improvement can be attained in all the objectives. The goal in this optimization is constructing the Pareto optima and the algorithm used in process calculation is described in (Kalyanmoy, 2001). Our approach finds a local Pareto front for multiple objective functions, each of four decision variables, using the genetic algorithm followed by a hybrid function. We also impose bound constraints on the decision variables as noted in model formulation. The input controls for genetic algorithm, GA and genetic hybrid algorithm, GHA and output parameters are given in table 1.

The final results for loading of 10,000 cargo units of the general cargo are obtained in form of points on Pareto front, figure 1, which coordinates are positioned in the space of optimal results that satisfy minimum of objective functions. That means each point represents minimum of costs and associated minimum of operational time, reached along with specific combination of number of service places by phase. Since there is no unique optimal result, ship operator will be able, taking into consideration the real case, take decision on how long the cargo operations will last and get the amount of associated costs, and vice versa.

Figure 2 shows that in the first part (up to 16 h) curve quickly descend which may be explained by the fact that the ship service time grows inversely proportional to the number of service places per phase, resulting in almost linear decrease of costs per hour. The second part of curve falls considerably slower and asymptotically approaches specific cost value. Extreme right points on the Pareto front mark minimal savings in costs per hour considering the extension of the duration of the service time.

Lines of the table 2 show some of the iterations of costs and service time calculations on Pareto front along with numbers of service places in each phase. The results match the expectations in performing loading operations on board. If ship operator, in the area of optimal solutions, decides for a solution obtained in the iteration 14, the operational cost will amount to 2988.06 mu/h, while the time required for execution will be 16.93 h.

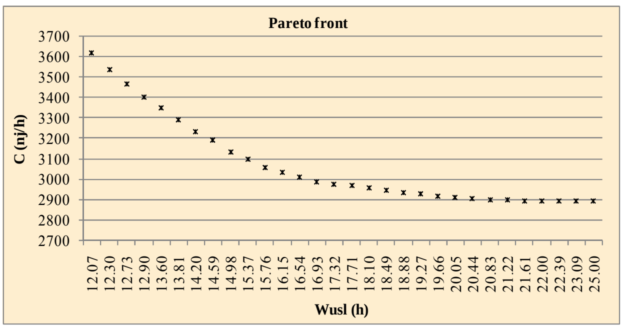

Fig. 1. Pareto front of costs *C* and service time W_{usl}

Iteration	C (nj/h)	Wusl (h)	S1	S2	S3	S4
11	3031.42	16.15	4	4	12	7
28	3011.57	16.54	4	3	10	5
14	2988.06	16.93	3	4	9	2
⋮	⋮	⋮	⋮	⋮	⋮	⋮
31	2895.52	21.61	3	2	8	3
23	2896.98	22.00	2	2	6	3

Tab. 2. Values of objective functions and decision variables for some points on Pareto front

In this case, in the first phase three cranes work on four cargo holds, in the second phase four forklifts are distributed in four holds. Furthermore, nine workers are needed for cargo securing and two workers for cargo marking and separation.

Ship operator, on the basis of data from the table, can accurately determine the total costs related to the transhipment in the port, and duration of transhipment along with the resources needed per phase. Moreover, taking into consideration the current state of the shipping market and the rates and terms of ports, ship operator takes optimal business decision.

5. CONCLUSION

Given the complexity of model with multiobjective functions, several decision variables and constrained solution space, the approach taken here to search for solution is based upon adapted genetic optimization algorithm in combination with hybrid optimization algorithm for the purpose of achieving improved results. In the space of possible solutions (Pareto front) computational process, with variations of different methods of crossover and mutation for GA and optimization options for GHA produces results that match the experiences from practice when performing cargo loading operations on board general cargo ship.

The advantage of suggested process of solution search manifests itself in obtaining the space of optimal solutions, which provides ship operator with possibility of selecting one of them in a broader consideration of business making on the shipping market.

Analogy could be drawn to observe the process of unloading, or a combination of cargo loading/unloading, in which case phases would be arranged differently, which, may be the subject of further research.

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