A Multi Objective Liner Scheduling Problem for Short Range Route

Kenichiro NAGAIWA*, Saburo TSURUTA**, Hirohito KUSE** and Hisayuki KUROKAWA**

1. Introduction

In Japan, the manned islands that exceeds over about 400 except for the mainland (Honshu, Hokkaido, Shikoku, Kyushu) are located. We have been supported the life by aquatic resources such as fish and seaweed from the sea, and sea and river have been utilized as a field of the transportation since ancient times. It is possible to operate the ship supported by buoyancy over the water by very small force, though its speed may be slow. Therefore, the ship has widely been utilized in the transportation of human and cargo since the ancient.

At the present, ground or air transportation facilities of automobiles, trains or air has made progress. The transportation of the passenger gradually changes into these traffic facilities of automobiles, trains and airplane. However, there are many islands where the traffic is not possible, if it were not for a ship. And, there are some routes in which the ship is also more convenient passing the water on the straight line.

In such routes, the working style of the ship-crew is different from that of ship-crew on a long distance liner. Though the crew of a long distance liner are on board for the long term (over 24 hour are onboard), those of a short-range liner work from the first departure to the last arrival. The time zone between them is defined here as “on-service time zone”.

As for working hour of the ship-crew, the low has regulated boarding hours restrictions per day, per week and a holiday per week. Ship size determines the minimum number of crew requirements according to the law.

The wage of the ship-crew in short range route occupies a large proportion of the operation cost.

Therefore, it is important for the operator to make a traffic schedule with the minimum number of ship-crew so as to satisfy these constraints.

2. Problem Formulation

2.1 Approaches to Problem

Increase of the number of traffic and extension of the on-service time zone are more desirable than the speedup and amenity of the ship. Ship-crew are needed more in order to realize these requirements.

The operation cost also gets high, when the number of traffic is increasing. Especially, the increase of number of ship-crew raises the operation cost.

The operator reduces the number of ship-crew and the operation cost to make the schedule while the user wants the largest traffic service.

We proposed a multi-objective liner scheduling problem. One objective is minimization of such operation cost, the other maximization of the traffic service.

We formulated it as integer planning
problem with two objectives on the short-range liner service, and proposed the solution algorithm.

The scheduling problem of the ship-crew is obtained as the set-covering problem of integer programming.

Crew scheduling problems are well known and several mathematical programming techniques have been proposed to solve them, in particular using the set-covering formulation.

2.2 Problem Formulation
Formulating the problem several assumptions must be made. These assumptions are as follows:
1. Use only a timetable in the usual time.
2. The route connects directly two harbors, and we consider one way as a traffic unit.
3. Seaman's working hour is constant; it is the average of onboard time per the number of traffic. Working hour is included on board time, idle time and repair time.
4. Reserved seamen, spare ships are not included in this problem.

The problem may be formulated as a multi-objective integer program as follows:

\[ \text{Maximize} \left( \text{ATL} \right), \Sigma D_i \right), \text{Minimize} \left( F(X) \right) \] subject to

\[ T_j \leq TLL \quad \forall j \in N \quad \forall k \in P \] (a.1)

\[ T_j \leq TRL \quad \forall j \in N \quad \forall k \in P \] (a.2)

\[ T_j \leq TRL \quad \forall j \in N \quad \forall k \in P \] (a.3)

\[ \sum_{i=1}^{N} X_{ja} = 1 \quad \forall j \in N \quad \forall a \in K \] (a.5)

where,
\[ i = \{ 1, \ldots, D \} \] : number of traffic
\[ j = \{ 1, \ldots, N \} \] : number of seaman
\[ k = \{ 1, \ldots, P \} \] : number of planning day
\[ N \] : the set of seamen
\[ P \] : the term of scheduling (usually 7 days=a week)
\[ D \] : the traffic of \( k \)th planning day's

\[ \text{ATL} \] : the on-service time zone
\[ F(X) \] : operating cost and navigation cost
\[ ST_{ia} \] : the fixed seamen's boarding number of the traffic \( i \) at \( k \)th planning day
\[ T \] : working hours per one traffic (on board time, addle time and repair time are included)
\[ AT \] : non working hours between traffics
\[ TLL \] : the upper limit in working hours for a seaman per day
\[ TRL \] : the upper limit in restricted hours for a seaman per day (Recess by Labour Standards Law 34th section is contained)
\[ TWL \] : the upper limit in working hours for a seaman per week
\[ K \] : the set of boarding schedule made, considering the constraint in working hours
\[ a \] : the elements constituting \( K \)

\[ X_{ja} \begin{cases} 1, & \text{if seaman } j \text{ is allocated at boarding schedule } a \\ 0, & \text{otherwise} \end{cases} \]

\[ a_{i,j,k,a} \begin{cases} 1, & \text{if boarding schedule, } j, a, \text{ of set, } i, k, \text{ is allocated} \\ 0, & \text{otherwise} \end{cases} \]

The variables in the formulation are \( a_{i,j,k,a} \), and \( X_{ia} \) that are dependent on \( a_{i,j,k,a} \). Constraints (a.1) ensure that every seaman must work less than the upper limit in working hours per day. The upper limit in working hours per day for each day of the week is 8 hours, excluding rest periods. Constraints (a.2) ensure that every seaman must work less than the upper limit in restricted hours the seaman per day. Restricted times are decided by the employment agreement. Constraints (a.3) ensure that every seaman must work less than the upper limit in restricted hours per week and must be had at least one rest day per week. The upper limit in working hours per week is 40 hours, excluding rest periods. Constraints (a.4) ensure fix the minimum requirements decided by operator.
Constraints (a.5) ensure that one schedule must be allocated to each seaman.

In this problem, the optimum solution is determined, if, simultaneously, one object optimum value optimizes the other object value.

However, this multi objective problem doesn't always give the optimum solution. In general there exist trade-offs between these objectives.

In such cases, the decision maker finally chooses a satisfying solution as pareto optima among all feasible service levels with the minimum number of ship-crew.

The both objective functions could not be formulated, because it was complicated.

Then, the one objective function for the convenience of the user is removed, and it transformed in the problem that makes a single objective function of the cost into that of the smallest seaman number.

(M2)  \[
\text{Minimize} \left( \sum_{j \in N_2-K} \sum_{k \leq K} X_{jk} \right) \\
\text{subject to } (a.1)-(a.6)
\]

This problem enumerates all patterns of possible boarding number of traffic and shows the operable combination of minimum seaman number.

The scheduling problem of the ship-crew is obtained as the set-covering problem of integer programming.

Crew scheduling problems are well known and several mathematical programming techniques have been proposed to solve them, in particular using the set-covering formulation.

In the field of OR, crew scheduling problem in the set covering problem is the research object of the efficiency improvement of computational algorithm. But, our original program is developed in order to obtain the solution rather than the efficiency improvement of the algorithm.

The algorithm that obtains the solution is shown as follows.

**step1.** The value of each variable is set. 
(ALT/T)=upper limit of number of traffic on a ship per day.

**step2.** The set of the schedule per day of the seaman that satisfies the equation (a.1)-(a.3) in T is M.

\[M=\{a_1, a_2, \ldots, a_n\}\]

**step3.** The families of set Pn of the boarding schedule at least one rest day per week of the seaman are requests from the element of the sets M, those sets are made to be K.

\[K=\{p_1, p_2, \ldots, p_n\}\]

**step4.** Boarding schedule of each seaman is searched in order from the element of set K.

If the constraint (a.4) is not satisfied during the planning term, the search is stopped, then goes to the next.

If all constraint is satisfied, then it becomes the optimal solution for the number of seaman.

If all K are searched, when the constraint is not satisfied, then adding one to the number of seaman, **step4** is repeated.

### 3. Numerical Experiments

The problem is examined for the following 6 cases.

On 6 cases shown at the table 1, maximum traffic operation number by number of seaman is obtained.

The calculation result is shown in table 2. From this, maximum traffic operation number of service in the route is calculated by substituting the variable.

\[D_{\text{max}}=F(T, N)/ST \quad \text{(b.1)}\]

\[D_{\text{max}}: \text{the maximum traffic operation number}\]

\[F(T, N): \text{the maximum boarded number by seaman N of working hour T}\]

For examples, the seaman number neces-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The model route of numerical experiments working hour(minutes)</th>
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<td>Case1</td>
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4. Conclusions

This paper presents the Liner scheduling for short-range route that is a support system in the traffic service level decision-making. This scheduling problem is hardly researched as a problem of the engineering. We proposed a multi-objective liner-scheduling problem between one objective is viewpoint of the operator and the other objective is viewpoint of the user, and we developed the solution for this problem. However, the both objective functions were complicated, and it could not be formulated. Then, the problem transformed a single objective function of the cost into that of the smallest seaman number. Finally, some sample computations are performed to demonstrate this problem.

This program that we developed can be applied to two points for the daily transportations. The operation cost can be calculated easily in order to obtain the necessary smallest crew number. Detailed cost model for this program is built in, and then it becomes an effective technique for the service level examination.

An additional remark, this research was

Table 2 Calculation results of $F(T, N)$

| Num. of Seaman | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Case1         | 64  | 91  | 114 | 137 | 160 | 182 | 206 | 228 |
| Case2         | 38  | 54  | 68  | 82  | 96  | 110 | 123 | 137 | 150 | 164 | 178 | 192 | 205 | 219 |
| Case3         | 26  | 38  | 48  | 58  | 68  | 77  | 87  | 97  | 106 | 116 | 126 | 136 | 145 | 155 | 165 | 174 | 184 | 194 | 204 |
| Case4         | 20  | 30  | 37  | 45  | 53  | 60  | 68  | 75  | 83  | 90  | 98  | 106 | 113 | 121 | 128 | 136 | 143 | 151 | 159 |
| Case5         | 16  | 24  | 30  | 36  | 43  | 49  | 55  | 61  | 67  | 73  | 79  | 86  | 92  | 98  | 104 | 110 | 116 | 122 | 129 |
| Case6         | 14  | 20  | 25  | 30  | 36  | 41  | 46  | 51  | 56  | 61  | 66  | 72  | 77  | 82  | 87  | 92  | 97  | 103 | 108 |

Table 3 Example calculation results of necessary number of seaman

<table>
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<th>ST</th>
<th>Case1</th>
<th>Case2</th>
<th>Case3</th>
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Figure 1 Calculation results of $F(T, N)$ number.
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References