Scheduling Annual Surveys for Ship Fleet: A Case of Tramp Shipping Services

船隊歲檢排程～以不定航船運為例

Hua-An Lu*, Yu-Chang Hsu**

Abstract

Ships have to assure their seaworthiness and safety while sailing at sea. In the global maritime communities, owners are requested to obtain seaworthiness certificates for ships, under a comprehensive survey scheme, and then to recognize ships that have remained satisfactory for their intended service. This study focuses on the scheduling of annual surveys of ships for tramp shipping services. In a five-year cycle, annual surveys must be held within three months before or after the anniversary date of each ship, which is the ship's delivery or renew date and month, but only before the anniversary date at the fifth year. This study formulates a 0-1 integer programming model for the annual survey arrangement of ships in month scale for a long time horizon. Besides the regulation constraint, this model also takes into account how to balance the workloads for engineers in preparation of various inspected items. The constraint system of this model has the property of total unimodularity, so an integer solution can be obtained rapidly in every instance. This model can assist owners, particular those who maintain a large ship fleet, to monitor and decide an ideal plan of annual surveys. A tramp service case is tested for scheduling annual surveys of twenty ships. Using a variety of parameter settings, this

* Corresponding Author. Associate Professor, Department of Shipping and Transportation Management, National Taiwan Ocean University. (E-mail: halu@mail.ntou.edu.tw)

** Ph.D Student, Department of Shipping and Transportation Management, National Taiwan Ocean University. (E-mail: D98730006@mail.ntou.edu.tw)

paper also discusses some practical requirements for exploring further applications of the formulated model.

Keywords: Annual survey, Tramp shipping service, 0-1 integer programming model, Total unimodularity,

摘要

船舶在海上航行時必須確保其適航性與安全。在全球航運社羣中所設定完整的船舶檢驗機制，要求每艘商船必須取得適航證書以認可其能安全地滿足所欲進行的服務。本文以不定航船運爲例，探討船隊歲檢安排問題，所依據的是每艘船舶在其五年之歲檢循環中，必須在每年基準日(即下水日或更新日)之前後三個月內執行(第五年需在基準日之前)。本研究以長期規劃之觀點建構船隊歲檢月排排程之 0-1 整數規劃模式，模式中除了法規之限制外，亦考慮平衡船東之工程師在準備工作上的負荷，所形成的限制式系統具有完整單一模化(total unimodularity)之特性，因此可在任何案例中迅速獲得最佳解。此一模式可協助船東，尤其擁有大規模船隊之航商，監控與決策理想的歲檢規劃。本研究以我國某航商 20 艘船舶之案例進行模式測試，並以不同的參數設置探討模式在實務案例中之可行應用。

關鍵詞：歲檢、不定航船運、0-1 整數規劃模式、完整單一模化

1. Introduction

To maintain a ship's seaworthiness is one of the most important aspects of ship management. For preventing maritime distress and ensuring sailing safety, the International Maritime Organization (IMO) has built a ship survey framework to be conducted in the global maritime communities. According to early provisions of the International Convention for the Safety of Life at Sea (SOLAS) 1974 and of the International Convention on Load Lines (LL) 1966, ships have to implement necessary surveys for ensuring their seaworthiness and safety while sailing at sea. Ship surveys consist of six kinds of inspections: initial, periodical, intermediate, additional, and mandatory annual surveys, plus an unscheduled inspection[1].

The survey system has been transferred into a concrete legislation for ship management by port registry administrations in the global countries. Not only are all ship owners and

[1] International Maritime Organization (1987), *Guidelines on Surveys Required by the 1978 SOLAS Protocol, the International Bulk Chemical Code, and the International Gas Carrier Code*, IMO, London.

classifications enforced to set up reliable safety equipment for avoiding distress, pollution and increasing sailing safety, but also the port registry administrations and the port state control must conduct ship inspections to meet relative regulations[2,3]. Safety certificates are the first item that port state control officers inspect. Ship owners must keep these certificates in effect throughout the schedule arrangement of surveys in a five-year cycle.

From the perspective of ship owners, the work of scheduling ship surveys and maintenance activities is relatively limited, especially for merchandise ships. Brown et al.[4] formulated a generalized set partitioning model to assign major operations, exercises, maintenance periods, inspections and other events for the annual planning of naval surface combatants. Deris et al.[5] explored ship maintenance scheduling, which concerns the start times of maintenance activities. The plan has to optimize ship availability and satisfy all precedence and resource constraints. The proposed genetic algorithm with constraint satisfaction was applied to the Royal Malaysian Navy. Manti et al.[6] used TOC project management for a research vessel to reduce the total cost by an efficient schedule for operation and maintenance activities. In addition, several studies, such as those by Blatchley et al.[7], Inozu and Karabaka[8], Finke et al.[9], and Cristóbal and Ramón[10], contributed to scheduling maintenance work in dry docking yards. Most of studies focused on the maintenance activities for a single ship or dock works. The arrangement of surveys for an

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9 Finke, D. A., Ligetti, C. B., Traband, M. T. and Roy, A. (2007). Shipyard space allocation and scheduling. *Journal of Ship Production* 23(4), 197-201.

10 Cristóbal, S. and Ramón, J. (2009). A goal programming model for vessel dry docking. *Journal of Ship Production* 25(2), 95-98.

entire ship fleet is lacked to discuss. This topic concerns with an important decision and even affects the regular services of a shipping company.

This study focuses on scheduling annual surveys of ships from the perspective of owners. The scope of annual surveys includes a general inspection of the structure, machinery and equipment, to ensure that the ship remains satisfactory for its intended period of service. Annual surveys must be held within three months before or after each anniversary date, which is the delivery or renew date and month of a ship. The execution places are ports with qualified conditions to support the survey requirements. The space and time to arrange annual surveys might not be so critical. However, tramp service ships easily overextend the range of dates for their annual surveys because of uncertain itineraries in the chartering period. Parts of ships have been neglected because surveys were densely gathered within the wrong time period, or the company's engineers had uneven workloads. However, the most significant factor contributing to the mismanagement of surveys is that owners may not have a comprehensive plan that combines the management of the entire fleet and the inner resources of the company. Therefore, a detailed plan for scheduling ship surveys in accommodation with workload distribution is necessary.

This study formulates a 0-1 integer programming model for the annual survey arrangement of ships in month scale for a long time horizon. The regulations of annual surveys and the balance of workloads are considered. The constraint system of this model has the property of total unimodularity, so the model can obtain an integer solution rapidly. A tramp service case is discussed for scheduling annual surveys of twenty ships. Using a variety of parameter settings, the paper also discusses some practical requirements for exploring further applications of the formulated model.

2. Model Formulation

For the flexible planning of annual surveys of the entire fleet, a monthly scale is considered. This section introduces the concept of recoding the months of a year to link the possible sequence year by year. Then, following this structure, this study proposes a mathematical model to schedule annual surveys.

2.1 Planning Structure

There is a specific anniversary date for each ship. For a long time planning horizon, owners can plan the schedule of annual surveys on a monthly scale so as to maintain flexibility of arrangements. Since the anniversary dates of some ships may be at the beginning or the end of a year, all anniversary dates of ships in this study are figured to the mediate of a month. Consequently, the possible availability of conducting annual surveys will extend over seven months, as shown in Figure 1. It is noted that the last available month is less appropriate for ships with anniversary dates at the beginning of a month, while the first available month is less appropriate for ships with anniversary dates at the end of a month. This consideration is reflected in the parameter settings of the formulated model.

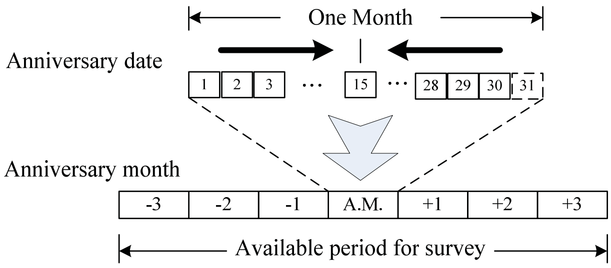

Figure 1. The concept of the anniversary month altered from the anniversary date

The possibility of assigning surveys to the last or next year for those ships with anniversary months at the early part or end of a year still requires to be taken into account. For every planning year, this study adds three pseudo-months before January and after December, which is in keeping with practical regulations. The new extension of recoded months, 18 months in total, is the maximum possible assignment for every year. Following this concept, the "first three months" refers to the last three months of the last year, while the "last three months" indicates the first three months of the next year. Figure 2 displays the scheme of the new month codes in the planning horizon. The formulated model in the next section will follow this recoded structure of months.

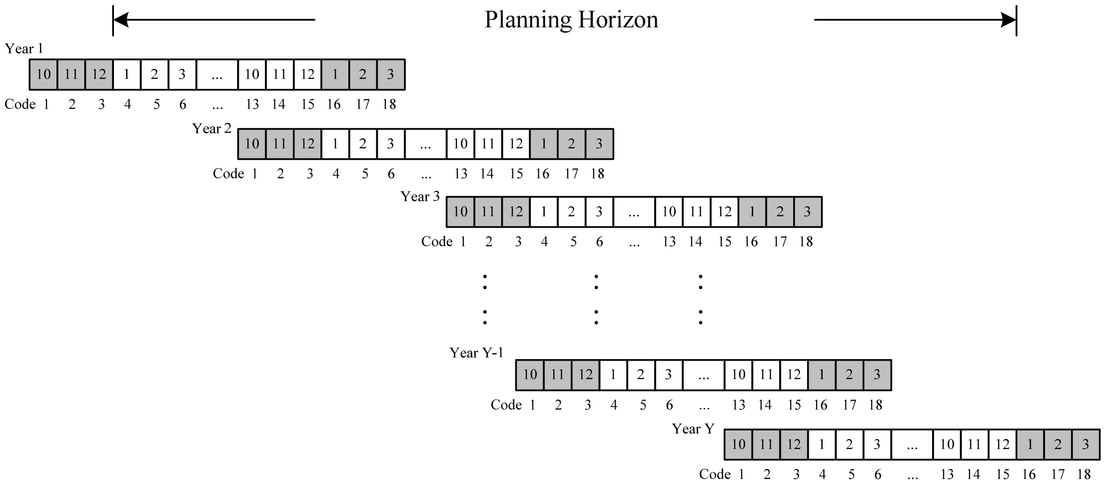

Figure 2. Month codes for every planning year

2.2 Mathematical Model

Different planning results may produce variable impacts on the ship owner. This study assumes that for each available month, the impact of the survey assignment can be quantified for every ship. The owner aims to minimize the total impact. Besides the regulation of the available seven-month period for annual surveys has to be followed, the limitation of allocating a maximal number of ships surveyed in each month is necessary.

Indexes are used in model formulation for K ships planned in a Y-year horizon with 18 month codes for each year as the following:

$y = 1, \ldots, Y$;
$m = 1, \ldots, 18$;
$k = 1, \ldots, K$;
d^k: Start year for planning annual surveys of ship k;
s^k: Anniversary month code for ship k, $s^k \in \{4, 5, \ldots, 14, 15\}$.

The decision variable and parameters are defined as follows.

x_{ym}^k : If ship k implements a survey at month code m in year y, 1 for yes, 0 otherwise.
w_{ym}^k : Penalty weights for implementing a survey at month code m in year y for ship k.
a_{ym} : Allowable ships implementing surveys at month code m in year y.

A 0-1 integer programming model can be formulated as Equations (1) to (8).

$$Min. \quad z = \sum_{k=1}^{K} \sum_{y \geq d^k}^{Y} \sum_{m=s^k-3}^{s^k+3} w_{ym}^k x_{ym}^k \tag{1}$$

$$s.t. \quad \sum_{m=s^k-3}^{s^k+3} x_{ym}^k = 1 \quad \forall k, \ \ y \geq d^k \tag{2}$$

$$\sum_{\substack{k=1 \\ d^k=1 \\ m-3 \leq s^k \leq m+3}}^{K} x_{1m}^k \leq a_{ym} \quad \forall m = 4,\ 5,\ 6 \tag{3}$$

$$\sum_{\substack{k=1 \\ d^k \leq y \\ m-3 \leq s^k \leq m+3}}^{K} x_{ym}^k + \sum_{\substack{k=1 \\ d^k \leq y-1 \\ s^k \geq m+9}}^{K} x_{y-1,m+12}^k \leq a_{ym} \quad \forall y = 2,\ \ldots,\ Y;\ \ m = 4,\ 5,\ 6 \tag{4}$$

$$\sum_{\substack{k=1 \\ d^k \le y \\ m-3 \le s^k \le m+3}}^{K} x_{ym}^k \le a_{ym} \quad \forall y,\ m = 7,\ ...,\ 12 \tag{5}$$

$$\sum_{\substack{k=1 \\ d^k \le y \\ m-3 \le s^k \le m+3}}^{K} x_{ym}^k + \sum_{\substack{k=1 \\ d^k \le y+1 \\ s^k \le m-9}}^{K} x_{y+1,m-12} \le a_{ym} \quad \forall y = 1,\ ...,\ Y-1;\ m = 13,\ 14,\ 15 \tag{6}$$

$$\sum_{\substack{k=1 \\ d^k \le Y \\ m-3 \le s^k \le m+3}}^{K} x_{Ym}^k \le a_{Ym} \quad \forall m = 13,\ 14,\ 15 \tag{7}$$

$$x_{ym}^k \in \{0,\ 1\} \quad \forall k, y \ge d^k, s^k - 3 \le m \le s^k + 3 \tag{8}$$

The objective function, Equation (1), aims to minimize the sum of total penalties for all ship survey assignments in every available month during the planning horizon. The consideration for the real anniversary date at the beginning or end of a month can be appropriately set. When the timing of a ship falls into the fifth year in the five-year cycle, the objective coefficient can be set as infinite large to avoid the inspect timing over the regulation. Equation (2) limits every ship to conduct one survey within three months before or after its anniversary month for every year. Equations (3) to (7) represent the limitation of allowable surveys for every month of every year in the planning horizon. The first equation, Equation (3), represents the first three months of the first year. Equation (4) indicates the constraints in the same months for the rest of years. Note the assignments of the last three pseudo months have to be included. Equation (5) shows the same constraint for April to September of every year. Equation (6) refers to the allowable constraints from October to December for every year except the last one. Note the assignments of the first three pseudo months also have to be included. Equation (7) represents the same constraint for the last three months of the last year. Equation (8) is the binary constraint of variables.

Property: Constraints (2) to (7) are totally unimodular.

Proof: The elements in the technique coefficient matrix of this constraint system are either 0 or 1. It is easy to find that there are two elements equal to 1 for every column corresponding to x_{ym}^k. One appears in constraint (2). Another one exists in the corresponding constraint among Equations (3) to (7) because these constraints cover every element in Figure 1 just one time. Each determinant value of the minor square matrix of the technique coefficient matrix equals to 1, 0 or -1. Therefore, this constraint system is totally unimodular.

This property ensures the solution obtains integral values for decision variables if the values of right hand sides in the constraint system are all integers[11]. One can use the algorithm for solving the linear programming problem to rapidly obtain the optimal result. The dual prices of Equations (4) to (7) can also reveal the months of the years that will be the workload bottleneck and the penalty decrements for increasing one ship allowance. Furthermore, the model can also measure the largest workload limitation if a_{ym} is released as the variable, and the totally unimodular property will still hold.

Basically, this model can be used dynamically. It can be limited on a self-designed planning horizon as the requirement of shipping lines. The decision makers can obtain an ideal planning result of annual surveys for the entire ship fleet on time scale. This plan can avoid ships violating the regulated survey period and reduce engineers work burden within a specific period. In particular, the decision of this model is very fast and effective, even planning a large ship fleet for a five-year planning period, based on the totally unimodular property. The shipping lines can easily apply this model to their practical operations, but a most important concept is how to define the penalty weights.

3. Example

This section takes as an example to schedule annual surveys of twenty ships within five years for testing the formulated model with the commercial optimization package–CPLEX 6.0[12]. Table 1 shows the start planning years and months for all of the ships. The upper limitation of surveys at each month is set as two ships. The principle of setting penalty weights is the difference between the available month and the ship’s anniversary month. This means there is a penalty of three units three months later or prior to the anniversary month. Differences of two months and one month are given penalties of two and one units, respectively. Of course, the penalty is zero if the survey is implemented exactly on the anniversary month.

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11 Nemhauser, G. L. and Wolsey, L. A. (1999). *Integer and Combinatorial Optimization*, John Wiley & Sons, New York, pp. 540-549.

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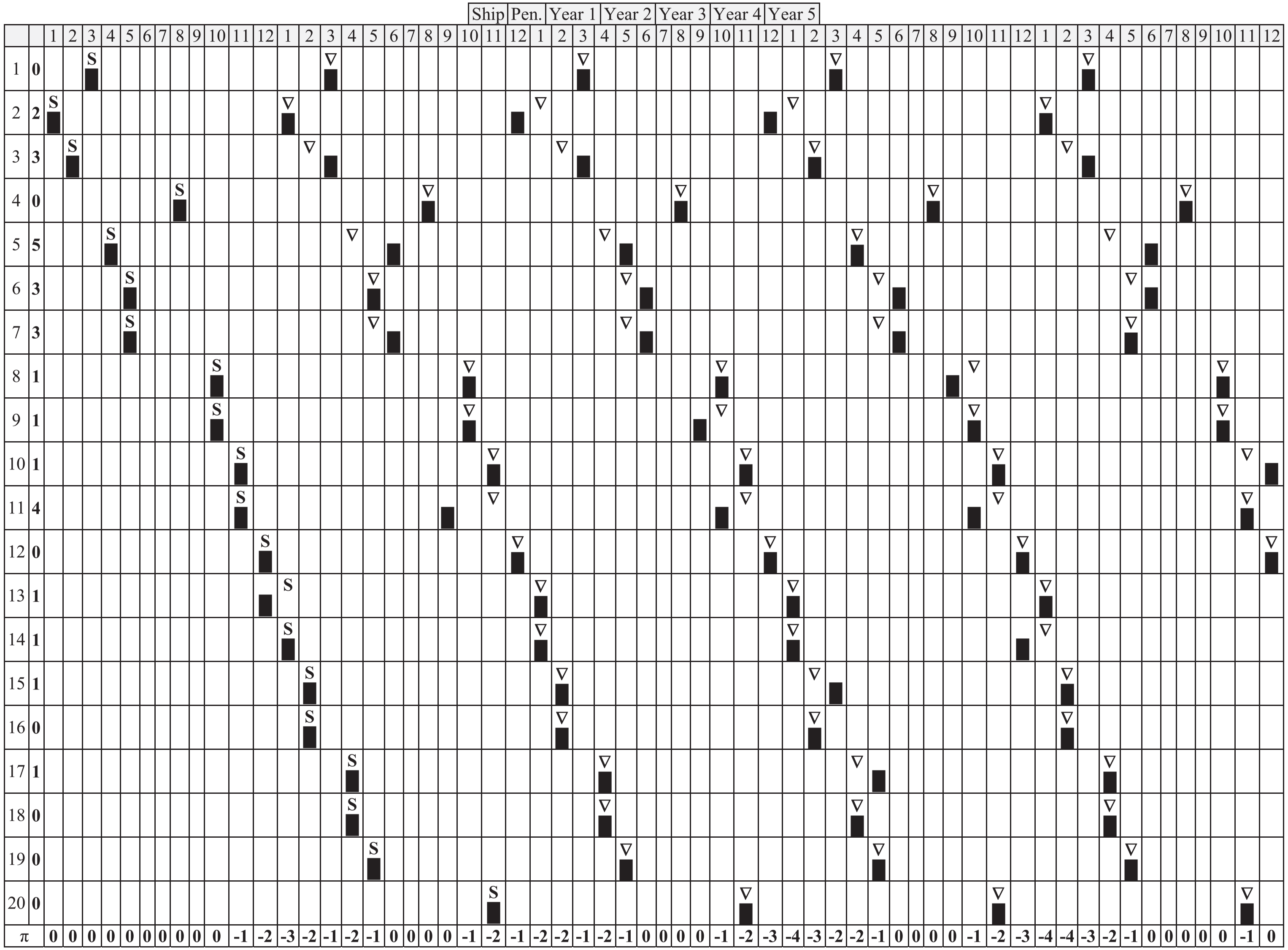
Table 1. Anniversary data for test ships

Ship	Start Year	Anniversary Month	Ship	Start Year	Anniversary Month	Ship	Start Year	Anniversary Month	Ship	Start Year	Anniversary Month
1	1	Mar.	6	1	May	11	1	Nov.	16	2	Feb.
2	1	Jan.	7	1	May	12	1	Dec.	17	2	Apr.
3	1	Feb.	8	1	Oct.	13	2	Jan.	18	2	Apr.
4	1	Aug.	9	1	Oct.	14	2	Jan.	19	2	May
5	1	Apr.	10	1	Nov.	15	2	Feb.	20	2	Nov.

This case has 644 decision variables and 152 constraints, and obtains the optimal objective value of 27 units. This means there are 27 month variances that satisfy the current survey allowance. Figure 2 displays the planning results for all ships in each year. Each month is arranged to conduct surveys for two ships at most. The surveys of thirteen ships are shifted at least once during this planning period.

The disturbance rate, which is defined the number of disturbed ships divided by the total number of planned ships, is 65%. The largest penalties are five units, which occurred on ship 5, while the maximum span of difference is two months, which appeared on the same ship and on ship 11. It is also found that on two occasions ship 2, whose anniversary month is in January, shifted the surveys early to the end of the last year for avoiding a violation of the survey allowance limitation. Regarding the values of dual prices, January in years 4 and 5 and February in year 5 have the largest objective decrements if the survey allowance limitation is increased by one ship.

If the survey allowances are all released as variables, the optimal result without any penalty is same as the intuitive result, because the optimal allowance of each month is just equals the accumulated number of ships whose anniversary months are in the current month. Figure 4 displays a comparison of implemented surveys with two settings. From it, one can find the purpose of the proposed model, which is to shift the spills from allowances to months that still have available resources.



Pen.: Penalties, **S**: Anniversary month of start year, ∇: Anniversary month without penalty, π: Dual price.

Figure 3. Planning results for the example (z = 27)

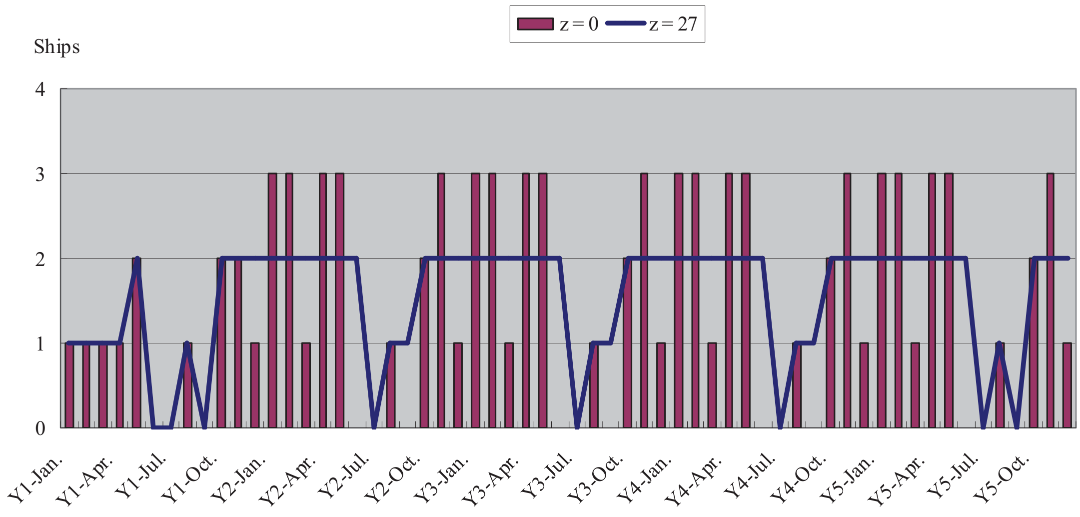


Figure 4. Assignment comparison for no allowance limitation and a limitation of 2 ships

4. Analysis of Practical Requirements

Through parameter settings, this section will bring into consideration practical requirements for exploring the further applications of the formulated model. The following analysis will use some indexes, besides the objective value. These indexes are defined as follows.

(i) Influenced ships: how many ships have to be shifted at least once from their anniversary months during the planning horizon.

(ii) Disturbance rate: the ratio of influenced ships divided by the total number of planned ships.

(iii) Influenced variables: the number of assignments that are not exactly on the anniversary month.

(iv) Maximum span of difference: the largest shifts in month among influenced variables.

(v) Largest variances for a single ship: the largest total shifts among influenced ships.

4.1 Influence of Leasing Considerations

The leasing status always influences the owner's decision as to when the ship's surveys will be implemented in the time charter market. Charterers are likely to postpone the survey if the lease will be terminated within a few months. They may also ask owners to complete the ship's surveys as soon as possible prior to the start of a new contract. Occasionally, during a contract longer than one year, charterers will expect owners to arrange surveys within a specific period to accommodate the ship's transport schedule. In the spot market, owners will observe the dynamics of the demand market to arrange surveys after finishing a contract. The proposed model can adjust the penalty weights for the indicated ships when specific requirements are known before planning.

A special instance, which we assume for testing, occurs when ships are asked to arrange surveys only on or after the anniversary month. The penalties of prohibited months for these limited ships are set large enough to distinguish these months from the original ones. Our test considers seven cases, each of which limits three ships more than the case preceding it, until all the ships, are compared with the original example, which has no upper limitation. Table 2 shows the results of the mentioned indexes from the solutions for the original example and the other seven cases. The objectives when the first twelve ships have been limited are the same as that of the original example. When the limited ships are set to ship thirteen and more, the penalties increase. Influenced ships and variables do not have a consistent pattern with the number of limited ships. We find that the flexible execution period for annual surveys give the model a margin for deciding the optimal assignment. It also reminds us of the possibility that multiple optimal solutions exist. However, the maximum span of difference and the largest variances for a single ship are more than the number of limited ships, because the allowable assignments are increasingly tight.

Table 2. Sensitivity analysis for increasing limited ships

Case	Limited ships	Influenced ships	Total penalties	Disturbance rate (%)	Influenced variables	Maximum span of difference (months)	Largest variances for a single ship (months)
0	Nil	13	27	65.0	23	2	5
1	1 ~ 3	10	27	50.0	23	2	6
2	1 ~ 6	11	27	55.0	24	2	6
3	1 ~ 9	10	27	50.0	20	2	7
4	1 ~ 12	11	27	55.0	21	2	6
5	1 ~ 15	12	35	60.0	25	2	8
6	1 ~ 18	11	44	55.0	26	3	11
7	1 ~ 20	12	44	60.0	25	3	11

4.2 Fleet Scale

Ship owners may have an expansion plan on fleet scale. A sensitivity analysis for the planned number of ships is conducted by increasing one ship per month. It is intuitive that the allowable ships per month will be not enough, and that more ships will be required to participate in the survey arrangement. Once the allowable ships per month prove infeasible in tests, one ship is added until the feasible solution is found.

Table 3 shows the results for the original case and three cases with thirty-two, forty-four, and fifty-six ships, respectively. The minimum allowance for ship surveys is larger than the number of participating ships. The influenced ships and variables do not have a consistent tendency, but the disturbance rate decreases with a larger number of ships. This is because the allowable surveys are increasing faster than the number of participating ships. Regarding the maximum span of difference and largest variances for a single ship, case 2 just met a tighter assignment resulting in a larger impact on the influenced ships and the objective value.

Table 3. Sensitivity analysis for increasing the number of planned ships

Case	Number of ships	Minimum allowance (ships/month)	Influenced ships	Total penalties	Disturbance rate (%)	Influenced variables	Maximum span of difference (months)	Largest variances for a single ship (months)
0	20	2	13	27	65.0	23	2	5
1	32	3	11	29	34.4	26	2	6
2	44	4	13	37	29.5	23	3	10
3	56	5	12	28	21.4	25	2	5

4.3 Allowances for Implementation

In this last section, we analyze the allowable ships implementing surveys, which is critical to scheduling the whole fleet. More allowances mean that workloads will be increased within a month, but the surveys assigned to the anniversary months will be relatively increased. For example, the original instance can not have any penalty when the allowance adds one more ship. All of ships can arrange surveys exactly on their anniversary months.

An extension of the mentioned analysis is here discussed. The allowance surveys are increased ship by ship until the penalty (or disturbance rate) equals zero. As shown in Table 4, the same situation applies with regard to total penalties as well as other indexes, which are decreased as the allowance of surveys becomes larger in spite of the different fleet scale.

Table 4. Sensitivity analysis for allowance surveys

Case	Number of ships	Allowance of survey ships (ships/month)	Influenced ships	Total penalties	Disturbance rate (%)	Influenced variables	Maximum span of difference (months)	Largest variances for a single ship (months)
1	32	3	11	29	34.4	26	2	6
		4	9	12	28.1	12	1	2
2	44	4	13	37	29.5	23	3	10
		5	4	8	9.1	8	1	3
		6	3	4	6.8	4	1	2
3	56	5	12	28	21.4	25	2	5
		6	6	12	10.7	12	1	4

5. Conclusions and Suggestions

Ship surveys are the primary prevention approach for a ship's seaworthiness and sailing safety. This study focused on scheduling annual surveys of ships for tramp shipping owners. A model with the property of total unimoduarity has been proposed so that scheduling can be conducted very fast even when many ships are involved. This model can assist shipping companies in planning the annual survey program for an entire owned fleet. Ship owners can further arrange suitable manpower for annual survey preparation and meet future requirements by realizing to the planning results.

This study has also considered various situations and their application to tramp service. The proposed model can be also used on liner services and industrial carriers in coordinating the ship schedule with port conditions and other criteria. Industrial carriers have to take the annual surveys of owned ships into account in planning the whole annual program of procurement and transport. In future research, the survey decision might include other regular activities, such as dockings and deliveries of ships.

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