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Coordinated dock operations: Integrating dock arrangement with ship discharging [1]

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Abstract

The operations of material docks involve two major tasks: dock arrangement and ship discharging. The former concerns the sequencing of ships waiting to be berthed for discharging whereas the latter considers the combinations of ship unloaders, conveyors and stackers, so that the total demurrage cost incurred is minimized. Apparently, different arrangements of the docks have different effects on the time required for the subsequent discharging operations. On the other hand, the arrangement of the docks is also affected by the time required for discharging. Hence, a careful coordination of these two tasks is deemed necessary. In this paper an interactive procedure which passes the necessary information between the two subsystems is devised to integrate the two tasks. This procedure is applied successfully to the material docks of the China Steel Corporation. Under complicated situations, the demurrage cost saved is estimated to reach 70%. An example is provided to stress that the performance of the integrated system is better than that of conducting the two tasks independently.

Keywords: Computer-assisted system; Industry application; Scheduling; System integration

1. Introduction

The operations of the docks of a port are generally divided into two stages: dock arrangement and ship discharging. When a ship arrives at a port, the captain of the ship sends an N/R (notice of readiness) to the port. On receiving the N/R, the port has a period of time called turntime to arrange the docks to let the ship berth. This is the first stage. After a ship is berthed, the discharging operations start subsequently. Usually the ship owner has a contract with the port regarding the discharging time of the ship. If the discharging operation cannot finish within the contract time, a demurrage cost is charged to the port. On the contrary, if it finishes before the contract time, then the port earns a dispatch revenue from the ship owner. This is the second stage. Sometimes a port is congested so that an arriving ship is unable to berth within the turntime. In this case, the ship owner will start counting the operation time right after the turntime even though the ship is not being discharged yet. From the standpoint of the port, a policy for sequencing the ships for berthing and the subsequent discharging operations which minimizes the total demurrage cost is desired.

The whole process of the dock operations is quite complicated even for a small port with a few docks. Therefore, it is usually divided into two stages as

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described previously, each operating somewhat independently of the other. At the first stage, the ships are assigned to the docks in a sequence according to their contract times, weights, materials carried, etc. At the second stage, following the arrangement of the docks of the first stage, a discharging schedule is planned for the ships waiting for discharging. Kao et al. [1] introduced a knowledge-based approach to arrange the docks so that the total estimated time that the ships spend in the port is minimized. In another study, Kao et al. [2] constructed a heuristic evaluation function from the knowledge of experienced foremen to schedule the subsequent discharging operations. Both approaches have been applied to the material docks of the China Steel Corporation in Taiwan, ROC. Nevertheless, since the two systems are operated independently, the decisions in a global sense are occasionally astray from the ideal. For relatively simple cases, an experienced foreman may be able to detect the inconsistency between the decisions of the two stages and make an appropriate adjustment. However, as the situations get complicated, it is hardly possible for a human expert to judge the appropriateness. Hence, if an integrated system which takes the possible inconsistency of the two stages into account is designed, the performance of the whole process of the dock operations will be improved.

There exist several studies which investigate the issue of improving the efficiency of a system by integrating its subsystems in a coordinated manner [3]. Among these, mathematical modeling and interactive procedures are the two major approaches. In the category of mathematical modeling, two studies are worth mentioning. Askin and Mitwasi [4] integrated facility layout with capacity planning and process selection in planning a manufacturing system by a mixed-integer mathematical formulation. Markland et al. [5] applied three approaches, i.e., zero–one programming, integer goal programming and two heuristics, to generate solutions for coordinating the production of line items such that all items are produced at or near the same time, and as close to the due date as possible. There are also other studies, such as Baker et al. [6], Russell and Morrel [7], etc. For complicated systems, the interactive procedure is more appropriate. This approach has been applied to many fields, such as the assignment of aircraft, personnel and equipment [8], crew scheduling [9], energy planning [10] and project scheduling [11].

In coordinating dock operations, many factors are involved, which make a mathematical formulation look horrible. Furthermore, since the operation environment differs from one port to another, a general formulation is almost impossible. Hence, an interactive approach seems more appropriate. To assist explaining the idea proposed in this paper, the material docks of the China Steel Corporation are used for discussion. In the sections that follows, firstly, the solution methods proposed by Kao et al. [1,2] for the two major tasks of dock operations are presented. Then the problem associated with implementing the two systems independently is addressed. Finally, an interactive procedure which integrates the two systems taking the human opinion into consideration is devised to improve the performance of dock operations.

2. System description and operations

One class of ocean shipping problems is that an organization imports large quantities of a bulk commodity from different sources by ships, and the organization contracts with tramp steamers to carry the commodities [12]. For China Steel, the commodities imported for making steel are coal, ore and stone. These materials are discharged at the material docks of China Steel, which consist of two docks numbered 97 and 98. Surrounding the docks is the yard which is divided into ten sections as shown in Fig. 1. Each dock is equipped with two ship unloaders (S/ULs) to unload materials to the yard via conveyors. Dock 97 has two conveyors labeled D-1(r) and D-21 whereas Dock 98 has D-101 and D-102(r). The letter "r" indicates that the associated conveyor is reversible. Different materials are stored in different sections of the yard: coals are stored in Sections C, E, F, H and I; ores are stored in Sections A, B, D, G and J; and stones are stored in Sections A, B and D. Stacking and reclaiming materials are implemented by the same machine called stacker/reclaimer (S/R), and there are seven S/Rs serving the ten sections of the yard. Due to the special geography and the capacity differences among different machines, searching for an optimal policy for sequencing and discharging the arriving ships is very difficult.

The scheduling of ships can be distinguished as medium-term scheduling and actual scheduling [13,14]. Medium-term schedules serve as guidelines whereas actual schedules ensure the ships arrive at specific times. The study of Kao et al. [15] is an example of medium-term scheduling. At the material docks, China Steel is more concerned about actual scheduling. Kao et al. [1,2] devised solution procedures to solve the problems of sequencing and discharging ships, respectively. To discuss the integration, a brief review of the two systems will be helpful.

2.1. Dock arrangement

As shown in Fig. 1, the port of this area looks like a sack. When Dock 97 is occupied by a ship of general size, other ships can neither enter nor leave Dock 98. At any point of time, the state of the docks can be classified into four types, each being associated with different possible decisions.

State 0: both docks are empty. One ship can enter either Dock 97 or Dock 98.

State 98: only Dock 98 is occupied. One ship can (1) berth in Dock 97, (2) berth in Dock 98 by moving the ship at Dock 98 to Dock 97, or (3) berth in Dock 98 by waiting until the ship at Dock 98 finishes discharging.

State 97: only Dock 97 is occupied. One ship can (1) berth in Dock 98 by towing the ship at Dock 97 away to clear the route first, (2) berth in Dock 97 by moving the ship at Dock 97 to Dock 98, or (3) berth in Dock 97 by waiting until the ship at Dock 97 finishes discharging.

State 2: both docks are occupied. In this case no decisions can be made until one of the docked ships finishes discharging. If the ship at Dock 97 finishes earlier, then the state changes to State 98. On the contrary, if the ship at Dock 98 finishes earlier, then there are five decisions to consider. (1) To wait until the ship at Dock 97 also finishes, then two ships leave in sequence to change the state to State 0. (2) To leave by towing the ship at Dock 97 away to clear the route first, and the state changes to State 97. (3) To leave by removing the ship at Dock 97 first, then return the ship to Dock 98, and the state changes to State 98. (4) To leave by removing the ship at Dock 97 first, then bring one ship to Dock 98, the state remains at State 2. (5) To leave by removing the ship at Dock 97 first, then move the ship to Dock 98 and bring one ship to Dock 97, the state remains at State 2.

Within a prespecified time horizon, there will be a number of ships arriving for discharging. Each time a ship leaves the dock, its demurrage cost is calculated and the state changes to another according to the decision made. Different alternatives for the ar-

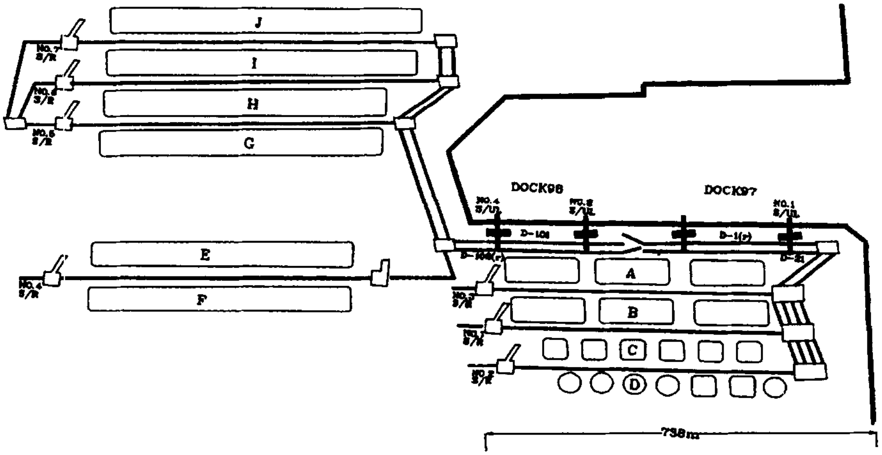


Fig. 1. Material docks and the yard of the China Steel Corporation.

rangement of the docks result in different total costs. To generate the best alternative by the dock-arrangement system designed by Kao et al. [1], the following data for each ship must be supplied:

1. ship number;
2. materials carried (coal/ore/stone);
3. weight (in tons);
4. demurrage rate (in US dollars per day);
5. contract time (in hours);
6. estimated discharging time at Dock 97 (in hours);
7. estimated discharging time at Dock 98 (in hours);
8. time from N/R accepted to a base time (in hours)
    - − for arrived ships,
    - + for arriving ships.

For the common case of three ships waiting outside and both of the docks occupied, there are approximately 2400 alternatives for the arrangement of the docks. Based on an exhaustive search, the dock-arrangement system generates the three best alternatives for the user to choose.

2.2. Ship discharging

Given the ships berthed in the two docks, the materials carried by the ships must be unloaded to the yard in an efficient way. Hence, in the process of discharging, the foreman has to decide which hold of the ship to discharge to what extent by using which S/UL and which conveyor to send to the yard to be stacked by which S/R under different conditions. Each combination of an S/UL, conveyor and S/R is called a flow-path. When conditions change, the flow-path has to change accordingly to make the discharging process efficient. To discharge one ship, the conditions may change for at least 50 times. Under each condition there are 100 to 500 feasible flow-paths. If all possibilities are considered, there are at least $100^{50} = 10^{100}$ combinations, a typical case of "combinatorial explosion". Kao et al. [2] proposed an approach of constructing a heuristic evaluation function [16] from the working rules used by human experts. As condition changes, the evaluation function is applied to each feasible flow-path to obtain a score, and the one with the highest score is selected for operation. This process is repeated until the ship finishes discharging.

From years of experience, China Steel has concluded with several working rules. To operate under these rules will be more efficient than operating at will.

1. Whenever possible, Docks 97 and 98 should be discharged at the same time. In changing holds to discharge, the holds closer to the current hold are preferred.
2. If two holds are to be discharged at the same time, it is better to have one in the front and one in the back.
3. Sections A, D, E, F, G and J have higher priority in using S/Rs.
4. When the same material is unloaded to different sections, it is preferable to finish operating on these sections at about the same time.
5. Sections B, C, H and I are preferable to use S/Rs No. 3, No. 2, No. 5 and No. 7, respectively.
6. It is preferable to use Conveyor D-1 at Dock 97 and Conveyor D-102 at Dock 98.
7. The frequency of switching to different materials to discharge should be minimized.
8. For two neighboring holds containing one material, if their total weight is greater than the total weight of other holds which contain the same material, it would be better to discharge one of these two holds with another hold which contains different materials to different sections of the yard at the early stage of discharging.
9. In cases where two docks are discharging at the same time, if there are materials from the two ships which have to be discharged to one specific section of the yard and the amount is over one half of the total weight of the two ships, then whenever the associated S/R of that specific section is available, it should be used.
10. It is better to discharge one half of every hold before any hold can discharge further.
11. At the early stage of discharging, it is better to use two conveyors to operate with two S/Rs, whereas at the final stage it is better to use one conveyor with one S/R.

Based on these working rules, a heuristic evaluation function was constructed by Kao et al. [2]. For each feasible flow-path, if any of the above rules are followed, then the associated scores are added to that flow-path. After all feasible flow-paths are evaluated, the one with the highest score is selected for operation.

3. Independent local solutions

In real-world operations, the status of the two docks and the states of the arriving ships are supplied to the dock-arrangement system to find the optimal sequence for berthing. Based on the states of the docked ships, the ship-discharging system generates an efficient schedule for unloading the materials carried by the ships. Once a ship finishes discharging, a new ship enters the dock, and the ship-discharging system will be executed again to generate a new discharging schedule. The original discharging schedule for the ship still berthing in the dock may well be changed depending on the states of the new ship.

The dock-arrangement system and the ship-discharging system are interrelated. In arranging the docks, the discharging times for Docks 97 and 98 must be provided for each arriving ship. However, since there are two docks, which ships are to be discharged together is not known beforehand. When a ship is berthed to discharge, the real discharging time may vary depending on the states of the ship berthed in the neighboring dock. Thus, the discharging times provided are estimates. If the difference between the estimated discharging time and the actual discharging time is small, then the sequence produced by the dock-arrangement system may still be an optimal one. However, if the difference is significant, then the sequence may not be appropriate. As an example, suppose there are three ships, one in Dock 98 and the other two are arriving. Their basic data required by the dock-arrangement system are contained in Table 1. In addition, changing docks each time takes about two hours and a navigating cost of US $1800 is charged. The dispatch rate is half the demurrage rate. The three best alternatives generated by the dock-arrangement system are as follows.

Alternative 1:

Step 1. BR-138 enters Dock 97.
Step 2. UC-056 waits until BR-138 finishes and two ships leave in sequence.
Step 3. ARA-11 enters Dock 98.
Step 4. ARA-11 leaves.

Alternative 2:

Step 1. BR-138 enters Dock 97.
Step 2. UC-056 waits until BR-138 finishes and two ships leave in sequence.
Step 3. ARA-11 enters Dock 97.
Step 4. ARA-11 leaves.

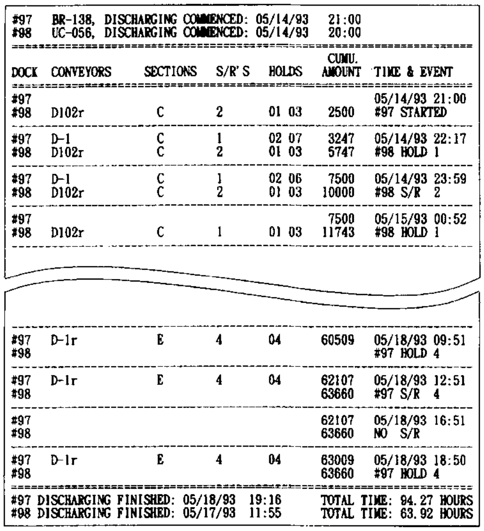
Alternative 3:

Step 1. BR-138 enters Dock 97.
Step 2. BR-138 moves out to let UC-056 leave and ARA-11 enters Dock 98.
Step 3. BR-138 leaves.
Step 4. ARA-11 leaves.

All of the three best alternatives suggest that the first step is to bring Ship BR-138 to Dock 97 to

Table 1
Basic data of the three ships for dock arrangement

	Dock 98	Two arriving ships	
Ship number	UC-056	BR-138	ARA-11
Materials carried	coal	coal	ore
Weight	63718	63580	63080
Demurrage rate	7000	7000	7120
Contract time	72	70	72
Estimated discharging time at Dock 97	72	68	70.5
Estimated discharging time at Dock 98	60	65	65
Time from N/R accepted to the base time	−2.8	1.0	6.0
Discharging time already consumed	2	–	–
Discharging time still required	58	–	–



```
#97   BR-138, DISCHARGING COMMENCED: 05/14/93   21:00
#98   UC-056, DISCHARGING COMMENCED: 05/14/93   20:00
===================================================================
                                                CUMU.
DOCK  CONVEYORS     SECTIONS  S/R'S   HOLDS    AMOUNT  TIME & EVENT
===================================================================
#97                                                    05/14/93 21:00
#98   D102r            C        2     01 03     2500   #97 STARTED
-------------------------------------------------------------------
#97   D-1              C        1     02 07     3247   05/14/93 22:17
#98   D102r            C        2     01 03     5747   #98 HOLD 1
-------------------------------------------------------------------
#97   D-1              C        1     02 06     7500   05/14/93 23:59
#98   D102r            C        2     01 03    10000   #98 S/R  2
-------------------------------------------------------------------
#97                                             7500   05/15/93 00:52
#98   D102r            C        1     01 03    11743   #98 HOLD 1
-------------------------------------------------------------------

-------------------------------------------------------------------
#97   D-1r             E        4     04       60509   05/18/93 09:51
#98                                                    #97 HOLD 4
-------------------------------------------------------------------
#97   D-1r             E        4     04       62107   05/18/93 12:51
#98                                            63660   #97 S/R  4
-------------------------------------------------------------------
#97                                            62107   05/18/93 16:51
#98                                            63660   NO  S/R
-------------------------------------------------------------------
#97   D-1r             E        4     04       63009   05/18/93 18:50
#98                                            63660   #97 HOLD 4
===================================================================
#97 DISCHARGING FINISHED: 05/18/93  19:16      TOTAL TIME: 94.27 HOURS
#98 DISCHARGING FINISHED: 05/17/93  11:55      TOTAL TIME: 63.92 HOURS
```

Fig. 2. A partial computer printout of the schedule generated by using estimated times.

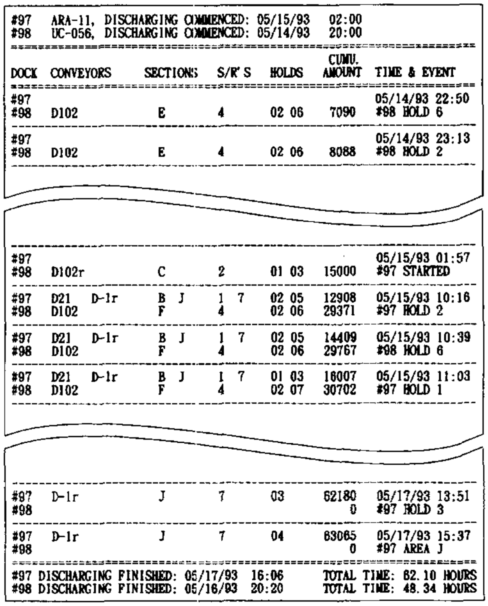
discharge. Therefore, the ship-discharging system takes the data of UC-056 berthed in Dock 98 and BR-138 berthed in Dock 97 to generate a schedule for discharging. Fig. 2 is a partial computer printout of the schedule with the intermediate flow-paths omitted. As indicated at the bottom of Fig. 2, the discharging time actually required for Ship UC-056 is 63.92 hours, which is very close to its estimated time of 60 hours (refer to Table 1). The actual time of Ship BR-138, i.e., 94.27 hours, on the contrary, is quite different from its estimated time of 68 hours. In fact, if the problem is examined carefully, it is not surprising to get this result. The originally estimated discharging time of 68 hours is the most likely time that a ship needs to discharge at Dock 97. The actual time, however, depends strongly on the ship being discharged simultaneously at Dock 98. In this example, both Ships UC-056 and BR-138 are carrying coals. According to the arrangement of the yard, coals are stored in Sections C, E, F, H and I. Unloading the materials to these sections at the same time causes difficulties in sharing the same equipment. Hence, most of the time the two docks are applying a single S/UL–conveyor–S/R combination to discharge. Consequently, an unexpected long discharging time is experienced. This big difference between the estimated time and the actual time intimates that the sequence generated by the dock-arrangement system may not be appropriate.

4. System integration

From the discussion of the preceding section, it is clear that arranging the docks and scheduling the discharging operations by two independent systems may give some results which are unexpected. A consequence is that extra costs are incurred. This phenomenon is common to most large systems where whole operations have to be divided into parts, each of manageable size. If these parts can be integrated in a coordinated manner, then the performance of the whole system will be improved. To integrate several subsystems into a large one, different approaches have been proposed [4,11]. In this paper, due to the complexity of the problem, an interactive procedure is devised.

The idea is to apply the result of one system to another system to derive a better estimate for the former system. For dock operations, firstly, rough estimates of the time required for a number of ships for discharging at different docks are applied to the dock-arrangement system to produce an optimal sequence for berthing the ships. Based on the sequence and the states of the ships to be berthed for unloading, an efficient schedule for discharging is generated by the ship-discharging system. The associated discharging times, which are more realistic, are then applied to the dock-arrangement system again to produce another sequence for berthing the ships. If this new sequence is the same as the sequence produced in the previous round, then this sequence and the associated discharging schedule are considered as realistic and are adopted for dock operations. If, on the contrary, the new sequence is different from the old, then the discharging system is executed again based on the new sequence to generate another set of estimates of the discharging time for the dock-arrangement system to use. This procedure is repeated until two consecutive sequences generated by the dock-arrangement system are the same or the users are satisfied with one of the alternatives. In the interactive process, the alternatives for sequencing the ships produced by the dock-arrangement system can be modified by the user for the ship-discharging system to generate schedules, and the discharging times solved from the ship-discharging system can also be adjusted for the dock-arrangement system to produce the sequences for berthing ships. This function enhances the flexibility of the integrated system.

In Kao et al. [1], the dock-arrangement system was implemented in OPS5 [17] on a Micro VAX II computer whereas the ship-discharging system of Kao et al. [2] was coded in Turbo-C on a PC. To integrate systems, it is essential that the same computer language be used in the same computer environment. In this study the first task is to re-code the dock-arrangement system in Pascal. Since inferencing rules is much slower than manipulating numbers [18], converting a program written in OPS5 to Pascal improves the execution efficiency to a very large extent. The source codes of Pascal and C are then compiled to objective codes. Finally, an interactive procedure which integrates the two objective codes following the logic described previously and provides the media for the user to interact with the system is written in Clipper and implemented on a 486 PC. An area is created to store the data which are common to both systems. This treatment reduces the time for keying in the same data to the two systems on one hand, and avoids the problems caused by data inconsistency on the other hand.



```
#97  ARA-11, DISCHARGING COMMENCED: 05/15/93  02:00
#98  UC-056, DISCHARGING COMMENCED: 05/14/93  20:00
===========================================================================
                                                   CUMU.
DOCK CONVEYORS        SECTIONS  S/R'S   HOLDS     AMOUNT   TIME & EVENT
===========================================================================
#97                                                        05/14/93 22:50
#98  D102               E        4      02 06      7090    #98 HOLD 6
---------------------------------------------------------------------------
#97                                                        05/14/93 23:13
#98  D102               E        4      02 06      8088    #98 HOLD 2
---------------------------------------------------------------------------

---------------------------------------------------------------------------
#97                                                        05/15/93 01:57
#98  D102r              C        2      01 03     15000    #97 STARTED
---------------------------------------------------------------------------
#97  D21   D-1r         B  J     1  7   02 05     12908    05/15/93 10:16
#98  D102               F        4      02 06     29371    #97 HOLD 2
---------------------------------------------------------------------------
#97  D21   D-1r         B  J     1  7   02 05     14409    05/15/93 10:39
#98  D102               F        4      02 06     29767    #98 HOLD 6
---------------------------------------------------------------------------
#97  D21   D-1r         B  J     1  7   01 03     16007    05/15/93 11:03
#98  D102               F        4      02 07     30702    #97 HOLD 1
---------------------------------------------------------------------------

---------------------------------------------------------------------------
#97  D-1r               J        7      03        62180    05/17/93 13:51
#98                                                   0    #97 HOLD 3
---------------------------------------------------------------------------
#97  D-1r               J        7      04        63065    05/17/93 15:37
#98                                                   0    #97 AREA J
===========================================================================
#97 DISCHARGING FINISHED: 05/17/93  16:06      TOTAL TIME: 62.10 HOURS
#98 DISCHARGING FINISHED: 05/16/93  20:20      TOTAL TIME: 48.34 HOURS
```

Fig. 3. A partial computer printout of the schedule generated by using modified times.

To illustrate how the integrated system improves the performance of the whole process of dock operations, the example discussed in the preceding section is adopted for illustration. By applying the data of Table 1 to the integrated system, three alternatives for arranging the docks are produced. The user can select any one or propose a new one to generate a schedule and calculate the required times for discharging. The discharging times, which can be modified by the user, are then served as new estimates for the dock-arrangement system to produce three new alternatives for sequencing the ships. If the user is satisfied with one of the alternatives, then the solution process is finished. Otherwise one of the alternatives, or a new one, is selected for the discharging system to generate a new schedule for discharging the ships. In the example, the discharging times calculated at the first round are 94.27 hours for Ship BR-138 and 63.92 hours for Ship UC-056 (refer to Fig. 2). By using these times as the new estimates to replace the old estimates of 68 hours and 60 hour, respectively, three new alternatives are produced as follows:

New alternative 1:

Step 1. ARA-11 enters Dock 97.
Step 2. UC-056 waits until ARA-11 finishes and two ships leave in sequence.
Step 3. BR-138 enters Dock 98.
Step 4. BR-138 leaves.

New alternative 2:

Step 1. ARA-11 enters Dock 97.
Step 2. ARA-11 removes to let UC-056 leave. BR-138 enters Dock 98 and ARA-11 returns to Dock 97.
Step 3. ARA-11 leaves.
Step 4. BR-138 leaves.

New alternative 3:

Step 1. BR-138 enters Dock 97.
Step 2. BR-138 removes to let UC-056 leave. BR-138 berths in Dock 98 and ARA-11 enters Dock 97.
Step 3. BR-138 waits until ARA-11 finishes and two ships leave in sequence.

Table 2
Results of the old alternative 1 compared with that of the new alternative 1

	Old alternative 1			New alternative 1		
Ship name	UC-056	BR-138	ARA-11	UC-056	BR-138	ARA-11
Arrival time	−3	1	6	−3	1	6
Departure time	64	95	160	48	133	68
Discharging time	67	94	154	51	132	62
Contract time	72	70	72	72	70	72
Demurrage time	−5	24	82	−21	62	−10
Demurrage cost	−729	7000	24327	−3063	18083	−1483
Total demurrage cost			30598			13537

The first two alternatives suggest that at the first step Ship ARA-11, instead of BR-138 as produced at the first round, should enter Dock 97. As a matter of fact, the first new alternative is the real best alternative. Fig. 3 is a partial computer printout showing the schedule of discharging Ship ARA-11 at Dock 97

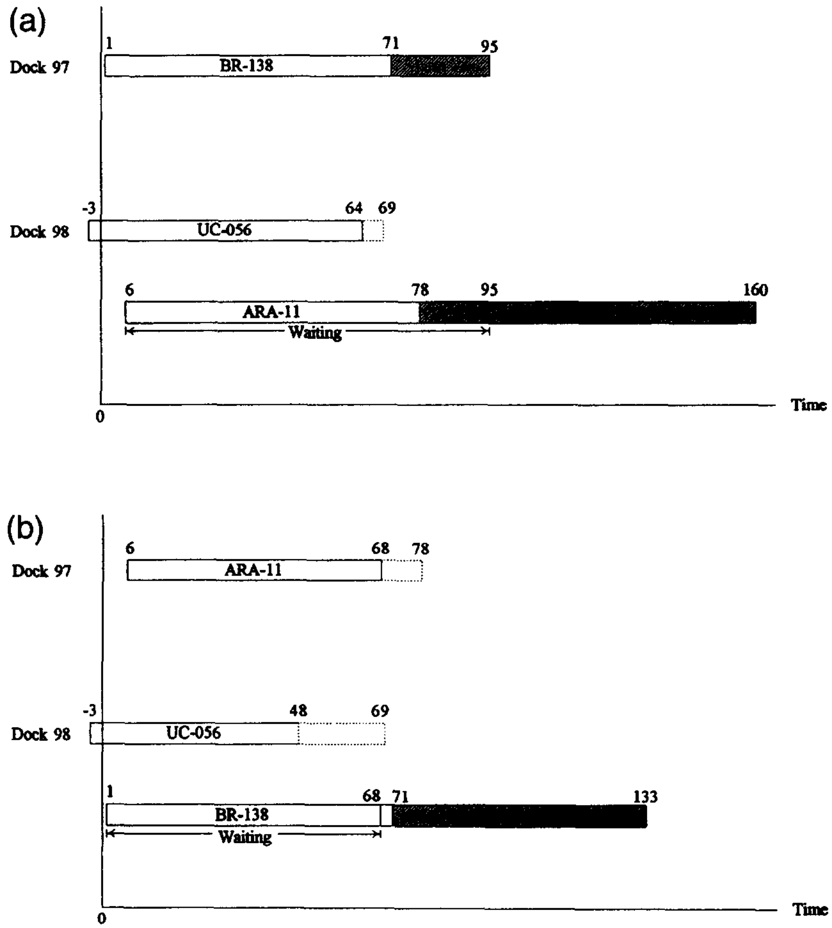


Fig. 4. Gantt-like chart showing the occupation status of the two docks for (a) the old alternative 1 and (b) the new alternative 1; shaded areas indicate tardiness.

and Ship UC-056 at Dock 98. To efficiently utilize the equipment, the ore-ship ARA-11 is sequenced in front of BR-138 to discharge together with UC-056 which carries coals. With this arrangement, most of the time both docks are applying two S/UL–conveyor–S/R combinations to discharge. Consequently, less time is used for discharging. It is worthwhile to note that none of the three old alternatives has captured this best policy for dock arrangement.

Table 2 summarizes the results of adopting the old alternative 1 and the new alternative 1 for discharging. The arrival time and the departure time are relative times compared with a base time. Their difference is the discharging time, and the difference between the discharging time and the contract time is the demurrage time. The demurrage cost is the product of the demurrage rate and the demurrage time. Note that the dispatch rate is one half of the demurrage rate. Summing over the demurrage costs of the three ships results in the total demurrage cost of each alternative as shown in the last row of Table 2. The total demurrage cost for adopting the old alternative 1 is \$30 598 whereas for adopting the new alternative 1 it is \$13 537. The cost saved by integrating the dock-arrangement system with the ship-discharging system in this example is around 56%.

Fig. 4 is a Gantt-like chart showing the occupation status of the two docks for the old alternative 1 and the new alternative 1. For the old alternative 1, Ship BR-138 arrives at Dock 97 at the first hour after the base time. The contract time finishes at the 71st hour. However, the real discharging operation stops at the 95th hour, which causes a tardiness of 24 hours. At Dock 98, Ship UC-056 finishes operation at the 64th hour, which is five hours ahead of the contract time. Ship ARA-11 berths at the 95th hour and finishes operation at the 160th hour. Since this ship is expected to arrive at the port at the 6th hour and to complete discharging before the 78th hour, the resulting tardiness is 82 hours. For the new alternative 1, Ship ARA-11 berths at Dock 97 instead of waiting to be berthed at Dock 98 as is the case of the old alternative 1. With this new arrangement, Dock 97 is freed at the 68th hour and Dock 98 is freed at the 48th hour. Ship BR-138 berths at Dock 98 at the 68th hour and finishes at the 133rd hour. The total demurrage time and demurrage cost of these two alternatives are summarized in Table 2. The benefits acquired by integrating the dock arrangement subsystem with the ship discharging subsystem are manifest.

5. Conclusion

The whole process of dock operations is very complicated since many factors are involved and the equipment for discharging ships are limited in their quantities and capacities. Hence, to efficiently utilize the equipment so that each ship can finish its discharging operations before the contract time is a very difficult task. The study of Kao et al. [1] discussed the optimal sequence of the arriving ships for discharging. In a later study, Kao et al. [2] proposed a heuristic approach for scheduling the discharging operations based on the states of the ships berthed in different docks for discharging. Since these two systems operate independently, it is suspected that the decisions generated in a global sense are not efficient.

In this paper, the dock-arrangement system and the ship-discharging system designed for the material docks of China Steel are presented with an example showing that the suspicion is correct. The most likely discharging time supplied to the dock-arrangement system may differ from the actual discharging time generated from the ship-discharging system to a very large extent. An interactive procedure which integrates the dock-arrangement system with the ship-discharging system is devised. This integrated system allows the user to modify the estimated discharging times and the alternatives for sequencing the ships derived from the two systems, respectively, to generate better decisions. For a case of one ship berthed in Dock 98 and two ships which are arriving in one and six hours, respectively, the difference between the total demurrage costs of the old independent systems and the new integrated system is around 56%. It is expected that the cost saved will reach as high as 70% for more complicated cases. Furthermore, the old systems were coded in different languages and implemented on different computers. A problem of data inconsistency may occur. When the two systems are integrated, this problem is eliminated.

Finally, although the explanation of this paper is based on the material docks of China Steel, the idea can nevertheless be applied to other docks of similar operations.

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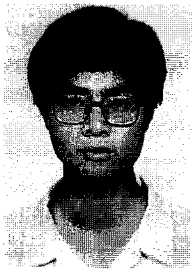

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