



CARGO TERMINAL SHIFT SETTING AND MANPOWER SUPPLYING IN SHORT-TERM OPERATIONS

Shangyao Yan

*Professor, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.,
t320002@cc.ncu.edu.tw*

Chung-Kai Chen

Master, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.

Chia-Hung Chen

Ph.D. Candidate, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.

Follow this and additional works at: <https://jmstt.ntou.edu.tw/journal>



Part of the [Civil and Environmental Engineering Commons](#)

Recommended Citation

Yan, Shangyao; Chen, Chung-Kai; and Chen, Chia-Hung (2006) "CARGO TERMINAL SHIFT SETTING AND MANPOWER SUPPLYING IN SHORT-TERM OPERATIONS," *Journal of Marine Science and Technology*: Vol. 14: Iss. 2, Article 6.

DOI: 10.51400/2709-6998.2064

Available at: <https://jmstt.ntou.edu.tw/journal/vol14/iss2/6>

This Research Article is brought to you for free and open access by Journal of Marine Science and Technology. It has been accepted for inclusion in Journal of Marine Science and Technology by an authorized editor of Journal of Marine Science and Technology.

CARGO TERMINAL SHIFT SETTING AND MANPOWER SUPPLYING IN SHORT-TERM OPERATIONS

Acknowledgements

This research was supported by a grant (NSC 93- 2211-E-008-022) from the National Science Council of Taiwan. We would like to thank the cargo terminal for providing the test data and its valuable opinions on this research. We would also like to thank the two anonymous reviewers for their helpful suggestions on the presentation of the paper.

CARGO TERMINAL SHIFT SETTING AND MANPOWER SUPPLYING IN SHORT-TERM OPERATIONS

Shangyao Yan*, Chung-Kai Chen**, and Chia-Hung Chen***

Key words: air cargo terminal, manpower supply, flexible strategy, integer linear program.

ABSTRACT

In this research, we develop two short-term manpower supply models from air cargo terminal perspectives. The models are expected to be effective tools for air cargo terminals to plan their manpower supplies and shift schedules. We first incorporate two flexible management strategies and the related operating constraints into the development of a mathematical programming model. By suitably modifying the model, we then construct a strategic model, involving different combinations of manpower supply principles, which can help air cargo terminals manage more effectively their terminal manpower supplies. To evaluate the models in practice, we perform a case study using real operation data from a Taiwan air cargo terminal, with the assistance of C computer programs and a mathematical programming solver. The preliminary results are good, showing that the models could be useful for planning air cargo terminal manpower supply.

INTRODUCTION

The air cargo industry has been expanding rapidly and is forecast to continue in the near future, making the air freight markets more competitive than before. Under these circumstances, the air cargo terminals (for convenience, hereinafter called terminals) have to provide better service with lower cost in order to maintain their competitive edge. However, terminal crew costs involve a large investment among all operating costs. Hence, terminals are continually seeking better ways to allocate efficiently their crew resources. A good terminal manpower supply plan helps air cargo terminals deal with their cargoes efficiently and maintain excellent service quality, which could help terminals reduce their

operation cost efficiently, and is therefore a very important issue to terminals.

In practice, terminal manpower supply plans are usually classified into short- and long terms ones. The short-term terminal manpower supply plan, which involves the current terminal's operations, is usually performed before the beginning of the next period (generally seasonally). On the other hand, the long-term terminal manpower supply plan is usually performed at the beginning of the year (or several years in advance), according to the predicted cargo/manpower demands based on historical information. The constraints in these two types of plans are different. In particular, the manpower available for a short-term plan is constrained by current manpower resource. How to set a good manpower supply plan for short-term operations is more difficult than for long-term ones. Therefore, in this research we focus on a short-term manpower supply plan. Using a domestic Taiwan air cargo terminal (Terminal C) as an example, we introduce the procedure for determining short-term terminal manpower supply plan in practice.

As shown in Figure 1, there are several departments in Terminal C, such as cargo receiving, cargo loading, and so on. In practice, these departments' manpower supply plans are independent, mostly because different operating times are required. Currently

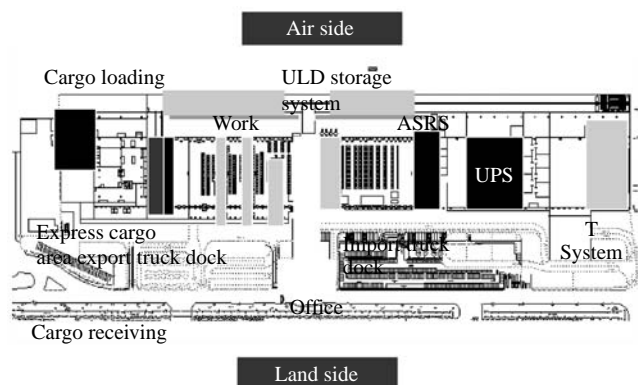


Fig. 1. Diagram of a Taiwan air cargo terminal (<http://www.cksairport.gov.tw/>).

Paper Submitted 09/22/05, Accepted 12/07/05. Author for Correspondence: Shangyao Yan. E-mail: t320002@cc.ncu.edu.tw.

*Professor, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.

**Master, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.

***Ph.D. Candidate, Department of Civil Engineering, National Central University, Chungli, Taiwan 32054, R.O.C.

among these departments, three shifts are the number normally used (although sometimes up to six shifts are occasionally used) and there are normal seven different flexible working hour types, from 4 to 10 (although sometimes 11 and 12 working hour types are occasionally used). In theory, more shifts would increase the degrees of freedom in scheduling, thus conserving manpower, but this results in a more complicated manpower supply plan. Therefore, for ease of scheduling, Terminal C simplifies its manpower supply plan to have three shifts, which is one of the reasons why the terminal operations are not efficient and is one of the motivations for this research.

The planning procedure for terminal short-term manpower supply is defined as follows: (1) the initial cargo demand estimation, (2) the terminal manpower supply plan, and (3) the crew assignment. The first stage is to establish the distribution of cargo/manpower demands according to historical information. The second stage is to set up a terminal manpower supply plan to meet the required demand, as determined in the first stage. A plan is generated, specifying the number of shifts and the shift starting times, which facilitates the assignment of individual terminal crew into appropriate shifts. Owing to the inherent complexity of the scheduling problem, it is both difficult and time-consuming to set up efficiently a terminal manpower supply plan that meets the required demand. The final stage is to assign individual crew members, while still satisfying vacation schedules and any associated regulations.

Among the three stages, the first stage is typically simple, a statistical work. The second stage is complicated and its results serve as the basis of the third stage – crew assignment. In other words, crew assignment is handled after the manpower supply problem is solved. A good terminal manpower supply plan not only can make crew assignment easy to apply, but also reduce the terminal manpower crew cost. However, in current practice, Terminal C usually utilizes a trial-and-error experience-based method for a feasible terminal manpower supply plan, without optimization from a systemic perspective. In particular, a number of shifts (traditionally three) are first set, based on experience. A set of different work types, each with a number of crew members, are then calculated manually, via a trial-and-error process, to meet the required demand, still being constrained by the available manpower supply, for each time slot. Note that in short-term operations it is difficult to calculate available manpower supply for each time slot before a detailed crew assignment is made. Indeed, this is related to the current manpower resource and crew assignment rules, which are in turn related to personnel work/day-off/training/vacation regulations, personnel seniority, and other associated information.

In current practices, Terminal C usually determines the manpower supply available for each time slot based on experience. The available manpower supply for all time slots, as well as the manpower supply plan, are then used as a basis, and may be slightly adjusted, for the crew assignment stage, at which point all formal employees in short-term operations are assigned to different work type shifts. As can be seen, such a trial-and-error experience-based method is neither efficient nor effective, especially for large terminals. Therefore, this research focuses on planning short-term terminal manpower supply, which corresponds to the second stage of the overall planning procedure mentioned above.

Much research has already been devoted to personnel scheduling problems, which can be classified into three groups, according to the industry characteristics: airline crew scheduling, mass transit crew scheduling, and generic crew scheduling problems [3]. Each group has often been discussed, e.g., the airline crew scheduling [14, 16, 17, 22, 24-27], the mass transit crew scheduling [11, 13], and the generic crew scheduling [1, 4, 7, 8, 21]. Among the literature, the study of [21] is more related to our research. In particular, they developed a model and a solution approach to the freight handling personnel scheduling problem. However, the planning period was set to be one day which was difficult to apply to a week, as required in our research. Moreover, flexible management strategies, which will be addressed later, were not incorporated in the model. Consequently, Nobert and Roy's model and solution approach do not satisfy the needs of this research. It should be mentioned that some models have been developed to assist in airport apron service scheduling practices, for example, for ground staff scheduling [20, 23] and aircraft line maintenance scheduling [28]. Although these problems are related to ours, their operating characteristics are different. As a result, their models or solutions cannot be directly applied to our problems. As to the other studies, they have focuses different from that of this research, and thus cannot provide efficient manpower plan solutions for air cargo terminals.

Other than the above classification, personnel scheduling problems have also been classified into shift scheduling, day-off scheduling and tour scheduling problems [18]. Each problem has often been discussed, e.g., the shift scheduling problems [2, 15], the day-off scheduling problems [19], and the tour scheduling problems [5, 9, 10, 12]. Among these three categories, although our problem can be classified into the first category, the past shift scheduling problems are different from ours, and thus do not satisfy the needs of our research. As to the second and the third categories, they are related to the crew assignment stage of the aforementioned plan-

ning procedure, and therefore are different from ours.

There are many ways by which the efficiency of a terminal manpower supply plan can be improved. One of these is the flexible management strategy. Flexible management strategies have become more and more commonly used in modern business and industry. Of all the various flexible management strategies, the four that have recently attracted the most attention and discussion are: (1) numerical flexibility, (2) temporal flexibility, (3) wage flexibility, and (4) functional flexibility [6]. They can increase the different degrees of freedom in the schedule, thus conserving manpower. To the best of the authors' knowledge, no study has yet addressed the particular issues of air cargo terminal manpower supply, with flexible management strategies. Moreover, applying the mathematical programming techniques commonly used in personnel scheduling can also be beneficial. Therefore, in this research, we incorporate flexible management strategies and the related operating constraints into the development of a mathematical programming model for terminal manpower supply plan. By suitable modification of the model, we construct a strategic model, involving different combinations of manpower supply principles, which can help an air cargo terminal manage more effectively its manpower supply. The models are formulated as integer and mixed integer linear programs and are solved using a mathematical programming solver. Finally, to evaluate the models in practice, we performed a case study using real operation data from Terminal C, with the assistance of C computer programs and a mathematical programming solver.

The scope of this research is confined to the subject of terminal manpower supplying and shift setting, given the projected manpower demands, the upper/lower bound of shifts, the shift starting time, the working hours of work types, and the related cost data. In addition, since Terminal C's schedule is rotated weekly, we use one week (seven days) as the planning cycle. For the planning week, the shift starting time has to be the same every day of the week. In other words, if shift s is assigned to time t , then shift s occurs in the same time J slot every day during the planning week, and has the same starting time. It should be mentioned that, in practice, the salary structure is different due to different personnel experiences, length of employment, education and other factors. It is complicated to model the objective function of a minimum salary expense in the stage of manpower supply plan. For ease of modeling, we focus on the minimization of manpower supply in man-hours.

The rest of the paper is organized as follows: In Section 2, we introduce the two models. In Section 3, a case study is conducted to evaluate the two models.

Finally, in Section 4, we offer some conclusions.

MODEL FORMULATION

In this section, according to Terminal C's current practices, we first formulate a terminal manpower supply planning model (RM) incorporating two flexible management strategies. We then modify the RM to construct a strategic model (SM), involving different combinations of manpower supply principles. The two models are described as follows.

1. The terminal manpower supply planning model (RM)

We focus on modeling a complicated short-term terminal manpower supply plan. According to Terminal C's manpower demand profile per week, demand will fluctuate from time to time. Sometimes in off-peak hours, there is even no demand. Therefore, flexible strategies are a good idea, allowing Terminal C to improve the efficiency of their terminal manpower planning. If we take into consideration Terminal C practices, two flexible strategies, developed from numerical and temporal concepts, can be proposed: flexible shifts and flexible working hours. The flexible shift strategy allows an employer to choose the preferable number of shifts per day and the shift starting times, while the flexible working hour strategy allows the company to hire different employees for different working hour. Both types of flexibility are incorporated into our model.

An effective combination of shifts and their starting times, and the number of different types of on-duty crews for each shift is the key to a successful manpower supply plan. Using the two proposed flexible strategies, we try to provide an effective terminal manpower supply plan, which can respond to wide variations in manpower demand. We list below the symbol notations of parameters and variables that will be used in the model formulation.

Parameters:

- i : the i^{th} day in a week.
- j : the j^{th} time slot in a day.
- z : the objective value representing the minimum total system cost.
- Q : the set of different work types (there are nine different work types, from 4 to 12 hours, respectively, in this research).
- q : type q work; $q \in Q$.
- r_q : the working hours for type q work.
- l : the lower bound of the total number of shifts in one day.
- u : the upper bound of the total number of shifts in one day.

- c_1 : the regular manpower cost per man-hour.
- B : a very large value for ease of modeling.
- C : the set of days in a week. Since our planning period is one week (seven days), $C \equiv \{0: \text{Sunday}, 1: \text{Monday}, 2: \text{Tuesday}, 3: \text{Wednesday}, 4: \text{Thursday}, 5: \text{Friday}, 6: \text{Saturday}\}$.
- N : the set of shift starting times in a day. The length of a time slot is set to be one hour. Since there are 24 hours in a day; $N \equiv \{0, 1, 2, 3, 4, 5, \dots, 23\}$.
- s : the starting time of a shift s ; $s \in N$. If a terminal does not prefer to specify starting times for setting shifts (for example, to prevent the yielding of shifts together too close), then these starting times can be removed from N .
- d_{ij} : the manpower demand (in persons) in time slot j on day i .
- D_{ij} : the upper bound of the manpower which can be supplied in time slot j on day i .
- H_{ijq} : the set of all shifts working for type q work in time slot j on day i . H_{ijq} can be defined by Eq. (1) as follows:

$$\text{if } \begin{cases} j = 0 \sim (q+1) & H_{ijq} = \{(i', s') \mid i' = (i+6) \bmod 7, 23 - (q+1) \\ & + j \leq s' \leq 23\} \cup \{(i', j') \mid i' = i, 0 \leq s' \leq j\} \\ j = (q+2) \sim 23 & H_{ijq} = \{(i, s) \mid j - (q+2) \leq s' \leq j\} \end{cases} \quad \forall i, \forall q \quad (1)$$

The purpose of Eq. (1) is to represent the relationship between the manpower supply of shifts for different work type and the working time slots. Using H_{ijq} , we can identify all the shifts of type q work that will be on duty in time slot j on day i . To illustrate Eq. (1), in Figure 2 we show two H_{ijq} examples, for eight working hours (type 1) and for four working hours (type 2). For example, suppose that shift represents the shift for type 1 work that starts on day 6, at 02:00 and ends on day 6, at 10:00. H_{691} contains shifts (6, 2, 1), (6, 3, 1), (6, 4, 1), (6, 5, 1), (6, 6, 1), (6, 7, 1), (6, 8, 1), and (6, 9, 1), $H_{691} = \{(6, 2, 1), (6, 3, 1), (6, 4, 1), (6, 5, 1), (6, 6, 1), (6, 7, 1), (6, 8, 1), (6, 9, 1)\}$. On the other hand, H_{051} involves shifts that cross over two different days, $H_{051} = \{(6, 22, 1), (6, 23, 1), (0, 0, 1), (0, 1, 1), (0, 2, 1), (0, 3, 1), (0, 4, 1), (0, 5, 1)\}$. Similarly, $H_{052} = \{(0, 2, 2), (0, 3, 2), (0, 4, 2), (0, 5, 2)\}$ and $H_{692} = \{(6, 6, 2), (6, 7, 2), (6, 8, 2), (6, 9, 2)\}$.

Variables:

- V_{isq} : the number of type q workers starting at shift s on day i .
- x_s : The existence of a shift s in a particular

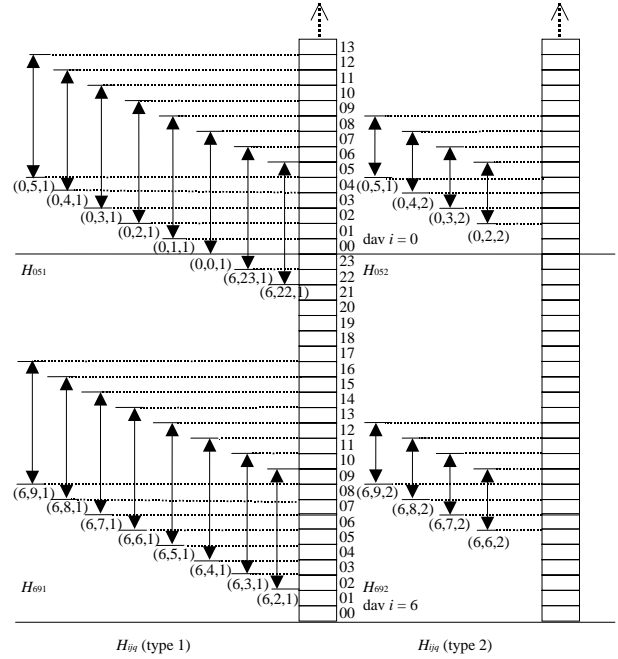


Fig. 2. Example for Set H_{ijq} .

one-hour time slot.

The RM is formulated as an integer linear program as follows:

$$\text{Min } z = c_1 \times \left(\sum_{i \in C} \sum_{s \in N} \sum_{q \in Q} V_{isq} \times r_q \right) \quad (2)$$

$$\text{s.t. } d_{ij} \leq \sum_{q \in Q} \sum_{s \in H_{ijq}} V_{isq} \leq D_{ij} \quad \forall i \in C, \forall j \in N \quad (3)$$

$$l \leq \sum_{s \in N} x_s \leq u \quad (4)$$

$$\sum_{i \in C} \sum_{q \in Q} V_{isq} \leq B x_s \quad \forall s \in N \quad (5)$$

$$x_s = 0 \text{ or } 1 \quad \forall s \in N \quad (6)$$

$$V_{isq} \geq 0 \ \& \ V_{isq} \in I \quad \forall i \in C, \forall s \in N, \forall q \in Q \quad (7)$$

Eq. (2) is the objective function that minimizes the total man-hour cost and is equivalent to the minimization of man-hours, since c_1 is a constant and is used for comparison with the second model addressed later. Eq. (3) states that the assigned crew members must be able to meet the manpower demands within their bounds in every time slot during their shift. Note that, in short-term operations, the maximum manpower which can be supplied for each time slot is limited and is typically

known before planning. Eq. (4) constrains the number of shifts within a reasonable range. Note that the cost resulting from different shifts is not significant for Terminal C in its current operations and therefore can be neglected. If this cost is significant in other applications, then the objective function can be modified as $z = c_1 \times (\sum_{i \in C} \sum_{s \in N} \sum_{q \in Q} V_{isq} \times r_q) + \sum_{s \in N} p_s x_s$ to reflect this concern, where p_s denotes the cost for setting shift s . Eq. (5) means that the manpower is assigned to a shift only when that shift exists. Eqs. (6) and (7) are integer constraints of variables. Given the required demand and the maximum supply of manpower for each time slot of each day, the work types, and the feasible range of shifts, the model determines the best set of shifts, each with a number of work types, in each day of the week. The model is solved using the mathematical programming solver, CPLEX.

2. The strategic model (SM)

In tradition, the carrier may only consider its manpower supply to match the demand in its manpower supply planning, neglecting the use of excess manpower. However, in practice, surplus manpower may be used in short-term operations by other departments, in order to enhance the efficiency of the company's operation. Thus, without considering using such excess manpower (as solved by the RM), the manpower supply plan may not be effective from a system perspective. On the other hand, if the manpower demands for continuous time slots fluctuate drastically (e.g. on the boundaries of peak and off-peak periods), then supplying too much manpower to meet the highest demand would result in too much surplus manpower and a waste of human resources, though they can be of use in some ways.

One of the approaches to dealing with such drastic fluctuation of demands is to provide manpower that can satisfy most of the demands, supplemented by temporary manpower from outside the company, whose unit man-hour cost is normally higher than the regular unit man-hour cost, c_1 . However, to determine how much manpower that trade-offs the surplus and insufficient manpower for each slot for each work type is very complicated and can hardly be solved without a systematic model. Since the RM is not applicable, we further construct a strategic model (SM) by modifying the RM as appropriate, taking into consideration both types of manpower supply, in order to help the carrier manage more effectively its terminal manpower supply under different circumstances. Contrast to the RM, the SM does not restrict the manpower supply to be greater than the manpower demand in each time slot. Therefore, excess or insufficient manpower could happen in some

time slots. By suitably trading off the surplus and inadequate manpower cost, the SM could help manage manpower more effectively, thus reducing the cost. Apart from the previous parameters/variables, we define the new parameters and variables used in the SM as follows.

- c_2 : the value per surplus man-hour for manpower supply exceeding demand. Note that the excess manpower may be used for supporting other departments to reduce the operating cost. Therefore, c_2 is in the form of a negative cost. In practice, $|c_2|$ is smaller than c_1 , because c_2 is the derivative value.
- c_3 : the cost per temporary man-hour supply for insufficient manpower. Note that insufficient manpower may be supplied by temporary manpower from outside the company. In practice, c_3 is greater than c_1 in short-term operations.
- α_{ij} : the excess manpower (in persons) in time slot j on day i .
- β_{ij} : the insufficient manpower (in persons) in time slot j on day i .

SM is formulated as a mixed integer linear program as follows:

$$\begin{aligned} \text{Min } z = & c_1 \times (\sum_{i \in C} \sum_{s \in N} \sum_{q \in Q} V_{isq} \times r_q) + c_2 \\ & \times \sum_{i \in C} \sum_{j \in N} \alpha_{ij} + c_3 \times \sum_{i \in C} \sum_{j \in N} \beta_{ij} \end{aligned} \quad (8)$$

$$\begin{aligned} \text{s.t. } & \sum_{q \in Q} \sum_{s \in H_{ijq}} V_{isq} - d_{ij} - \alpha_{ij} + \beta_{ij} = 0 \\ & \forall i \in C, \forall j \in N \end{aligned} \quad (9)$$

$$\sum_{q \in Q} \sum_{s \in H_{ijq}} V_{isq} \leq D_{ij} \quad \forall i \in C, \forall j \in N \quad (10)$$

$$l \leq \sum_{s \in N} x_s \leq u \quad (11)$$

$$\sum_{i \in C} \sum_{q \in Q} V_{isq} \leq Bx_s \quad \forall s \in N \quad (12)$$

$$x_s = 0 \text{ or } 1 \quad \forall s \in N \quad (13)$$

$$V_{isq} \geq 0 \text{ \& } V_{isq} \in I \quad \forall i \in C, \forall s \in N, \forall q \in Q \quad (14)$$

$$\alpha_{ij} \text{ \& } \beta_{ij} \geq 0 \quad \forall i \in C, \forall j \in N \quad (15)$$

To save space, we only introduce below the SM equations that are different from the RM ones. Eq. (8) is the objective function that minimizes the total system

cost, including the regular manpower cost, the negative surplus value of excess manpower, and the temporary manpower supply cost for insufficient manpower. Eq. (9) states that the assigned crew members, subtracting excess manpower and adding temporary supplied manpower, must be able to meet the manpower demands in every time slot during their shift. Eq. (10) ensures that the amount of manpower in every time slot during their shift does not exceed its available amount of manpower. Eq. (15) is a non-negativity constraint of variables. Note that α_{ij} s and β_{ij} s are not constrained to be integer. However, due to constraint (9) and the integrality of d_{ij} s, they are naturally integers. Given the required demand and the maximum supply of manpower for each time slot of each day, the work types, the feasible range of shifts, and the related cost, the SM determines the best set of shifts, each with a number of work types, and the excess or temporary supplied manpower in each time slot, in each day of the week. The model is solved using the mathematical programming solver, CPLEX.

CASE STUDY

To test how well the models may be applied in the real world, we performed numerical tests using operating data from Terminal C, with reasonable assumptions. We used the C computer language, coupled with the mathematical programming solver, CPLEX 8.1, to build the model and to solve the problems. The tests were performed on a Pentium 4 – 2G with 1Gb of RAM in the environment of Microsoft Windows XP. We first used the operating data to construct the models, and then solved the problems. Finally, we performed several sensitivity analyses.

1. Data analysis

We use the manpower demand of Terminal C's cargo receiving department during September of 2004 as our test data. Note that, there are several departments in Terminal C. All of them are independent in personnel scheduling, due to different operating times. Among these departments, the cargo receiving department is responsible for handling the out-bound freights, which plays a key role in Terminal C's operations. Figure 3 illustrates the average hourly terminal manpower demand in man-hours per week (1-168 hours). The largest terminal manpower demand appears on Friday, because most carriers need to send their cargos before the weekend. On the contrary, the least terminal manpower demand appears on Sunday when most companies are on holiday. In addition, the inputs, such as the upper bound of manpower supply in each time slot, the work-

ing hours of different work types, and the upper/lower bound of shifts, were primarily adopted from actual operating data and government regulations of Taiwan, with reasonable simplifications. Note that, according to the real practices, the upper bounds of the manpower (D_{ij}) in constraints (3) and (10) vary within eighteen. Nine different work types are set for the flexible working hour strategy (from 4 to 12 working hours). The lower and upper bounds of shifts (l and u) in constraints (4) and (11) are equal to 3 and 6, respectively. In the RM and the SM, the three cost parameter values, which are relative to each other, are set as follows. The regular manpower cost per man-hour (c_1) is set to be 10. The value per surplus man-hour for manpower supply exceeding demand (c_2) is set to be zero in this research, because Terminal C does not consider the use of excess manpower in their short-term manpower supply plan. Moreover, since it is not easy to supply temporary manpower from outside the company in short-term operations, the cost per temporary man-hour supply for insufficient man-power (c_3) is set to be 300 in this research to reflect the real practice. Note that, the three cost values are adjustable in other applications to meet the company's operating requirements.

2. Test results

Table 1 shows the problem sizes and test results. Note that to evaluate preliminarily the two models (the RM and the SM), the real manpower supply of Terminal C is used and its results obtained are referred to as "actual operations" for simplicity. As shown in Table 1, OBJ represents the system cost for the optimal solution obtained by CPLEX.

Models RM and SM yielded the same best solution, with an objective value of 6840. Note that the objective values of the two models are the same, because there is no temporary manpower to supply and the surplus value of excess manpower is set as zero. The actual operations performed worse, with an objective value of 7210. The results show that the two models outperformed the current trial-and-error method by a reduced cost of

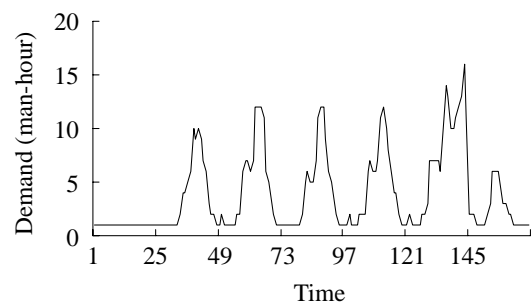


Fig. 3. Average hourly terminal manpower demand profile per week.

Table 1. Test results

	Actual operations	Model RM	Model SM
Number of variables	NA	1,536	1,872
Number of constraints	NA	362	362
OBJ (NT\$)	7,210	6,840	6,840
Computation time (sec.)	NA	716.69	424.25
Regular manpower (man-hours)	721	684	684
Excess manpower (man-hours)	70*	33*	33
Insufficient manpower (man-hours)	0**	0**	0
Required demand (man-hours)	651	651	651
Number of shifts	3	6	6
Shift starting times	01, 09, 17	01, 06, 09 13, 14, 20	01, 06, 09 13, 14, 20

*The excess manpower for the actual operations and RM are externally calculated to be 70 and 33, respectively.

**The insufficient manpower for the actual operations and RM are both 0 by definition.

5.4% ($= (7,210 - 6,840)/6,840$). Moreover, the excess and insufficient manpowers, which are 33 and 0, respectively, can be directly obtained from the SM's results, showing that SM is more flexible for planning terminal manpower supply.

For the number of shifts, there were currently three shifts for Terminal C. We set the feasible range of shifts from three to six. As shown in Table 1, both models yielded six shifts (*i.e.* starting at 01:00, 06:00, 09:00, 13:00, 14:00 and 20:00, respectively), showing that a larger number of shifts indicate more manpower flexibility and thus more feasible combinations. For the computation times, though the SM (424.25 seconds) is better than the RM (716.69 seconds) by 292.44 seconds, both are efficient for solving realistic problems in the planning stage.

To illustrate the model solution, we show the SM solution, the manpower demand and their difference (supply minus demand) in Figure 4. Note that the required demand for each time slot in each day is satisfied; therefore, the differences were all greater than zero. That is, there is excess manpower in some time slots, without insufficient manpower (or temporary manpower supply) in any time slot.

As seen in the test results, both the RM and the SM could improve over the current manual trial-and-error method. The SM was better than the RM in terms of computational efficiency and flexibility. In summary, both the RM and the SM are efficient and effective for terminal manpower supply planning and shift setting in short-term operations. Note that the results of the two models are the same. The reasons are twofold: 1) the regular manpower cost per man-hour ($c_1 = 10$) was set to be relatively small compared to the cost per temporary man-hour supply for insufficient manpower ($c_3 = 300$); 2) the required demand for test data is relatively low

compared to the available manpower supply for each time slot, resulting in no insufficient manpower (or temporary manpower supply) in any time slot. Therefore, the two model solutions are not distinguishable. However, when the required demand increases, the performance of the two models may differ. To verify this, we will now perform a sensitivity analysis on the manpower demand.

3. Sensitivity analyses

To understand the influence of the parameters on the model solutions, we performed a sensitivity analysis of the manpower demand, the flexible working hour shifts, the upper bound of shifts, and the manpower cost, all of which are essential inputs to the two models.

(1) The manpower demand (d_{ij})

To examine the influence of manpower demand on both model solutions, we tested four scenarios, ranging from 70% to 160% of the original manpower demand. It should be mentioned that if the manpower demand for

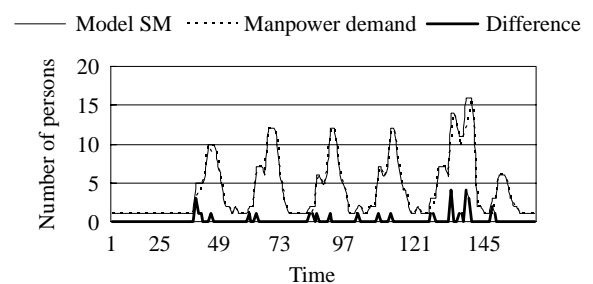


Fig. 4. The SM solution profile.

all time slots is greater than the upper bound of manpower supply, then the RM is not feasible for solving the associated scenarios, because insufficient manpower supply is not allowed in the RM. For comparison purpose, in addition to the SM, we also use the RM to solve the five scenarios under the above condition. The application of the RM is as follows. First, if there are manpower demands greater than their upper bound for some time slots, then we set these manpower demands to be their upper bounds and calculate the insufficient manpower (equal to the total manpower demands minus their upper bounds) and its temporary manpower cost (equal to the insufficient manpower multiplied by c_3). We then solve the modified problem using the RM. The final objective value for the RM is then equal to the the RM's objective value on the modified problem plus the temporary manpower cost for the aforementioned insufficient manpower. Note that since c_2 is set as 0, the excess manpower is not calculated. In addition, the application of the RM, which incorporates a manual adjustment without system optimization, generates only a feasible solution instead of the optimal solution obtained by the SM. Therefore, in theory, the RM will never be better applied than the SM. As shown in Figure 5, as the manpower demand increased from 70% to 130%, both the model objective values were the same and increased gradually from 5,510 to 10,870. For the scenario of 70% and 100%, there is no insufficient manpower. For the scenario of 130%, there is an insufficient manpower of 4 man-hours for both the RM and the SM. Although the manpower demand increased from 70% to 130%, the available manpower supply can meet most of the manpower demand for each time slot. Consequently, the results of two models are still the same. As the amount of required manpower increased from 130% to 160%, the RM's objective value increased to 22,560 with an insufficient manpower of 38 man-hours, while the SM's objective value increased to 21,060 with an insufficient manpower of 33 man-hours. The SM yielded a significantly better solution than the

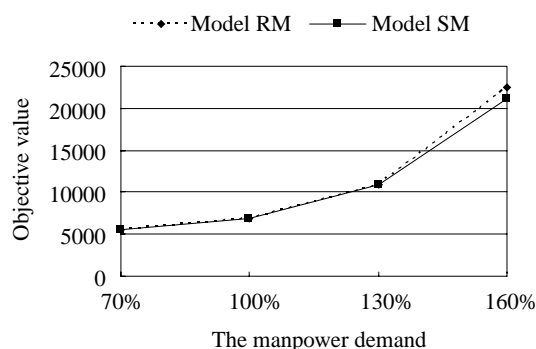


Fig. 5. Sensitivity analysis of the manpower demand.

RM, with an improvement of 1,500 (7.12%). The above results show that the SM was more flexible and more effective than the RM, especially when the available manpower supply is insufficient for the required demand.

(2) The flexible working hour shifts

To examine the influence of flexible working hour shifts on the model solutions, we tested three types of working hour shifts, such as full-time employees with eight working hour shifts, half-time employees with four working hour shifts and full-time employees with eight working hour shifts, and employees with shifts of flexible working hours ranging from 4 to 12. The results of the two models were all the same. As shown in Figure 6, when the types of working hours increased, the objective value of the two models decreased. In particular, when pure full-time employees were modified to flexible working hours, the objective value decreased from 8,320 to 6,840 (an improvement of 21.6%). The results showed that the models containing the flexible working hour strategy were more effective for terminal manpower supply plan.

(3) The upper bound of shifts

In current practices, there are three shifts for Terminal C's operations. To examine the influence of the upper bound of shifts on model solutions, we tested four scenarios, ranging from 3 to 6. The results of the two models were all the same. As shown in Figure 7, when the upper bound of shifts increased from 3 to 6, the objective value decreased from 7,400 to 6,840 (an improvement of 8%). This implies that, more shifts would result in greater manpower flexibility, and thus better solution.

(4) The manpower cost

In this research, the three manpower costs (c_1 , c_2 , and c_3) were set relatively according to Terminal C's practices. Therefore, we performed three sensitivity analyses of these manpower costs to one or both models.

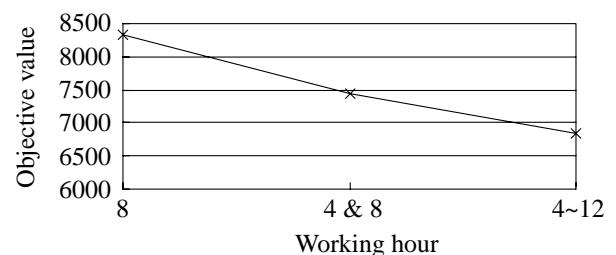


Fig. 6. Sensitivity analysis of flexible working hour shifts.

A. The regular manpower cost per man-hour (c_1)

Five scenarios, for c_1 ranging from 10 to 90, were tested. Both models generated the same solutions. No insufficient manpower was found in these solutions, because c_3 is significantly higher than c_1 and c_2 was set as 0. As shown in Figure 8, the objective value increased as c_1 increased.

B. The value per surplus man-hour for manpower supply exceeding demand (c_2)

The excess manpower may be effectively used by the terminal to improve its operations. Five scenarios, for c_2 ranging from 0 to -8, were tested to examine the influence of c_2 on the SM solution. As shown in Figure 9, when c_2 decreased (*i.e.* the value per surplus man-hour increased), the SM objective value decreased, because there was excess manpower and the terminal could use excess manpower more effectively. No insufficient manpower was found in these solutions, because c_3 is significantly greater than c_1 and c_2 .

C. The cost per temporary man-hour supply for insufficient manpower (c_3)

Five scenarios of c_3 ranging from 200 to 400 were tested on the SM. The results showed that the SM objective value was not affected by the c_3 changes. In particular, no temporary manpower (*i.e.* insufficient manpower) was found in these scenarios, because c_3 is significantly greater than c_1 and c_2 , and the available

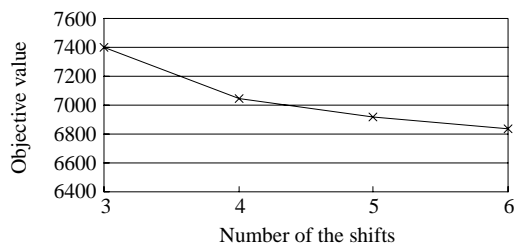


Fig. 7. Sensitivity analysis of the upper bound of the shifts.

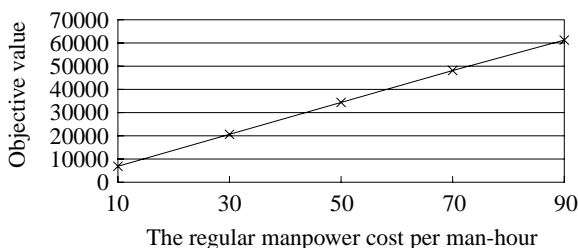


Fig. 8. Sensitivity analysis of the regular manpower cost.

manpower is enough to supply the demand in short-term operations.

CONCLUSION

A good manpower supply plan of terminal officers helps air cargo terminals deal with their cargoes efficiently and maintain excellent service quality. In the past, most of the cargo terminals depend on the staff experience in establishing the manpower supply plans and shift schedules, without optimization from a systemic perspective. Therefore, in this research, we incorporate flexible management strategies and the related operating constraints into the development of a mathematical programming model. By suitable modification of the model, we further construct a strategic model, associated with different combinations of manpower supply principles, which can help an air cargo terminal manage more effectively its terminal manpower supply and set its shift schedule. The models are formulated as integer and mixed integer linear programs that are solved using a mathematical programming solver.

A case study utilizing the operations of a domestic Taiwan air cargo terminal was conducted to illustrate model application in the real world. The results showed that both the RM and the SM could improve over the current manual trial-and-error method. Moreover, the SM was better than the RM in terms of computational efficiency and flexibility. In summary, both the RM and the SM are efficient and effective for terminal manpower supply planning and shift setting in short-term operations. To understand how the essential parameters could affect the model solutions, several sensitivity analyses were also performed. Although the preliminary test results show that the models are potentially useful for manpower supply planning and shift setting, especially for Taiwan's domestic air cargo terminals, more tests or case studies should be conducted, so that users may grasp their limitations, before putting them to practical use. The models, the case study, and the sensitivity analyses, should all be useful references for air cargo terminals when determining the most optimal short-term manpower schedule.

Finally, the scope of this research is confined to the second stage of the procedure for short-term termi-

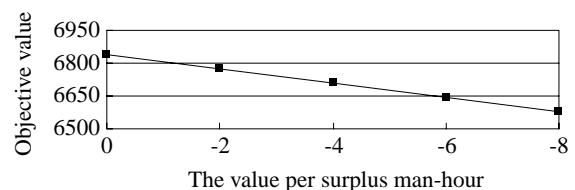


Fig. 9. Sensitivity analysis of the value per surplus man-hour.

nal manpower supply plan. How to integrate the manpower supply plan and the crew assignment into an integrated terminal manpower scheduling model could be a topic of future research. In addition, in actual operations, some of the model parameters, such as manpower demands, are stochastic. Therefore, how to modify the deterministic models to become stochastic models for a closer match of actual operations could also be a topic of future research.

ACKNOWLEDGEMENTS

This research was supported by a grant (NSC 93-2211-E-008-022) from the National Science Council of Taiwan. We would like to thank the cargo terminal for providing the test data and its valuable opinions on this research. We would also like to thank the two anonymous reviewers for their helpful suggestions on the presentation of the paper.

REFERENCES

- Alfares, H.K., "An Efficient Two-Phase Algorithm for Cyclic Days-off Scheduling," *Computers and Operations Research*, Vol. 25, pp. 913-923 (1998).
- Aykin, T., "A Comparative Evaluation of Modeling Approaches to the Labor Shift Scheduling Problem," *European Journal of Operational Research*, Vol. 125, No. 2, pp. 381-397 (2000).
- Beasley, J.E. and Cao, B., "A Tree Search Algorithm for the Crew Scheduling Problem," *European Journal of Operational Research*, Vol. 94, No. 3, pp. 517-526 (1996).
- Beaumont, N., "Scheduling Staff Using Mixed Integer Programming," *European Journal of Operational Research*, Vol. 98, pp. 473-484 (1997).
- Bechtold, S.E., Brusco, M.J., and Showalter, M.J., "A Comparative Evaluation of Labor Tour Scheduling Method," *Decision Sciences*, Vol. 22, No. 4, pp. 683-699 (1991).
- Blyton, P. and Morris, J., "HRM and the Limits of Flexibility," in Blyton, P. and Turnbull, P. (eds.), *Reassessing Human Resource Management*, pp. 116-130 (1992).
- Brusco, M.J., "Solving Personnel Tour Scheduling Problems Using the Dual All-Integer Cutting Plane," *IIE Transaction*, Vol. 30, pp. 835-844 (1998).
- Brusco, M.J. and Jacobs, L.W., "Elimination Redundant Columns in Continuous Tour Scheduling Problems," *European Journal of Operational Research*, Vol. 111, pp. 518-525 (1998).
- Brusco, M.J. and Johns, T.R., "Improving the Dispersion of Surplus Labor in Personnel Scheduling Solutions," *Computers and Industrial Engineering*, Vol. 28, No. 4, pp. 745-754 (1995).
- Brusco, M.J. and Johns, T.R., "A Sequential Integer Programming Method for Discontinuous Labor Tour Scheduling," *European Journal of Operational Research*, Vol. 95, No. 3, pp. 537-548 (1996).
- Caprara, A., Fischetti, M., Toth, P., Vigo, D., and Guida, P.L., "Algorithms for Railway Crew Management," *Mathematical Programming*, Vol. 79, pp. 125-141 (1997).
- Easton, F.F. and Rossin, D.F., "Equivalent Alternate Solutions for the Tour Scheduling Problem," *Decision Sciences*, Vol. 22, No. 5, pp. 985-1007 (1991).
- Higgins, A., "Scheduling of Railway Track Maintenance Activities and Crews," *Journal of the Operational Research Society*, Vol. 49, pp. 1026-1033 (1998).
- Langerman, J.J. and Ehlers, E.M., "Agent-Based Airline Scheduling," *Computers and Industrial Engineering*, Vol. 33, No. 3-4, pp. 849-852 (1997).
- Lau, H.C., "On the Complexity of Manpower Shift Scheduling," *Computers and Industrial Engineering*, Vol. 23, No. 1, pp. 93-102 (1996).
- Lavoie, S., Minoux, M., and Odier, E., "A New Approach for Crew Pairing Problems by Column Generation with an Application to Air Transportation," *European Journal of Operational Research*, Vol. 35, pp. 45-58 (1988).
- Lučić, P. and Teodorovic, D., "Simulated Annealing for the Multiobjective Aircrew Rostering Problem," *Transportation Research Part A*, Vol. 33, pp. 19-45 (1999).
- Morris, J.G. and Showalter, M.J., "Simple Approaches to Shift, Days-off and Tour Scheduling Problems," *Management Science*, Vol. 29, No. 8, pp. 942-950 (1983).
- Narasimhan, R., "An Algorithm for Single Shift Scheduling of Hierarchical Workforce," *European Journal of Operational Research*, Vol. 96, No. 1, pp. 113-121 (1996).
- Niklas, K. and Erik, H., "Airport Ground Staff Scheduling," *INFORMS Miami 2001 Annual Meeting Sponsor: Aviation Applications*, Session: SA36.3 (2001).
- Nobert, Y. and Roy, J., "Freight Handling Personnel Scheduling at Air Cargo Terminals," *Transportation Science*, Vol. 32, pp. 295-301 (1998).
- Ryan, D.M., "The Solution of Massive Generalized Set Partitioning Problem in Aircrew Rostering," *Journal of the Operational Research Society*, Vol. 43, pp. 459-467 (1992).
- Sorensen, M.D. and Clausen, J., "Decentralized Ground Staff Scheduling," *IMM-Technical Report*, pp. 603-627 (2002).
- Teodorovic, D. and Lučić, P., "A Fuzzy Set Theory Approach to the Aircrew Rostering Problem," *Fuzzy Set and System*, Vol. 95, pp. 261-271 (1998).
- Yan, S. and Chang, J.C., "Terminal Cockpit Crew Scheduling," *European Journal of Operational Research*, Vol. 136, No. 3, pp. 501-511 (2002).
- Yan, S., Tang, T.T., and Tu, Y.P., "Optimal Construction of Airline Individual Crew Pairings," *Computers and Operations Research*, Vol. 29, pp. 341-363 (2002).
- Yan, S. and Tu, Y.P., "A Network Model for Terminal Cabin Crew Scheduling," *European Journal of Operational Research*, Vol. 140, No. 3, pp. 531-540 (2002).
- Yan, S., Yang, D.H., and Chen, S.H., "Airline Short-Term Maintenance Manpower Supply Planning," *Transportation Research Part A*, Vol. 38, pp. 615-642 (2004).