A Mixed Integer Programming Method for the Health Examination Center Scheduling Problems with Sequence-dependent Transportation Time

Hui-Mei Wang
Department of Hotel Management, Vanung University, Jung-Li, Tao Yuan, Taiwan
Email: amywang@mail.vnu.edu.tw

Fuh-Der Chou
Department of Industrial Management, ChienHsin University, Jung-Li, Tao Yuan, Taiwan
Email: fdchou@tpts7.seed.net.tw

***Abstract*—This paper considers the health examination center scheduling problem. In the center, there are three major health examination services including (1) Physical examination (PE); (2) Organ system checks; (3) Organ structural inspection, with a variety of check-up items. Additionally, the order of these check-up items done is irrelevant, but all check-up items in the contract should be finished for individual examinee. Each examinee is expected that they could finish smoothly all items without waiting. According the operative characteristics, the health examination scheduling problem is analogous to a multiprocessor open shop scheduling problem with sequence-dependent transport time, and the objective is to minimize the mean flow time. To our best knowledge, the problem is first proposed. A mixed integer programming method is introduced to specify the problem systematically, and in the end, an example with 9 examinees is used to validate the proposed model successfully.**

***Index Terms*—health examination center, scheduling, flow time, mixed integer programming**

I. Introduction

Health examination is becoming increasingly important as many people value the concept of "An ounce of prevention is worth a pound of cure". In Taiwan, the gross value of health examination is estimated to be a range of 5.5 billion to 7.5 billion a year, and it has growing by a rate of 15% annually. Therefore, many hospitals extend their affairs to manage a professional health examination center and invest lots of money in high valued equipment. The purpose of health examination is to screen some potential diseases, and it is usually classified into main three parts: (1) Physical examination (PE); (2) Organ system checks; (3) Organ structural inspection. The outline of the examination procedures is shown in Fig. 1. Based on the procedures it is obvious that the order of these check-up items done is irrelevant, but all check-up items in the contract should be finished for individual examinee. In the real world, the examination sites are possible on different floors or spaces, and the operation at each site is isolation which implies the nurses are waiting for examinees passively and follow the policy of 'first-registration, first-check'. This way is likely to bring about unbalanced loads when some sites are crowded and the others are not. At the meantime, it would result in large waiting time for the examinees. Therefore, a scheduling system integrating the information of all sites to obtain an optimal or feasible route for examinees is necessary.

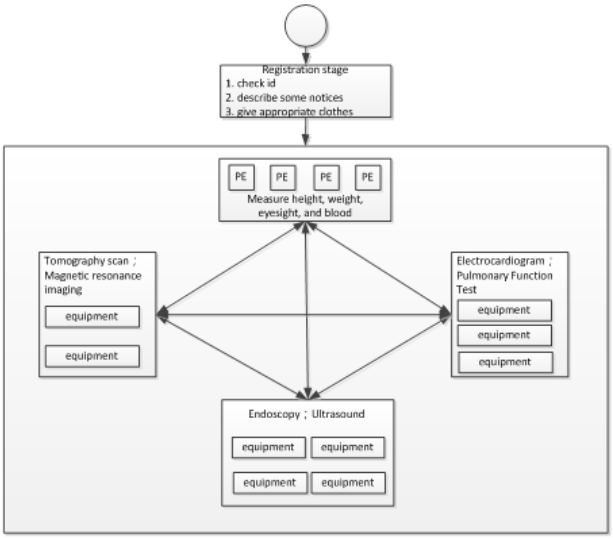

Figure 1. The outline of the examination procedure

Based on the above mentions, the health examination center scheduling problem could be referred as a multiprocessor open shop problem with sequence-dependent transportation time. In the literature, some considering health examination scheduling problems have been reported. Liu *et al.* [1] considered the problem with thirty patients for twenty-two check-up items; and attempted to minimize examination time, number of patients waiting over fifteen minutes, and total waiting time. For the problem they proposed multi-objective genetic algorithms and obtain good enough solutions.

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Petrovic *et al.* [2] addressed a mathematical programming method and three genetic algorithms to solve the scheduling of radiotherapy treatments for categorized patients. Matta [3] considered the scheduling problem of diagnostic tests for a big hospital. There are fourteen facilities to deal with diagnostic test and the order of these tests are done is irrelevant. Due to these facilities are very expensive, Matta considered the objective of minimizing makespan and proposed a mathematical programming model and genetic algorithms. Later, Matta and Elmaghraby [4] considered balanced proportionate multiprocessor open shop problem to find better number of diagnostic facilities at each examination stage, and given number of facilities at each stage they proposed algorithms to obtain better diagnostic sequences for the patients. Chiu and Yeh [5] adopted Mamdani-style fuzzy inference process to construct a fuzzy-based dynamic scheduling system which could tell each patient where the next stage is. Through the system the average time for finishing all examination decreases from 6-to-24 hour to 0.5-to-1 hour. Chern *et al.* [6] proposed a heuristic algorithm to minimize the waiting time for both of examinees and examiners. For open shop problems, Tang and Bai [7] presented a lower bound and a heuristic algorithm to minimize total completion time. Naderi *et al.* [8] indicated that only one machine at each stage for processing is unusual case in the real world, and considered multiprocessor open shop scheduling problem with the objective of total completion time. For the problem, they developed a mix integer programming model and memtic algorithm (MA). Sevastianov and Woeginger [9] also considered the same problem of Naderi *et al.* [8] where the objective is to minimize makespan, and proposed a lower bound and an approximation algorithm. To our best knowledge, there has been little reported research on considering both multiprocessors and transportation time in the open shop problem just like the problem we study in the paper. In the following, a brief problem definition is given in section 2. In section 3 we formulate a mixed integer programming model systematically, and validate it by a small example in section 4. The result of sequences is illustrated by the Gantt chart as well. Finally, section 5 summarizes the concluding remarks.

II. Problem Definition

In this section the assumptions of the health examination center scheduling problem are described as follows.

- The reservation times of all examinees for health examination could be known in advance, and it is referred as an arrival time.
- The times of each examination item for being ready to be check-up could be known in advance, and it is referred as a ready time.
- The number of examinees for check-up at each examination item is known in advance.
- The check-up items for each examinee are known, and the time of each check-up item is given and determined.
- The transportation time between sites of check-up items can be estimated and known in advance.
- Each channel examines only an examinee in a time, and preemptive is not allowed.
- The breakdown of equipment is not allowed.

III. An Mixed Integer Programming (MIP) Model

In this section, we formulate the scheduling problem introduced in Sect. 2 as an MIP model. In Sect. 3.1, we introduce the notations used in the model and variables as well. We formulate the objective function and the constraints, respectively in Sect. 3.2.

A. Notation

n : Number of examinees

s : Number of check-up items

m_k : Number of channelsavailable for check-up item*k*; $k = 1,2,3,\ldots,s$

r_j : The arrival time of each examinee j ; $j = 1,2,3,\ldots,n$

p_{jk} : The check time for examinee j at check-up item*k*; $j = 1,2,3,\ldots,n$; $k = 1,2,3,\ldots,s$

t_{fk} : The transportation time between sites of check-up items (*f*,*k*); $f = 0,1,2,\ldots,s$; $k = 1,2,3,\ldots,s$

M : An extreme big integer number

F_j : The time for examinee*j* finishing all check-up items in their contracts; $j = 1,2,3,\ldots,n$

C_{jk} : The completion time for examinee j at check-up item*k*; $j = 1,2,3,\ldots,n$; $k = 1,2,3,\ldots,s$

FT_j : The flow time for examinee*j* at health examination center; $FT_j = (F_j - r_j)$; $j = 1,2,3,\ldots,n$

X_{jfk} : 1 if check-up item*f* is checked before check-up item*k* for examinee*j*, otherwise 0. $j = 1,2,3,\ldots,n$; $f = 0,1,2,\ldots,s$; $k = 1,2,3,\ldots,s$; $f \neq k$

Y_{ijka} : 1 if examinee*i* is checked before examinee*j* at channel*a* of check-up item *k*, otherwise, 0. $i = 1,2,3,\ldots,n$; $j = 1,2,3,\ldots,n$; $k = 1,2,3,\ldots,s$; $a = 1,2,3,\ldots,m_k$; $i \neq j$

Z_{jka} : 1 if examinee*j* is exactly processed at channel*a* of check-up item*k*, otherwise, 0; $j = 1,2,3,\ldots,n$; $k = 1,2,3,\ldots,s$; $a = 1,2,3,\ldots,m_k$

W_{jfk} : 1 if check-up item*k* is immediately processed after check-up item*f* for examinee*j*, otherwise, 0; $j = 1,2,3,\ldots,n$; $f = 0,1,2,\ldots,s$; $k = 1,2,3,\ldots,s$; $f \neq k$

B. Model

For minimizing the mean flow time, we link two variables of F_j and r_j by $FT_j = (F_j - r_j)$ and the objective function is as follows.

Objective

$$Min. \quad \frac{1}{n} \cdot \sum_{j=1}^{n} FT_j \tag{1}$$

Constraints

For each examinee, number of the permutations in total for check-up items is specified as follows.

$$\sum_{f=0}^{s} \sum_{k=1}^{s} X_{jfk} = \frac{s \times (s+1)}{2} \qquad \forall \quad j = 1,2,3,\ldots,n \tag{2}$$

For each examinee, each check-up item is exactly performed only once at one channel which is formulated by

$$\sum_{a=1}^{m_k} Z_{jka} = 1 \, \forall j = 1,2,\ldots,n; \; k = 1,2,\ldots,s \tag{3}$$

In addition, there only one check-up item is immediately followed by another one being checked and the relations are formulated by constraints (4) to (7).

$$\sum_{f=0}^{s} W_{jfk} = 1 \qquad \forall j = 1,2,\ldots,n; k = 1,2,\ldots,s \tag{4}$$

$$X_{jfk} - W_{jfk} \geq 0 \forall j = 1,2,\ldots,n; f = 0,1,2,\ldots,s; k = 1,2,\ldots,s; f \neq k \tag{5}$$

$$\sum_{v=1}^{s} X_{jfv} - \sum_{v=1}^{s} X_{jkv} - X_{jfk} + M(W_{jfk} - 2) \leq 0 \forall j = 1,2,\ldots,n; f = 0,1,2,\ldots,s; k = 1,2,\ldots,s; f \neq k \tag{6}$$

$$\sum_{v=1}^{s} X_{jfv} - \sum_{v=1}^{s} X_{jkv} + M(1 - X_{jfk} + W_{jfk}) \geq 1 \forall j = 1,2,\ldots,n; f = 0,1,2,\ldots,s; k = 1,2,\ldots,s; f \neq k \tag{7}$$

Constraints (8) to (10) is used to identify any two examinees be checked on the same channel in the same check-up item or not.

$$Y_{ijka} + Y_{jika} \leq 1 \forall i = 1,2,\ldots,n; j = 1,2,\ldots,n; \mathrm{k} = 1,2,\ldots,\mathrm{s}; \mathrm{a} = 1,2,\ldots,m_k; i < j \tag{8}$$

$$(Z_{ika} + Z_{jka}) - 2 \times (Y_{ijka} + Y_{jika}) \geq 0 \quad \forall i = 1,2,\ldots,n; j = 1,2,\ldots,n; k = 1,2,\ldots,s; a = 1,2,\ldots,m_k; i < j \tag{9}$$

$$(Z_{ika} + Z_{jka}) - (Y_{ijka} + Y_{jika}) \leq 1 \forall i = 1,2,\ldots,n; j = 1,2,\ldots,n; k = 1,2,\ldots,s; a = 1,2,\ldots,m_k; i < j \tag{10}$$

Constraint (11) is used to specify the completion time for two examinees being checked on the same channel at a check-up item.

$$C_{jk} \geq C_{ik} + p_{jk} - M(1 - Y_{ijka}) \forall i = 1,2,\ldots,n; j = 1,2,\ldots,n; k = 1,2,\ldots,s; a = 1,2,\ldots,m_k \tag{11}$$

For individual examinee, its inherent completion time at each check-up item should be a sum of its arrival time, processing time, and transportation time which is defined as constraint (12)

$$C_{jk} \geq r_j + p_{jk} + \sum_{f=0}^{s} (t_{fk} \times W_{ifk}) \forall j = 1,2,\ldots,n; k = 1,2,\ldots,s \tag{12}$$

For two jobs for any two check-up items, the completion time for two jobs should obey the relationship formulated by constraint (13)

$$C_{jk} \geq C_{jf} + p_{jk} + \sum_{v=0}^{s} (t_{vk} \times W_{jvk}) - M(1 - X_{jfk}) \forall j = 1,2,\ldots,n; f = 0,1,2,\ldots,s; k = 1,2,\ldots,s; k \neq l \tag{13}$$

Constraint (14) and constraint (15) respectively defines the flow time for each examinee, and the total flow time.

$$F_j \geq C_{jk} \forall j = 1,2,\ldots,n; k = 1,2,\ldots,s \tag{14}$$

$$FT_j = (F_j - r_j) \forall j = 1,2,\ldots,n \tag{15}$$

IV. Model Validation

This section is to examine the proposed model by an example with nine examinees and five check-up items. The relevant information is listed in Tables I to IV.

TABLE I. Number of Channels in Each Check-up Item

	Item 1	Item 2	Item 3	Item 4	Item 5
Number of Channels	2	3	2	2	2

TABLE II. The Arrival Time of Each Examinee

	1	2	3	4	5	6	7	8	9
Arrival Time	3	4	0	2	8	6	1	5	0

TABLE III. Estimated Check-up Time at Each Item for Each Examinee

	1	2	3	4	5	6	7	8	9
Item 1	4	1	2	3	3	3	6	2	4
Item 2	3	5	7	2	6	6	4	7	7
Item 3	6	3	5	6	4	8	5	3	2
Item 4	2	7	1	2	7	2	1	1	9
Item 5	5	2	5	1	1	7	5	6	3

TABLE IV. The Transportation Time between Items

	Item 1	Item 2	Item 3	Item 4	Item 5
Item 0	1	3	2	2	2
Item 1	0	2	1	3	2
Item 2	2	0	1	2	3
Item 3	1	5	0	4	3
Item 4	4	2	3	0	1
Item 5	4	2	3	3	0

The model is implemented in IBM ILOG CPLEX Optimization Studio version 12.5 on a PC Xeon E5-1620 CPU with 3.6 GHz and 12 GB memory. For the example, the time taken for obtaining an optimal solution is 1305.32 second and the optimal solution of mean flow time is 29.33. Fig. 2 shows detailed sequences for the example by the Gantt chart.

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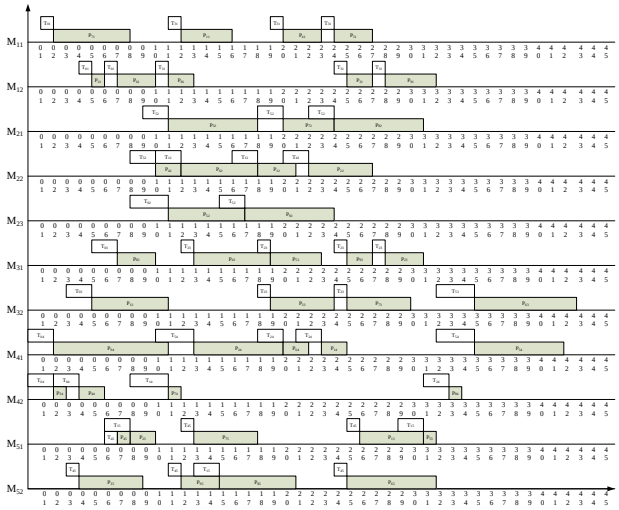

Figure 2. The Gantt chart for the solution of an example

V. CONCLUSIONS

As time goes by, more and more health examination centers will be launched because more and more people value preventive health care, especially in an aging society. To ensure their competitiveness, high technology and skill are not enough; they have to satisfy customer's expectation by decreasing customers' waiting time in the health examination center. Therefore, this paper attempts to consider the health examination scheduling problem as a multiprocessor open shop problem with sequence-dependent transportation times, and constructs a mixed integer programming (MIP) model to obtain optimal sequences for all examinees.

Validated by an example with nine examinees and five check-up items, the model suggested in this study can be useful for real health examination center. However, further research is needed since actual problems in the real systems may be larger than what could be solved by the model in this study. Thus, developing efficient meta-heuristic algorithms such as simulated annealing or genetic algorithm is research directions in the future.

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Fuh-Der Chou is a professor in the Department of Industrial Management at ChienHsin University, Taiwan. He received his M.S. degree in industrial engineering from Chung Yuan Christian University in 1988, and his Ph.D. degree in industrial engineering and management from National Chiao Tung University in 1997. His research interests includeproduction scheduling, semiconductor manufacturing management, and group technology.

Hui-Mei Wang is anassociate professor in the Department of Hotel Management at Vanung University. She received her M.S. and Ph.D. degrees in Department of Industrial Engineering and Management from the University of Yuan-Ze. Her present research interests include production scheduling and semiconductor manufacturing management.