Using Integer Programming for Airport Service Planning in Staff Scheduling

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Abstract: *Reliability and safety in flight is extremely necessary and that depend on the adoption of proper maintenance system. Therefore, it is essential for aircraft maintenance companies to perform the manpower scheduling efficiently. One of the objectives of this paper is to provide an Integer Programming approach to determine the optimal solutions to aircraft maintenance planning and scheduling and hence the planning and scheduling processes can become more efficient and effective. Another objective is to develop a set of computational schedules for maintenance manpower to cover all scheduled flights. In this paper, a sequential methodology consisting of 3 stages is proposed. They are initial maintenance demand schedule, the maintenance pairing and the maintenance group(s) assignment. Since scheduling would split up into different stages, different mathematical techniques have been adopted to cater for their own problem characteristics. Microsoft Excel would be used. Results from the first stage and second stage would be inputted into integer programming model using Microsoft Excel Solver to find the optimal solution. Also, Microsoft Excel VBA is used for devising a scheduling system in order to reduce the manual process and provide a user friendly interface. For the results, all can be obtained optimal solution and the computation time is reasonable and acceptable. Besides, the comparison of the peak time and non-peak time is discussed.*

Keywords: *airport service, aircraft, manpower scheduling, maintenance.*

1. Introduction

Nowadays, since air transport becomes more and more popular in the world, airline industry has been increasing rapidly on the demand of the aircraft service. Hansen (2004) claimed that from the year 1996 to 2016, the world-wide air traffic is expected to grow to unexpected levels. That causes the aircraft crew scheduling problem to become more and more complex and difficult faced by the aircraft company.

According to Cheung et al. (2005), in enabling airport support services companies to achieve effective and efficient operations; accurate planning, scheduling and control systems are important and essential. Traditionally, many approaches are introduced for scheduling and planning based on the experience and expert knowledge. However, Ernst et al. (2004) mentioned that it is difficult to find the optimal solutions since it involve many constraints and complex problems, such as costs minimization, meeting employee preferences, distributing equitably among employees and workplace satisfaction.

Currently, although many people involved in developing a scheduling system that can help them to make decisions in providing the right staff in the right place at the right time, it seems that the problem in aircraft crew scheduling is extremely complex and the solutions of that is not usual and maturity. One of the reasons is that they have many restrictions and limitations in terms of functions and features which do not suitable for aircraft industry as most of them are homogenous scheduling system. Moreover, there are many factors that should be considered and human factor likes licensing and qualification is the most important and unpredictable criteria needs to be handled in the aircraft industry and hence Cheung et al. (2002) pointed out that it is difficult to optimize the use of resource due to the variation in terms of aircraft types, training requirements, qualification, licensing coverage requirements, work demand and scheduling alternatives with the dynamic nature of aircraft flight operations and while license and training is the most especial factors that should be determined since it is important for employees to handle the jobs with the particular flight model. Also, the annual leave, public holiday and special restrictions such as special shift pattern, shift not assigned to particular staff, fixed holiday on a particular weekday are very important and substantial for the satisfaction of the staff. All these considerations make the roster generation more complex and complicated especially for the large number of staff.

There are many factors like qualifications, experience considerations, human factors and training requirements are regarded as concerns and should be considered when making task assignment and planning aircraft manpower schedule. Since licensing is the most critical and necessary factor in scheduling, the main focus of this paper would be on the licensing factor. In this paper, the studied company China Aircraft Service Limited (CASL) separates maintenance works into different categories - regular checks and short-term layover maintenance checks (transit check). These checks would be separated because they have different features and concerns. The regular checks required one or more days to finish checking and the flights need to stay at the CASL while short-term layover maintenance usually performed at the airport gates and takes just one-two hours. This paper would be focus on short-term layover maintenance which is the most important one from the point of view of programming and scheduling.

The objective of this paper is to overcome the complex scheduling problems using Integer Programming for CASL as a management decision support for better manpower allocation. Microsoft Excel Solver is used to implement the scheduling model and Integer Programming operations. Besides, Microsoft Excel VBA would be used for devising a scheduling system in order to reduce the manual process and provide a user friendly interface, and maximize the utilization and balance the workload of manpower.

2. Literature Review

According to Brucker (2002), "scheduling is concerned with the optimal allocation of scarce resources to activities over time". Lopez and Roubellat (2008) had stated that scheduling problem is the organization executes a set of tasks over time and need to consider on time constraints such as deadlines and priority constraints, capability and capacity constraints which are the resources that required for the tasks. Pinedo (2002) emphasized that scheduling is the process of decision-making for optimizing one or more objectives in order to achieve the goal. He has illustrated the role of scheduling process in the real-life situations and claimed that scheduling takes an important role in most manufacturing, production systems, information-processing environments, transportation, distribution setting as well as other types of service industries. Also, there are different forms of objectives such as minimization of mean flow time, completion time of the last task and maximization of the number of tasks completed.

Brucker (2002) stated that scheduling has been the subject of extensive research since the early 1950s. The first handbook of scheduling which provided a comprehensive coverage of the most advanced and timely topics in scheduling were written by Leung (2004). He mentioned that the scheduling problem studies were relatively simple and many efficient algorithms have been developed to obtain optimal solutions in the 1950s. Later on, the researchers found that it is difficult to provide efficient algorithms since the problems encountered became more sophisticated. Most of the scheduling problems were shown to be NP-hard in the 1970s. In the 1980s, there are several different directions in academia and industry. Now, there is an astounding body of knowledge in scheduling problems. Brucker (2002) also pointed out that much of the scheduling problem was concerned with the analysis of single-machine systems, parallel-machines systems and shop problems in the early time. Later on, more complex machine scheduling situations has been started to be studied. Recently, more and more resource-constrained project scheduling problem has been explored. Besides, Ernst et al. (2004) indicated that since business becomes more service oriented and cost sensitive in a global environment, manpower scheduling has become increasingly important.

2.1 Manpower Scheduling

Ernst et al. (2004) believed that "personnel scheduling is the process of constructing work timetables for staff so that an organization can satisfy the demand for its goods or services". Manpower Scheduling involves determining the number of staff. Bailey et al. (1995) pointed out that a manpower scheduling algorithm is then used to determine the number of workers assigned needed to satisfy the demand. Since different staff has different skills or qualification, manpower scheduling also need to meet the service requirement. According to Lau (1996), "manpower scheduling is concerned with the scheduling of manpower resources to meet temporal operational requirements in ways that satisfy the goals and policies imposed by the management, labor union and the government". It is a critical management activity in service organizations since they need to operate 24 hours and hence the workers are scheduled to work on multiple shifts. The scheduling of nurses in hospitals, ground crews in airports, and operators in telephone companies are the examples. Also, Glover & McMillan (1986) provided a good survey of the common manpower scheduling problems faced by industry today.

For the crew scheduling problem, Souai & Teghem (2009) and Chang (2002) also mentioned the stages of solving this problem. Both of them believed that the air crew scheduling problem is typically solved in two different stages. They are crew pairing and the crew rostering problems. The purpose of these classifications is to reduce the computational complexity. Crew pairing problem is to form a set of rotations, so that each flight segment or leg is covered at least once and the total cost is minimized. Besides, crew rostering problem is to construct personalized schedules for airline crew members. That means it is a further allocation to individual crew. There are two ways for allocation, namely the bidding system and the equitability system. In the bidding system, the senior crews could bid his preferred rotation in order to build their personalized schedule. In the equitability system, crew are assigned duties based on the equitability principle, trip preferences, vacation preference, crew requests, flight hours, duty days, layover days, vacation days, duty numbers, etc. Regarding Souai & Teghem (2009), the following Figure 1 illustrates the decomposed airline crew scheduling process.

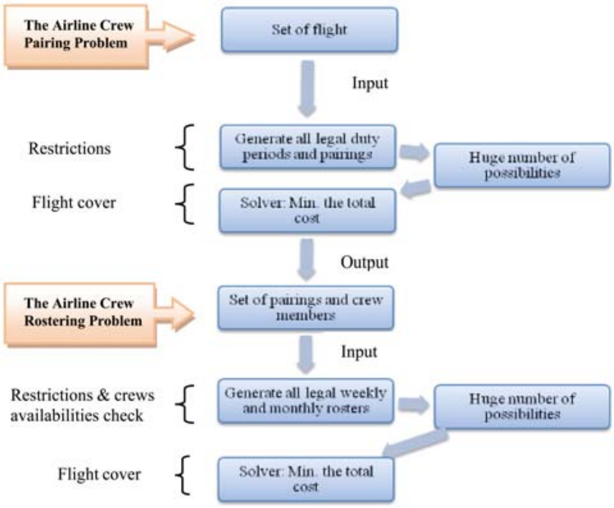

Fig. 1. The illustration of airline crew scheduling process by Souai & Teghem (2009)

2.2 Types of Manpower Scheduling Problems

According to Morris & Showalter (1983), manpower scheduling problems have been researched and classified as shift scheduling, day-off scheduling and tour scheduling problems. If organizations need to determine which eight-hour shift the employees should be worked in a day, shift scheduling problems arise. Next, if organizations need to determine which two days of a week the employees should be assigned to be off-duty, then this should be day-off scheduling problems. And the last one is tour scheduling problems. This problem determines daily shift and days-off schedules simultaneously. That means shift and days-off scheduling problems are the sub-problems of a tour scheduling problem. On the other hand, Beasley & Cao (1996) indicated that personnel scheduling problems can be classified into three types. They are airline crew scheduling, mass transit crew scheduling and generic crew scheduling problems.

2.3 Existing Classification in Solving Manpower Scheduling Problems

Tien & Kamiyama (1982) proposed a framework for solving manpower scheduling problem in three main stages. They are allocation, off day scheduling and shift assignment. First of all, allocation means computing the demands. In this stage, the number of workers needed for each shift in each day needed to determined, so that the temporal requirements can be met. Also, is included determines the level of employment such as the minimum number of workers needed to fulfill demands over the entire planning period is included in this stage. The next stage is off day scheduling. It is concerned with assigning off days on the schedule subject to off day and work stretch constraints. And the last stage is shift assignment. It completes the schedule by assigning shifts to the schedule subject to demands and the shift assignment constraints.

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2.4 Methods for Solving Scheduling Problems

Scheduling problems always been solved by approximation methods, likes integer programming, branch-and-bound, dynamic programming, simulated annealing method, goal programming, genetic algorithm and integer programming.

2.5 Integer Programming

On the other hands, many researchers have solved scheduling problems using integer programming. For example, Mason et al. (1998) formulated the staffing requirements as the input to an integer programming model for seeking an optimal solution of the full-time and part-time staff to each period of the working day. Moreover, three integer programming formulations are presented and different properties of the problem were discussed in Haghani & Shafahi (2002). All of the formulations in their paper are based on integer programming and some of them used the conventional branch and bound procedure for integer programming. That can be exploited for devising quick and near optimal heuristic solution algorithms. Besides, the model in Yan et al. (2004) is formulated as a mixed integer program which is characterized as NP-hard. They have developed a heuristic algorithm to solve the problem as the problem size of the proposed model was huge. Using this approach, the results they obtained can satisfy all the requirements and the demands in each time slot. In 1976, Egan et al. proposed an experimental method for scheduling the necessary maintenance activities on generation units. This problem is used integer programming and they developed a method which is based on the branch-and-bound technique. The method can consider complex constraints and apply to different kinds of objective functions. The paper of Sawik (2010) presented a time-indexed integer programming formulation for scheduling dependent jobs executed by a team of workers in a contaminated area. The problem solved by Sawik was modeled as an NP-hard problem of scheduling and a time-indexed integer programming formulation is proposed with binary assignment variables capable of making a joint decision on assignment, sequencing and timing of jobs. Moreover, Sawik mentioned that the proposed integer programming approach can be applied for solving different classes of scheduling problems with start time dependent processing times.

Nevertheless, the method of integer programming forms disadvantages. Firstly, round-off errors may cause problem when the algorithm is implemented on digital computer. Also, if the optimal solution cannot be reached, the solution will remain infeasible. That means that there will be no solution if the calculations need to be stopped prematurely as the limitations of budget or time (2010). Next, memory and solution time may rise exponentially if adding more integer variables. Even with highly sophisticated algorithms and modern supercomputers, they still have never sought optimal solution when the models have a few hundred integer variables (2010).

2.6 Goal Programming

Many researchers have developed many approaches for scheduling problems. For example, Chu (2007) found that goal programming (GP) is extremely useful for generating shift duties of fixed length. The result showed that it is good for crew scheduling as it can satisfy the working conditions and minimize idle shifts. This method is significant improved over existing manual staff assignment and it can improve future planning on the staffing level. However, GP requires the decision maker to specify fairly detailed of priority information about the levels and the importance of goals in the form of weights. Also, in many complex problems especially in the real situation, it is difficult or even impossible for the decision maker to provide the precise information required by this method. They found that they cannot obtain meaningful preference weights on a main scale although it is relatively easy to specify ordinal rankings for goals. Also, if the goals are unrelated to each other, these difficulties are aggravated further more.

3. Model Formulation

The formulation of the model is formulated according to the business nature of the studied company and is modified based on Haghani & Shafahi (2002). The notation would be defined as the following:

<u>*Notation*</u>

F Number of flights (f = 1 … F)

T Number of unit maintenance time slots (t = 1 … T, each time slot is 2 hours)

G Total number of maintenance groups (g = 1…G)

t^f The time required to perform maintenance for each flight f

t_1^f The earliest time slot for starting inspection for flight f

t_2^f The latest time slot for starting inspection for flight f

Decision variables:

K(t) is a matrix for each time period t which indicated that whether a particular inspection can be performed in a maintenance group. The elements of K (t) are defined as follows:

$$K_g^f(t) = \begin{cases} 1 & \text{If flight f can be accomplished in group g at time t} \\ 0 & \text{Otherwise} \end{cases}$$

Group g has the license of flight f:

$$L_g^f = \begin{cases} 1 & \text{If group g has the license of flight f} \\ 0 & \text{Otherwise} \end{cases}$$

$Y_g^f(t)$ is a matrix for each time period t which indicted that whether the inspection is working on flight f.

The elements of Y_g^f (t) are defined as follows:

$$Y_g^f(t) = \begin{cases} 1 & \text{If group g inspect flight f at time t} \\ 0 & \text{Otherwise} \end{cases}$$

Objection Function:

The objective function is to balance the workload σ_g of each maintenance group. That means the variation of the total number of working time in each maintenance group should be minimized.

$$\mu_g = \frac{\sum_{f=1}^{F} \sum_{t=1}^{T} Y_g^f(t)}{T}$$

$$\sigma_g = \sqrt{\frac{\sum_{f=1}^{F} \sum_{t=1}^{T} (Y_g^f(t) - \mu_g)}{T}}$$

$$\text{MinZ} = \sum_{g=1}^{G} \sigma_g$$

Constraints:

1. Inspection should be started for each flight during its required time interval for that type of maintenance.

$$\sum_{t=Max(T,t_1^f)}^{Min(T,t_2^f)} t_1^f = 1 \text{ where f = 1…F.}$$

2. Every flight must need to be inspected exactly 1 time which is two hours. Also, there is just one maintenance group allocated to perform inspection flight f during time period t.

$$\sum_{g=1}^{G} \sum_{t=t_1^f}^{t_2^f} Y_g^f(t) = 1 \text{ (for all f)}$$

3. A maintenance group can only perform the inspection with the corresponding aircraft licenses.

$$\sum_{t=1}^{T}\sum_{g=1}^{G}\sum_{f=1}^{f}\left[L_g^f - K_g^f\right]^2 = 0$$

4. A maintenance group with the corresponding aircraft license can only provide maintenance service for one flight at a time.

$$\sum_{f=1}^{F} Y_g^f(t) \le 1 \quad \text{(for all g and t)}$$

$$K_g^f(t) - Y_g^f(t) \ge 0 \quad \text{(for all g, t and f)}$$

4. Methodology

This paper proposed to apply Excel Solver to solve the problem. A case study will be used for illustration and demonstration of the methodology. For illustration, a simplified modified version of flights information is used. Suppose there are 68 flights in shift 1 and the information are shown in Table 1 below.

To assign flights to the maintenance groups according to the time constraints and still fulfill the aircraft licenses requirement, Microsoft Excel Solver would be used for solving the integer programming.

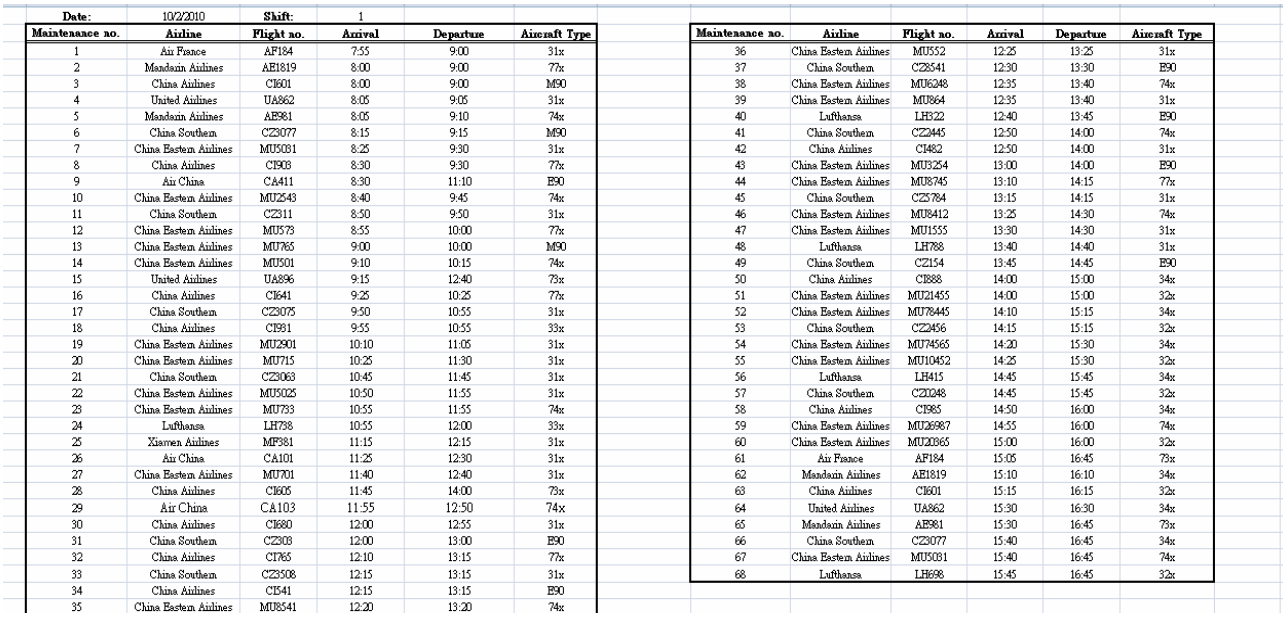
Solver is part of a suite of commands sometimes called what-if analysis tools which is a process of changing the values in cells to see how those changes affect the outcome of formulas on the worksheet. With Solver, an optimal value can be found for a formula in the target cell on a worksheet. Solver works with a group of cells that are related, either directly or indirectly, to the formula in the target cell. Also, solver adjusts the values in the changing cells which specified (adjustable cells) to produce the result you specify from the target cell formula. Constraints which are the limitations placed on a Solver problem and can be applied to adjustable cells; the target cell or other cells that are directly or indirectly related to the target cell, to restrict the values Solver can use in the model and the constraints can refer to other cells that affect the target cell formula.

As shown in Figure 2, the objective function is to balance the workload of each maintenance groups. Therefore, The function STDEV ($E$75, $I$75, $M$75) would be used for calculate the standard deviation of the total number of inspection time in each group. All variables are binary numbers. That means if it is “1”, the group would inspect the corresponding flight. Figure 3 used to illustrate the constraints. The flights must inspect once while each group cannot inspect more than 1 flight in the same time slot is illustrated in Figure 4. In order to ensure that all the flights can be inspected by the groups with the corresponding aircraft license, all the variables that become 1 must be available no matter in time constraints and the licensing factor as in Figure 5.

5. Results and Discussion

The results of this project can be summarized in the below Table 2.

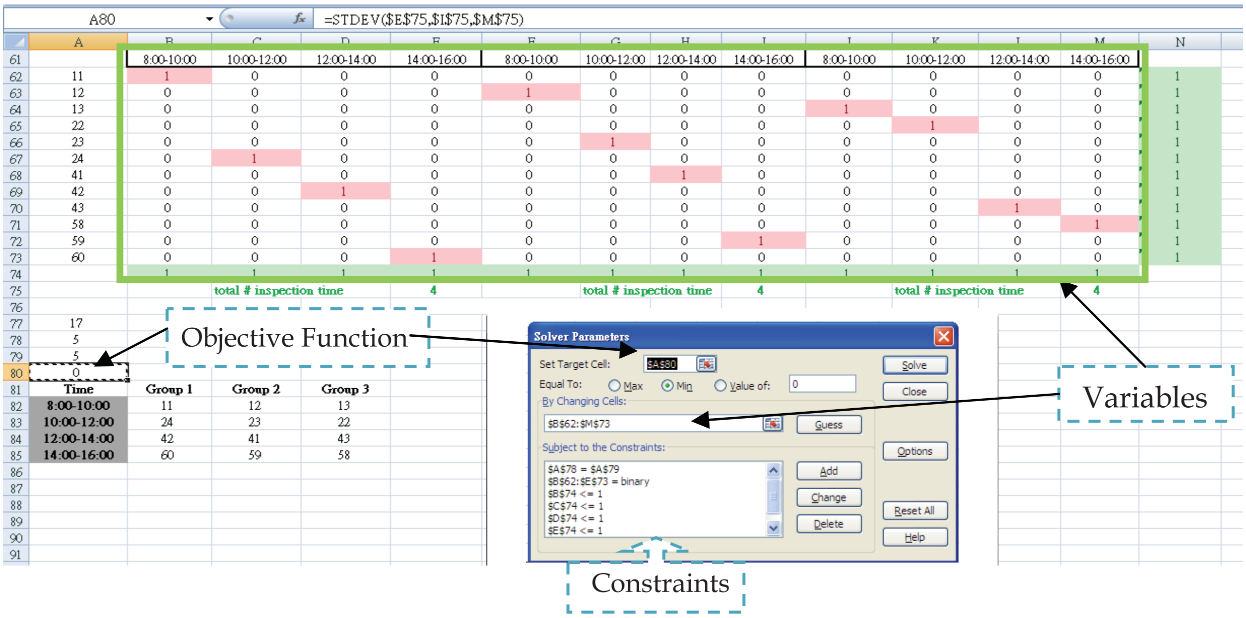
After reviewing all the results, all the cases can be obtained optimal solution. Although there are some variables that cannot become binary number, optimal solution is reached since the workload of each group is balanced and all the constraints are fulfilled after rounding up. Moreover, the computation time is reasonable and acceptable since the total computation time of a shift is only 53 sec.



Date: 10/2/2010 **Shift:** 1

Maintenance no.	Airline	Flight no.	Arrival	Departure	Aircraft Type
1	Air France	AF184	7:55	9:00	31x
2	Mandarin Airlines	AE1819	8:00	9:00	77x
3	China Airlines	CI601	8:00	9:00	M90
4	United Airlines	UA862	8:05	9:05	31x
5	Mandarin Airlines	AE981	8:05	9:10	74x
6	China Southern	CZ3077	8:15	9:15	M90
7	China Eastern Airlines	MU5031	8:25	9:30	31x
8	China Airlines	CI903	8:30	9:30	77x
9	Air China	CA411	8:30	11:10	E90
10	China Eastern Airlines	MU2543	8:40	9:45	74x
11	China Southern	CZ311	8:50	9:50	31x
12	China Eastern Airlines	MU573	8:55	10:00	77x
13	China Eastern Airlines	MU765	9:00	10:00	M90
14	China Eastern Airlines	MU501	9:10	10:15	74x
15	United Airlines	UA896	9:15	12:40	73x
16	China Airlines	CI641	9:25	10:25	77x
17	China Southern	CZ3075	9:50	10:55	31x
18	China Airlines	CI931	9:55	10:55	33x
19	China Eastern Airlines	MU2901	10:10	11:05	31x
20	China Eastern Airlines	MU715	10:25	11:30	31x
21	China Southern	CZ3063	10:45	11:45	31x
22	China Eastern Airlines	MU5025	10:50	11:55	31x
23	China Eastern Airlines	MU733	10:55	11:55	74x
24	Lufthansa	LH738	10:55	12:00	33x
25	Xiamen Airlines	MF381	11:15	12:15	31x
26	Air China	CA101	11:25	12:30	31x
27	China Eastern Airlines	MU701	11:40	12:40	31x
28	China Airlines	CI605	11:45	14:00	73x
29	Air China	CA103	11:55	12:50	74x
30	China Airlines	CI680	12:00	12:55	31x
31	China Southern	CZ303	12:00	13:00	E90
32	China Airlines	CI765	12:10	13:15	77x
33	China Southern	CZ3508	12:15	13:15	31x
34	China Airlines	CI541	12:15	13:15	E90
35	China Eastern Airlines	MU8541	12:20	13:20	74x
36	China Eastern Airlines	MU552	12:25	13:25	31x
37	China Southern	CZ8541	12:30	13:30	E90
38	China Eastern Airlines	MU6248	12:35	13:40	74x
39	China Eastern Airlines	MU864	12:35	13:40	31x
40	Lufthansa	LH322	12:40	13:45	E90
41	China Southern	CZ2445	12:50	14:00	74x
42	China Airlines	CI482	12:50	14:00	31x
43	China Eastern Airlines	MU3254	13:00	14:00	E90
44	China Eastern Airlines	MU8745	13:10	14:15	77x
45	China Southern	CZ5784	13:15	14:15	31x
46	China Eastern Airlines	MU8412	13:25	14:30	74x
47	China Eastern Airlines	MU1555	13:30	14:30	31x
48	Lufthansa	LH788	13:40	14:40	31x
49	China Southern	CZ154	13:45	14:45	E90
50	China Airlines	CI888	14:00	15:00	34x
51	China Eastern Airlines	MU21455	14:00	15:00	32x
52	China Eastern Airlines	MU78445	14:10	15:15	34x
53	China Southern	CZ2456	14:15	15:15	32x
54	China Eastern Airlines	MU74565	14:20	15:30	34x
55	China Eastern Airlines	MU10452	14:25	15:30	32x
56	Lufthansa	LH415	14:45	15:45	34x
57	China Southern	CZ0248	14:45	15:45	32x
58	China Airlines	CI985	14:50	16:00	34x
59	China Eastern Airlines	MU26987	14:55	16:00	74x
60	China Eastern Airlines	MU20365	15:00	16:00	32x
61	Air France	AF184	15:05	16:45	73x
62	Mandarin Airlines	AE1819	15:10	16:10	34x
63	China Airlines	CI601	15:15	16:15	32x
64	United Airlines	UA862	15:30	16:30	34x
65	Mandarin Airlines	AE981	15:30	16:45	73x
66	China Southern	CZ3077	15:40	16:45	34x
67	China Eastern Airlines	MU5031	15:40	16:45	74x
68	Lufthansa	LH698	15:45	16:45	32x

Table 1. The flight information of the case study.



A80 =STDEV($E$75,$I$75,$M$75)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
61		8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	
62	11	1	0	0	0	0	0	0	0	0	0	0	0	1
63	12	0	0	0	0	1	0	0	0	0	0	0	0	1
64	13	0	0	0	0	0	0	0	0	1	0	0	0	1
65	22	0	0	0	0	0	0	0	0	0	1	0	0	1
66	23	0	0	0	0	0	1	0	0	0	0	0	0	1
67	24	0	1	0	0	0	0	0	0	0	0	0	0	1
68	41	0	0	0	0	0	0	1	0	0	0	0	0	1
69	42	0	0	1	0	0	0	0	0	0	0	0	0	1
70	43	0	0	0	0	0	0	0	0	0	0	1	0	1
71	58	0	0	0	0	0	0	0	0	0	0	0	1	1
72	59	0	0	0	0	0	0	0	1	0	0	0	0	1
73	60	0	0	0	1	0	0	0	0	0	0	0	0	1
74		1	1	1	1	1	1	1	1	1	1	1	1	
75			total # inspection time		4		total # inspection time		4		total # inspection time		4	

	A	B	C	D
77	17			
78	5			
79	5			
80	0			
81	Time	Group 1	Group 2	Group 3
82	8:00-10:00	11	12	13
83	10:00-12:00	24	23	22
84	12:00-14:00	42	41	43
85	14:00-16:00	60	59	58

Solver Parameters

Set Target Cell: $A$80

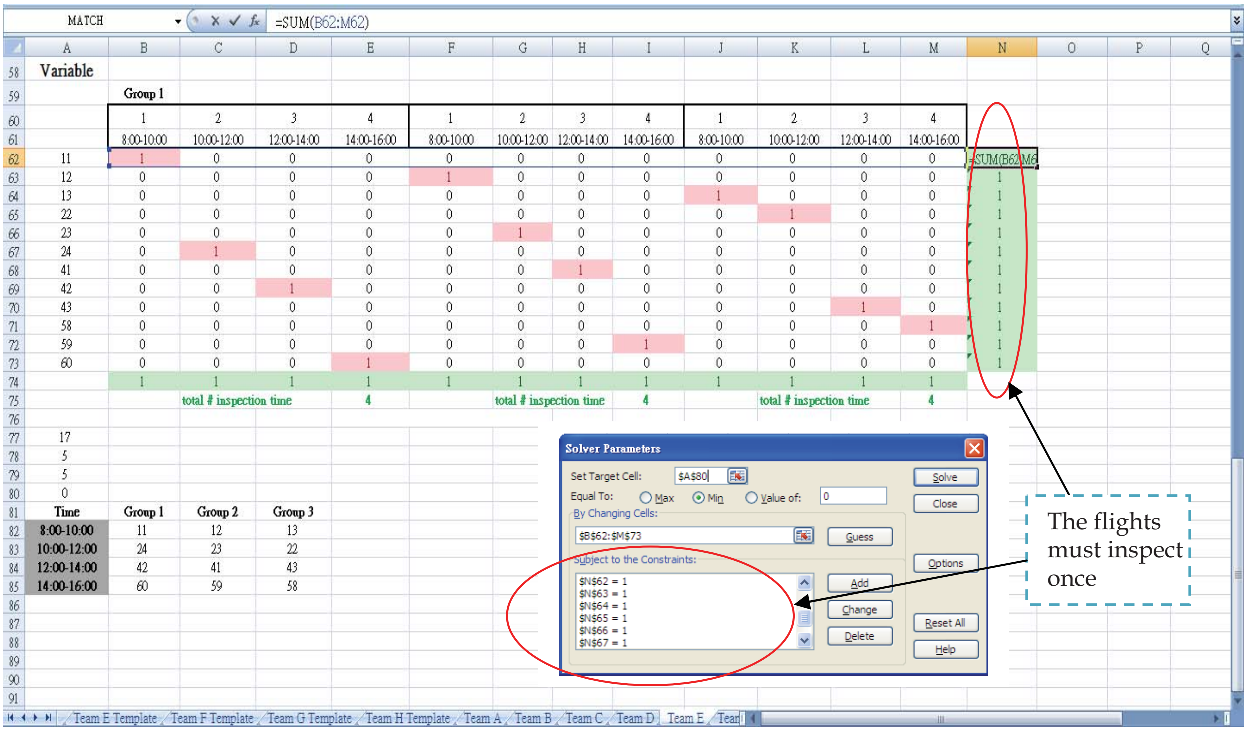
Equal To: ○ Max ● Min ○ Value of: 0

By Changing Cells: $B$62:$M$73

Subject to the Constraints:

$A$78 = $A$79
$B$62:$E$73 = binary
$B$74 <= 1
$C$74 <= 1
$D$74 <= 1
$E$74 <= 1

Fig. 2. Illustration of the objection function



MATCH =SUM(B62:M62)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
58	Variable													
59		Group 1												
60		1	2	3	4	1	2	3	4	1	2	3	4	
61		8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	
62	11	1	0	0	0	0	0	0	0	0	0	0	0	=SUM(B62:M6
63	12	0	0	0	0	1	0	0	0	0	0	0	0	1
64	13	0	0	0	0	0	0	0	0	1	0	0	0	1
65	22	0	0	0	0	0	0	0	0	0	1	0	0	1
66	23	0	0	0	0	0	1	0	0	0	0	0	0	1
67	24	0	1	0	0	0	0	0	0	0	0	0	0	1
68	41	0	0	0	0	0	0	1	0	0	0	0	0	1
69	42	0	0	1	0	0	0	0	0	0	0	0	0	1
70	43	0	0	0	0	0	0	0	0	0	0	1	0	1
71	58	0	0	0	0	0	0	0	0	0	0	0	1	1
72	59	0	0	0	0	0	0	0	1	0	0	0	0	1
73	60	0	0	0	1	0	0	0	0	0	0	0	0	1
74		1	1	1	1	1	1	1	1	1	1	1	1	
75			total # inspection time		4		total # inspection time		4		total # inspection time		4	

	A	B	C	D
77	17			
78	5			
79	5			
80	0			
81	Time	Group 1	Group 2	Group 3
82	8:00-10:00	11	12	13
83	10:00-12:00	24	23	22
84	12:00-14:00	42	41	43
85	14:00-16:00	60	59	58

Solver Parameters

Set Target Cell: $A$80

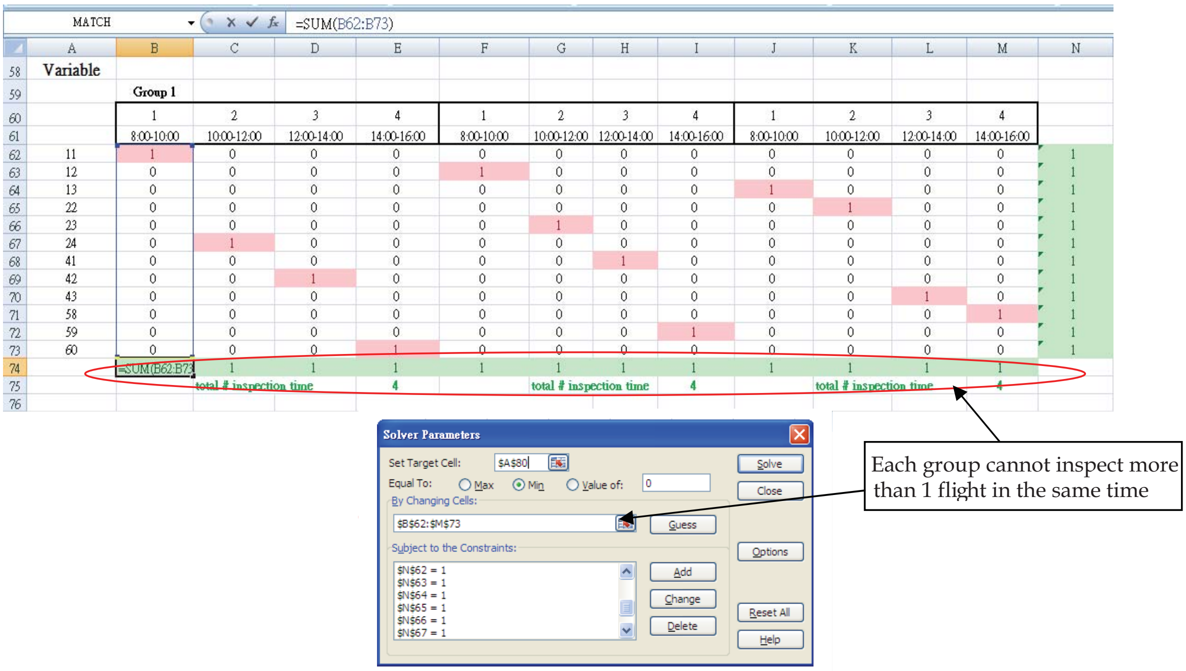
Equal To: ○ Max ● Min ○ Value of: 0

By Changing Cells: $B$62:$M$73

Subject to the Constraints:

$N$62 = 1
$N$63 = 1
$N$64 = 1
$N$65 = 1
$N$66 = 1
$N$67 = 1

Fig. 3. The constraints about the flights must inspect once.



MATCH =SUM(B62:B73)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
58	Variable													
59		Group 1												
60		1	2	3	4	1	2	3	4	1	2	3	4	
61		8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	
62	11	1	0	0	0	0	0	0	0	0	0	0	0	1
63	12	0	0	0	0	1	0	0	0	0	0	0	0	1
64	13	0	0	0	0	0	0	0	0	1	0	0	0	1
65	22	0	0	0	0	0	0	0	0	0	1	0	0	1
66	23	0	0	0	0	0	1	0	0	0	0	0	0	1
67	24	0	1	0	0	0	0	0	0	0	0	0	0	1
68	41	0	0	0	0	0	0	1	0	0	0	0	0	1
69	42	0	0	1	0	0	0	0	0	0	0	0	0	1
70	43	0	0	0	0	0	0	0	0	0	0	1	0	1
71	58	0	0	0	0	0	0	0	0	0	0	0	1	1
72	59	0	0	0	0	0	0	0	1	0	0	0	0	1
73	60	0	0	0	1	0	0	0	0	0	0	0	0	1
74		=SUM(B62:B73	1	1	1	1	1	1	1	1	1	1	1	
75			total # inspection time		4		total # inspection time		4		total # inspection time		4	
76														

Solver Parameters

Set Target Cell: $A$80

Equal To: ○ Max ● Min ○ Value of: 0

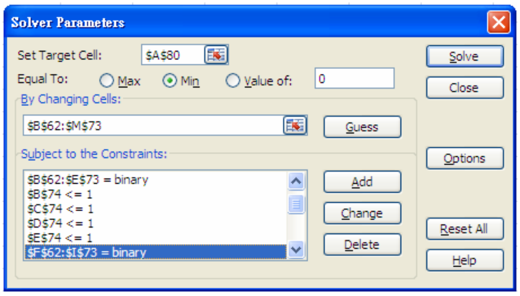
By Changing Cells: $B$62:$M$73

Subject to the Constraints:

$N$62 = 1
$N$63 = 1
$N$64 = 1
$N$65 = 1
$N$66 = 1
$N$67 = 1

Each group cannot inspect more than 1 flight in the same time

Fig. 4. The constraints about Each group cannot inspect more than 1 flight in the same time slot.



Solver Parameters

Set Target Cell: $A$80

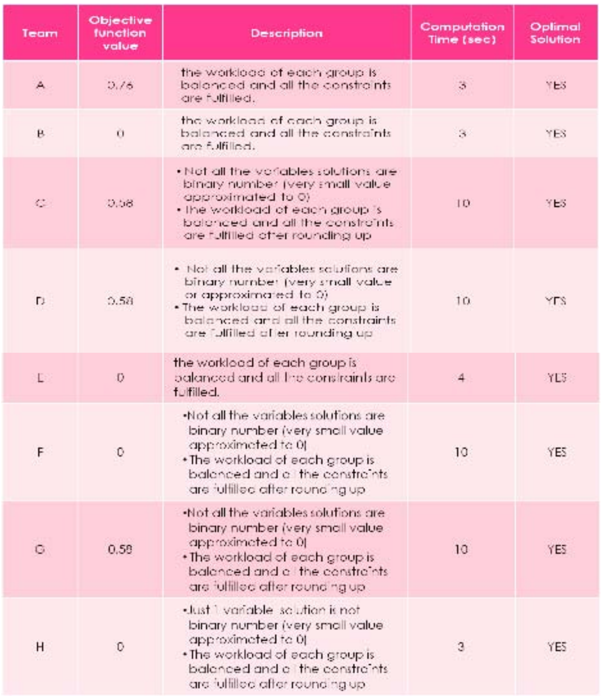
Equal To: ○ Max ● Min ○ Value of: 0

By Changing Cells: $B$62:$M$73

Subject to the Constraints:

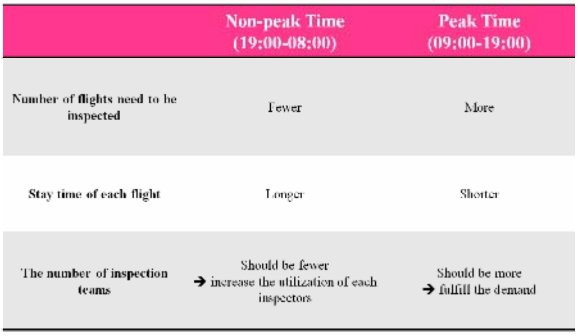
$B$62:$E$73 = binary
$B$74 <= 1
$C$74 <= 1
$D$74 <= 1
$E$74 <= 1
$F$62:$I$73 = binary

Fig. 5. The constraint about fulfilment of the time constraints and the licensing factor



Team	Objective function value	Description	Computation Time (sec)	Optimal Solution
A	0.76	the workload of each group is balanced and all the constraints are fulfilled.	3	YES
B	0	the workload of each group is balanced and all the constraints are fulfilled.	3	YES
C	0.58	• Not all the variables solutions are binary number (very small value approximated to 0) • The workload of each group is balanced and all the constraints are fulfilled after rounding up	10	YES
D	0.58	• Not all the variables solutions are binary number (very small value or approximated to 0) • The workload of each group is balanced and all the constraints are fulfilled after rounding up	10	YES
E	0	the workload of each group is balanced and all the constraints are fulfilled.	4	YES
F	0	•Not all the variables solutions are binary number (very small value approximated to 0) • The workload of each group is balanced and all the constraints are fulfilled after rounding up	10	YES
G	0.58	•Not all the variables solutions are binary number (very small value approximated to 0) • The workload of each group is balanced and all the constraints are fulfilled after rounding up	10	YES
H	0	•Just 1 variable solution is not binary number (very small value approximated to 0) • The workload of each group is balanced and all the constraints are fulfilled after rounding up	3	YES

Table 2. The summarized results of each team.



	Non-peak Time (19:00-08:00)	Peak Time (09:00-19:00)
Number of flights need to be inspected	Fewer	More
Stay time of each flight	Longer	Shorter
The number of inspection teams	Should be fewer → increase the utilization of each inspectors	Should be more → fulfill the demand

Table 3. The comparison of non-peak and peak time.

The maintenance personnel allocation would be different in peak and non-peak time and it can be shown in Table 3. Comparing with the peak and non-peak time, since the number of flights which need to be inspected would be reduced and the staying time of each flight is longer, the number of teams should be reduced in order to increase the utilization of each inspector. On the other hand, the number of flights which need to be inspected would be more since more than 1 flight would need to be inspected at the same time. Furthermore, the staying time of each flight would be shorter as most of the flights are only stay for around1 hour (urgent cases). Therefore, the number of inspection teams should be more in order to fulfill the demand.

6. Conclusion

This paper proposed an optimization approach to improve the manual maintenance scheduling process. Since scheduling would split up into different stages studied in the literature, different mathematical techniques should be adopted to cater for their own problem characteristics. There are 3 stages for solving the aircraft maintenance scheduling problem. They are initial maintenance demand schedule, the maintenance pairing and the maintenance groups assignment in a sequential way. In the first stage, all maintenance requests is aggregated and then create an initial schedule based on the flight timetable and possible maintenance demands. The input to the second stage is the estimated maintenance manpower demand generated from stage 1. Since maintenance groups can only work on the aircraft for which they with the corresponding aircraft licenses for permission to checking, repairing and inspecting, the aim of the second stage is to find out all the possibilities that the flights can be inspected by which maintenance groups. Finally, the last stage is to assign flights to the maintenance groups according to the time constraints and still satisfying certificate requirements. The major constraints are modeled in an Integer Programming model in this stage of the proposed methodology. Apart from the constraints, the objective is to balance the workload of each group.

Using the proposed methodology, although there are some variables that cannot become binary number, optimal solution is reached since the workload of each group is balanced and all the constraints are fulfilled after rounding up and the computation time is acceptable. One major contribution to aircraft maintenance scheduling is to provide a novel integer formation for a combined scheduling and assignment consideration, which has little been tackled in the literature. Also, a scheduling system is devised using Excel Solver in order to provide a user friendly and reduce the manual process. Comparing with the manual process, this approach can help manual decision making process and the computation time is reasonable. Moreover, the results obtained can be easy and clear for people to realize and read. Moreover, the proposed methodology is elaborate to reduce the complication and difficulties.

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