OPTIMAL CREW PLANNING THROUGH VARIABLE CAPACITY ASSIGNMENT FOR COMMERCIAL AIRCRAFT FLIGHT LINE MAINTENANCE

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Abstract - Crew planning and scheduling is researched intensively as it affects the aviation operational costs substantially. Maintenance crew planning is an integral part of the same where less emphasis paid compared to flying crew scheduling. This paper presents an optimal framework for commercial aircraft flight line maintenance labour planning. A mathematical model combined with a management framework named "variable crew assignment" is used to discover optimal crew combinations, shift sizes and shift starting times. Maintenance workforce is used as the main variable and is applied variably to suit the fluctuating demand. The framework is articulated in such a way that it can accommodate different types of aircraft with different maintenance certifications. This optimal framework would enable aircraft maintenance planners to identify most appropriate combinations of crew sizes, shift patterns and respective shift staring times to fulfil varying maintenance demand.

Keywords - Manpower planning, Integer Programming, Variable crew assignment.

I. INTRODUCTION

The contemporary aviation operations have become increasingly complex and dynamic in nature due to the rapid growth of global air travel demand. Attaining optimal productivity through limited resources has become extremely demanding (Jamili, 2017). In a managerial perspective, controlling crew costs are more feasible and practical. Periyar Selvam et al. (2013) describe airline crew cost to be the second largest cost contributor of operational budget. An optimal crew schedule not only enhances the cost benefits but also improves safety and reduces operational delays as well. Gill and Shergill (2004) reveals that more than fifty percent of departure delays are due to operational shortcomings including maintenance.

Unlike the other industries, aircraft maintenance requires highly skilled technicians, special equipment and complicated procedures. Short-term layover maintenance, which is also called flight line maintenance hereafter, is executed at the parking terminals during an aircraft's arrival and departure time interval. Flight line maintenance crew planning is an extremely tough task as it is inhibited by many variables like timetables, personal commitments, labour regulations, and infrastructure capacity limitations. The timetable punctuality alone induces a huge pressure on maintenance schedulers demanding meticulously planned schedules to prevent delays and to ensure optimal resource utilization. In addition, the requirement of maintenance certification further exaggerates the planning complexity. An approved maintenance type certification is vital for every crewmember who conduct aircraft maintenance. This is a strictly observed regulation throughout the industry with zero tolerance.

A. Literature review

Airline crew scheduling has undergone extensive research during past few decades in search of optimal solutions (Ernst, Jiang, Krishnamoorthy, Owens, & Sier, 2004). Due to cost constraints involved, even a minor percentile

saving leads to considerable cost reductions annually (Sasaki and Nishi 2016). Scientific personal scheduling literature trace back to Edie (1954) and Dantzig (1954) where they enumerate a toll booth scheduling problem mathematically.

According to Gopalakrishnan & Johnson (2005) , airline staffing and scheduling problem covers a large span of complexities ranging from aircraft routing, assignment, scheduling, crew rostering, scheduling and assignment. Lavoie et al. (1988) formulate a large-scale set covering problem with many columns where each represents a valid crew pairing. Based on generalized linear programming they propose a continuous relaxation to solve a scenario inclusive of 329 segments of flight legs through column generation method. Ryan (1992) introduces a generalized set partitioning model for aircrew scheduling involving more than 650 constraints and 200,000 binary variables. Yan & Chang (2002) discus cockpit crew scheduling in specific as the salary and remuneration of the pilots covers a significant portion of the overall crew costs. They formulate a set partitioning model and solve it through column generation. Deng & Lin (2011) use ant-colony optimization based algorhythem to solve airline crew scheduling problem with numerous enumerations. Mercier & Soumis (2007) solve the optimal crew-scheduling problem along with aircraft routing and retiming. These three areas are interdependent one each other and linking these constraints together ensures same schedule is used for both aircraft touting and crew scheduling. Kasirzadeh, Saddoune, & Soumis (2014) presents a detailed review on crew scheduling models and methods discussed since year 2014. As highlighted above, a majority of the of the crew scheduling research are allied with complex mathematics and heuristics mainly due to the complex nature (Barnhart & Cohn, 2004).

As per Medard and Sawhney (2007) a majority of the airline crew scheduling problems focus on flying crew and the emphasis applied on ground maintenance crew scheduling is relatively less. The problem setting of the two types are also diverse in nature due to several reasons. Unlike flying crew (inclusive of cockpit and cabin crew), the ground maintenance crew is stationed at the airline's base airport and do not move from one location to another. Further, the requirement of maintenance certification distinguishes the maintenance crew from the flying element. Hence, the general crew scheduling techniques needs adjustments before being applied to ground maintenance crew.

 Van Den Bergh et al. (2013) analyse several hard and soft constraints in their three-stage methodology such as legal restrictions, personal preferences and coverage constraints. They first formulate personal rosters for line maintenance using mathematical programming and then second stage evaluates the formulated rosters through discrete event simulation. The third sage ranks the most optimal rosters through data envelopment analysis and the model is validated through a real time case study. Alfares (1999) presents several findings in his study including cyclic roster change from five working days to seven working days and usage of some management strategies involving numeral flexibility, temporal flexibility and functional flexibility. Numeral flexibility proposes use of part-time employees and variable maintenance squad sizes while temporal flexibility proposes different shift starting times.

HoIver, Kasirzadeh et al. (2014), Gopalakrishnan and Johnson (2005), Barnhart and Cohn (2004) argues that mathematical modelling and complex simulations alone do not present the most feasible solutions for crew capacity planning problems. They support the argument with several examples. First, crew scheduling is a combination of crew pairing and crew assignment even though it is addressed unitedly in most literature. Second, many objectives and constraints in popular solution algorhythems are treated approximately due to large size of the problem, complex aviation safety agreements and various contractual rules.

B. Outline

The outline of this paper flows as below. Section 2 describe the problem setting and introduce the concept of "variable crew assignment" where I incorporate a mathematical model for solution. The following sections discuss the initial stage of data analysis and illustrate how to downsize the problem for ease of computation. Section 4 is the case study through which I try to test the model. Section 5 presents the overall conclusion.
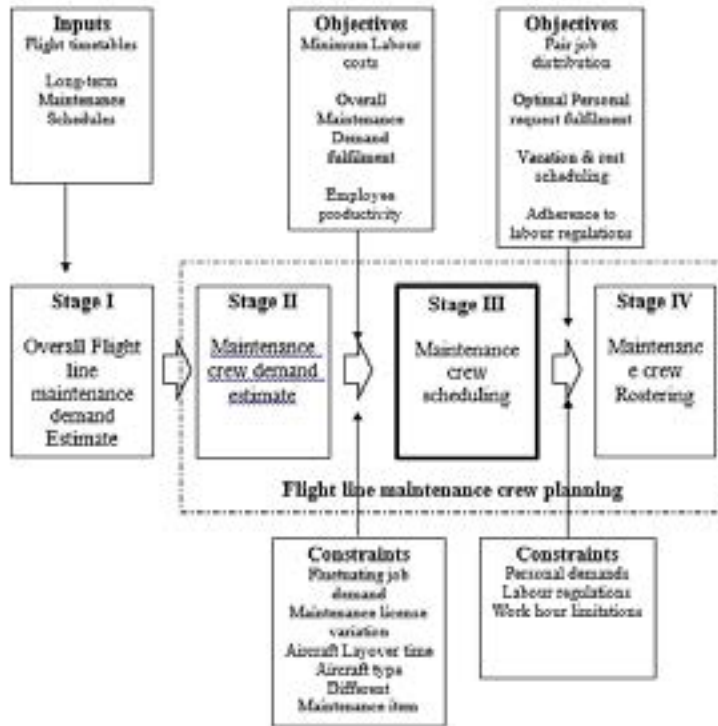
Figure 1. General Research Model

II. PROBLEM DEFINITION AND MODEL FORMULATION

Even though the number of members for a job squad is not assigned, I observed the average number of members in a squad are four in most of the instances. The day is divided to three eight-hour shifts and the excess demand is handled through overtime shifts of eight hours. However, as per the aviation regulations if a crewmember works two eight-hour shifts consecutively it raises several concerns. First, continuous work indulgence of 16 hours is beyond the authorized threshold of 12 hours. Second, the employees is entitled for a 48 hours shift off which deprives his service for almost two days.

C. Variable Crew Assignment Strategy

In view of addressing the above disadvantages, I introduce an innovative concept of varying labor utilization both numerically and duration wise. It is named as "Variable Crew Assignment" (VCA) strategy and will produce better solution for optimal crew scheduling when combined with durable maintenance workload forecasting. First, I formulate a common platform for the VCA strategy and incorporate it with a mixed integer linear programming (MILP) mathematical model. Then I move to validate the model through a case study regarding the sample airline "S". In this model, I try to vary the maintenance labour capacity through three variable channels. They are the number of members in a squad, number of squads in a maintenance group during a specific job duration and the number of shifts a crewmember works.

D. Mathematical Model

A mathematical model is formulated using mixed linear integer programming (MILP) incorporating the above VCA strategy. The primary input for the model is different type of maintenance demand $[m_{ia}]$ for different models of aircraft$[A_i]$ in each job duration(n). Flight line maintenance requirement (in terms of man-hours) for maintenance elements(i) of (a) type aircraft is considered (h_{ia}). The three types of maintenance elements are preflight checks, transit checks and the daily checks. The number of aircraft from (a) type is considered as (p_a).
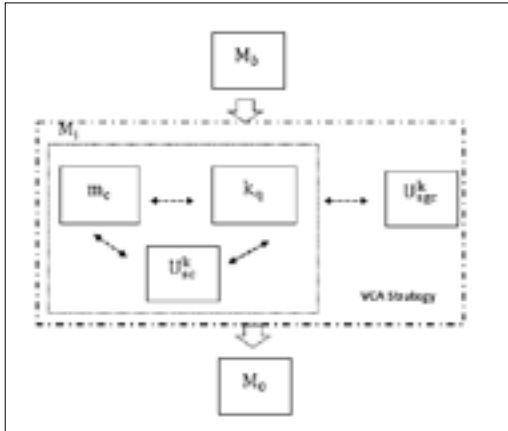
Figure 3. Optimal maintenance crew planning model with intermediate variables

1) Problem Setting

Nomenclature

Algebraic Notations

h_{ia} Maintenance man-hours required for (i) maintenance element of (a) type aircraft

t_a Layover time of (a) type aircraft

G   Set of job-squads in a maintenance group during (k) job duration

g   Number of job-squads in (G) maintenance group during (k) job duration, where (g ∈ G)

C   Set of different job-squad sizes (Number of engineers in a squad) during (k) job duration

c   Number of engineers in a job squad during (k) job duration, where (c ∈ C)

Q   Set of different shift combinations in a job duration.

q   Number of shifts included in (k) job duration starting at (s) shift starting time

A   Set of different aircraft types serviced at (k) job duration

a   A one type of aircraft requiring (i) maintenance element during (k) job duration where (a ∈ A)

k   A job duration with (q) number of shifts

S   Set of shift starting times

s   Shift starting time corresponding to (k) job duration where (s ∈ S)

d   A duration of shift in hours

I   Set of maintenance elements

i   Type of maintenance element required by (a) type aircraft during (k) job duration where (i ∈ I)

D_{ai}^{k} Maintenance manpower demand estimate to service (A) set of (a) type aircraft during (k) job duration

f   Lower bound of the number of type (c) job squads

h   Upper bound of the number of type (c) job squad

α   Lower bound of the number of shifts in (k) job duration

β   Upper bound of the number of shifts in (k) job duration

γ   Lower bound of the number of technicians in (c) type job squad

δ   Upper bound of the number of technicians in (c) type job squad

W   A very large positive value less than (∞) used for the ease of modelling

Z   Objective function, which aims to reduce total manpower utilization while catering optimal customer satisfaction.

Auxiliary Variable

L_{sgc}^{k} Amount of manpower provided by (G) maintenance group who start their duty at (s) starting time of (k) job duration with (q) number of shifts

Decision Variables

m_c Number of technicians in (c) type job squad

k_q Number of shifts in (k) job duration

U_{sgc}^{k} Number of type (c) job squads in group (g) whose duty commences at (s) starting time of (k) job duration

The integer-programming model for minimizing the manpower used for line maintenance through variable crew assignment is as below;

$$\text{Min } Z = \sum_{s \in S} \sum_{g \in G} \sum_{q \in Q} \sum_{c \in C} m_c \, k_q U_{sgc}^k \qquad (1)$$

The objective function; Equation (1), minimize the number of technicians in (c) type job squad, number of shifts in (k) job duration and number of type (c) job squads in group (g) whose duty commences at (s) shift starting time of (k) job duration.

$$\sum_{g \in G} L_{sgq}^k \geq \sum_{a \in A} D_{ai}^k \quad \text{For} \quad \forall g \in G, a \in A \qquad (2)$$

Equation (2); represents that the minimum amount of manpower provided by (G) maintenance group who start their duty at (s) starting time of (k) job duration with (q) number of shifts should be able to cover the maintenance manpower demand estimate to service (A) set of different (a) types of aircraft during (k) job duration.

$$\sum_{c \in C} \sum_{g \in G} m_c U_{sgc}^k \geq \sum_{g \in G} L_{sgq}^k \quad \text{For} \; \forall s \in S, c \in C \qquad (3)$$

Equation (3); represents the amount of workload provided by the total number of technicians in (c) type job squad in group (g) whose duty commences at (s) starting time of (k) job duration, has to be higher than the amount of manpower required by (G) maintenance group who start their duty at (s) starting time of (k) job duration with (q) number of shifts. Here it is to be noted that number of technicians in (c) type job squad in group (g) whose duty commences at (s) starting time of (k) job duration ($\sum_{c \in C} \sum_{g \in G} m_c U_{sgq}^k$) is difficult to be related to maintenance manpower demand estimate to service (A) set of (a) type aircraft during (k) job duration ($\sum_{a \in A} D_{ai}^k$) directly. The auxiliary variable (L_{sgq}^k) representing amount of manpower provided by (G) maintenance group who start their duty at (s) starting time of (k) job duration with (q) number of shifts; along with Equations (2, 3) are designed to facilitate this transformation.

$$\sum_{a \in A} D_{ai}^k \geq \sum_{i \in I} \sum_{a \in A} h_{ia} \quad \text{For} \quad \forall I \in I, a \in A \qquad (4)$$

Equation (4); states that total maintenance manpower supply estimate to service (A) set of (a) type aircraft during (k) job duration should satisfy the total Maintenance man-hours demand for (i) maintenance element of (a) type aircraft.

$$\sum_{a \in A} t_a \geq \sum_{i \in I} \sum_{a \in A} h_{ia} \quad \text{For} \qquad t_a \geq 0 \qquad (5)$$

Equation (5); highlights the cumulative aircraft layover time constraint, where the maintenance man-hours required for (i) maintenance element of(A) set of (a) type aircraft should be less than the cumulative layover time of (A) set of (a) type aircraft.

$$f \leq U_{sgq}^k \leq h \quad \text{For} \qquad f, h \geq 0 \text{ and} \qquad h > f \qquad (6)$$

Equation (6); limits the number of type (c) job squads in group (g) whose duty commences at (s) starting time of (k) job duration to a reasonable range as this is governed by several external factors such as the respective facilities' maintenance capacity, airport slot allocations and different labour regulations.

$$\alpha \leq k_q \leq \beta \qquad \text{For} \qquad \alpha, \beta \geq 0 \text{ and} \qquad \beta > \alpha \qquad (7)$$

Equation (7); limits the number of shifts in (k) job duration to a feasible range as it is governed by several constraints such as the maximum number of hours a technician could work continuously, minimal economic duration of employment for a paid technician and the complexity faced by the maintenance schedule planner.

$$\gamma \leq m_c \leq \delta \quad \text{For } \gamma, \delta \geq 0 \text{ and } \delta > \gamma \qquad (8)$$

Equation (8); limits the number of technicians in (c) type job squad to a feasible range.

$$\sum_{g \in G} \sum_{c \in C} U_{sgc}^k \leq W \qquad (9)$$

$$U_{sgc}^k \geq 0 \; ; \; \text{Where } \forall s \in S, c \in C, g \in G \qquad (10)$$

$$L_{sgq}^k \geq 0 \; ; \; \text{Where } \forall s \in S, a \in A, g \in G \qquad (11)$$

$$m_c, d, n_q, q, p_a, h_{ia} \geq 0 \; ; \; \text{For } m_c, d, n_q, q, p_a \in I \qquad (12)$$

Equations (10, 11, and 12) are the non-negativity constraints.

C. Solution Algorithm

1) Problem size

In order to ascertain the problem size I consider the sample airline "S" where it has six different aircraft types and the planning horizon is a seven-day working Week. I compare two models. The first one is the base model M_b, which represents the present crew scheduling method while the other represent the prospective optimal model M_o, formulated with the variable crew assignment strategy. M_b, does not incorporate any variables, it has three shifts, average four member crews and random maintenance certifications. On contrary M_o incorporates all three variable strategies, where c (number of crew in a job squad) h 5 variables (2,3,4,5,6), and q (number of shifts in job duration) has 2 variables (2,3). The variable number of squads in a work groups depend on the number of aircraft types maintained due to the maintenance certification constraint. Each day has six shifts of four-hour duration. If $G_{x,y}$ means the selection of x items from an array of y items, the possible job squad combinations for six aircraft types would be,

$$G_{1,6} + G_{2,6} + G_{2,6} + G_{4,6} + G_{5,6} + G_{6,6} = 63. \quad (13)$$

As there are five different squad sizes and six different shift starting times U_{sgc}^k will have (7 x 6 x 63 x 5) = 13,230 variables and L_{sgq}^k will have (7 x 6 x 63 x 4) = 10,584 variables. This adds up to 23,814 variables and there are some more related to Equations (2, 3, 4, and 5).

2) Interim problem formulation

Practically, solving a MILP (mixed integer leaner programming) problem of this size is complex and consume extended computational time. Therefore, I reduce the problem scope through several arbitrary iterations. In doing so, I observed the contribution of the variable; "number of aircraft types" expand the number of total variables compared to the other parameters as per Equation (13). For an example if the number of aircraft types are 10 to 12, the number of variable U_{sc}^k will almost double. Hence, I tried to decompose the original objective function as below assuming that the total maintenance demand is for a single aircraft type. Then I redefined the main decision variable as below and as a result, the objective function is modified as per Equation (14) where

model (M_o) has been adapted by removing aircraft type related variables (A) and (a), and maintenance related parameters (G) and (g), which are related to maintenance certification. The formulation of the first sub-problem is as follows:

U_{sc}^k - Represents the number of type (c) job squads whose duty commences at (s) starting time of (k) job duration where the variable number "g" becomes one type.

$$\text{Min } Z = \sum_{s \in S} \sum_{q \in Q} \sum_{c \in C} m_c \, k_q \, U_{sc}^k \quad (14)$$

Here, the number of job squads in a maintenance group will be similar and every member is certified to maintain single aircraft type available, as there are no variations. When analysing carefully, I understood that this is the lower boundary of the original problem even though it is not a feasible solution practically. The following constraints also get relaxed by removing variable g and reduces the number of variables. I call this model M_i or the intermediate model.

$$\sum L_{sq}^k \geq \sum D_j^k \quad \text{For} \quad a \in A \quad (15)$$

Equation (15); represents that the minimum amount of manpower provided by all equivalent (g) squads who start their duty at (s) starting time of (k) job duration with (q) number of shifts should be able to cover the maintenance manpower demand estimate to service all (a) type aircraft during (k) job duration.

$$\sum_{c \in C} m_c U_{sc}^k \geq \sum L_{sq}^k \quad \text{For} \quad \forall s \in S, c \in C \quad (16)$$

Equation (16) ; represents the amount of workload provided by the total number of technicians in (c) type job squad in group (g) whose duty commences at (s) starting time of (k) job duration, has to be higher than the amount of manpower required by (G) maintenance group who start their duty at (s) starting time of (k) job duration with (q) number of shifts.

$$\sum D_j^k \geq \sum_{i \in I} h_i \quad \text{For} \quad \forall I \in I, \quad (17)$$

Equation (17) ; states that total maintenance manpower supply estimate to service all (a) type aircraft during (k) job duration should satisfy the total Maintenance man-hours demand for (i) maintenance element of (a) type aircraft.

$$\sum_a t_a \geq \sum_{|\mathcal{E}|} h_i \quad For \quad t_a \geq 0, \tag{18}$$

Equation (18) ; highlights the cumulative aircraft layover time constraint, where the maintenance man-hours required for (i) maintenance element of(A) set of (a) type aircraft should be less than the cumulative layover time of (A) set of (a) type aircraft.

$$f'' \leq U_{sc}^k \leq h' \quad For\ f'', h' \geq 0 \text{ and } h' > f' \tag{19}$$

$$U_{sc}^k \geq 0\ ; \text{Where } \forall s \in S, c \in C, \tag{20}$$

Equations (19 and 20) are the non-negativity constraints and the revised boundary conditions of U_{sc}^k .

The rest of the equations remain unchanged. The main purpose of this intermediate model is to downsize the problem and to find appropriate number of shifts and the corresponding shift starting times. Then I will fix these optimal values and feed them as input to the main model. It reduce the number of variables related to main objective function and make the solving process easier. This indicate the feasible lower bound of the solution beyond which it will not be feasible to try. It will also reduce the span of probable solutions for the problem.

III. CASE STUDY

Test data collection for the mathematical model validation was done by the flight line maintenance operations of a medium scale South Asian airline with 94 international destinations.

Figure 4. Maintenance manpower demand throughout the day

The computational environment is a ASUS i7 personnel computer. In order to ensure ease of computation, the solution satisfactoriness was set to 10% gap (error margin) from the lower bound obtained by the intermediate modelM_i. Except for few, majority of the problems were solved within the above margin. However if the error margin was downsized, more accurate results would have been achieved in spite of the computational difficulties. The main attributes of the two comparative scenarios are as follows,

Table 1. Main attributes

Attribute	M_b	M_o
Work duration	8 – 16 Hrs	8 – 12 Hrs
People in a Squad	4 (On average)	2,3,4,5,6
Number of Shifts	3	6
Shift Starting times	0000 Hrs, 0800 Hrs, 1600 Hrs	0000Hrs, 0400Hrs, 0800Hrs, 1200Hrs, 1600Hrs, 2000Hrs

Out of the six shifts highlighted in M_o model, not all shits can be accommodated for an optimal solution due to several practical implications. If an optimal solution is found for one shift, the number of working hours per day will be only four hours, which is an underutilization of the labor resource. In the same essence, if I consider 5-6 shifts at a stretch, it is impractical for an employee to work beyond 16 hours continuously and it is against the industry norms. In order to identify the most appropriate shift schedule, I varied the shifts from two to four. The job durations spanned from 8 hours to 16 hours and the starting times Ire as per table 1. The results highlighted three-shift job duration is optimal in terms of man-hours utilization and there was 4.73% difference between the two-shift duration and three-shift duration as per table 2. The optimal shift starting times are 0400 Hrs, 0800 Hrs, 1600 Hrs, 2000Hrs. As per the computational results, shifts starting at 0000Hrs and 1200Hrs indicates infeasible solutions. These findings harmonized with the maintenance demand distribution (Figure 3) as well. In addition, all results of M_o model appeared to be better than M_b, which is an indication of the proposed model's effectiveness.

Table 2. Shift wise computational results

Number of shifts	M_b*	M_o*	Gap (%)
2	11464	11128	2.93
3	-	10921	4.73
4	-	11326	1.21

However, the optimal solution rises a concern. As per M_o model, three shifts means a job duration of 12 hours, which involves overtime payment. Therefore, it is to be highlighted that these results are mainly planning oriented, mathematical conclusions where actual rostering needs further calculations with thorough management involvement. Next, I moved to find the optimal squad size fixing the number of shifts to 3 and the results show a job squad with five members are more feasible than the rest. When compared with the present practice it has a 2.39% increment. Nevertheless, it is to be noted that the next best condition is the four-member squad size, which is in present practice even though the number is not fixed. These results further shows that smaller squad sizes such as two or three member squads are not feasible in terms of man-hour consumption.

Table 3. Squad wise computational results

Members in a Squad	M_p*	M_o*	Gap (%)
2	-	11492	-3.25
3	-	11618	-1.34
4	11464	11442	0.02
5	-	11191	2.39
6	-	11426	0.03

(*all figures are calculated in man-hours)

Finally, I combined the above optimal values and compared the overall results of the two models. Here the evaluation considered the starting times to be 0400 Hrs, 0800 Hrs, 1600 Hrs, 2000Hrs while the number of shifts varied from 2-4 and the squad size varied from 4 to 6 personnel.

Table 4. Integrated results

Number of shifts	Members in a squad	M_p*	M_o*	Gap (%)
2	4	11464	11386	0.06
	5	-	10968	4.37
	6	-	11410	0.05
3	4	-	11242	1.93
	5	-	10788	5.89
	6	-	11318	1.27
4	4	-	11412	0.06
	5	-	11334	1.22
	6	-	11492	-0.02

(*all figures are calculated in man-hours)

The results presented an interesting finding as shown in Table 4 and I further manipulated the findings as shown in Table 5. If the four members working on two shifts is signified by $2S^{4m}$, I rearranged the combinations according to the descending order of gap analysis.

These results clearly specify the most feasible combinations in terms of their efficiency compared to the existing system. I understand that most optimal combination cannot be used every time due to some practical

Table 5. Gap Analysis

	Combinations	Gap analysis
1.	$3S^{5m}$	5.89
2.	$2S^{5m}$	4.37
3.	$3S^{4m}$	1.93
4.	$3S^{6m}$	1.27
5.	$4S^{5m}$	1.22
6.	$2S^{4m}$	0.06
7.	$2S^{6m}$	0.05
8.	$4S^{4m}$	0.04
9.	$4S^{6m}$	-0.02

(*all figures are calculated in man-hours)

implications highlighted above and the complexion of the problem varies with the size of the variables. Especially as highlighted early, the number of aircraft types matters a lot. However, this framework is applicable to all scenarios for the planners to discovery the best possible combinations and it highlights a set of optimal combinations depending on the restrictions impose at the enumeration stage. It allows aircraft maintenance capacity planners to compute optimal crew assignment combinations with the appropriate shift starting times.

IV. CONCLUSION

The increasing air travel has augmented the pressure imposed on airline maintenance element. Specifically flight line maintenance, which is an integral part of the latter, has become more and more demanding due to timetable deadlines, delayed arrivals, capacity issues, environmental constraints and manpower issues. In this backdrop, flight line maintenance labor planning has become a demanding task. In addition, it has a direct bearing on critical operational attributes such as costs, safety and punctuality. However, the amount of research on maintenance manpower planning and scheduling is relatively less in comparison to pilot and flight attendant scheduling.

This paper focuses on the above gap while constructing a framework to plan flight line maintenance crew, optimally. I used both managerial insights and computational advantage of mixed linear integer programming and was able to formulate framework with which the

maintenance manpower planners could identify the most appropriate crew combinations and shift schedules. Here a special emphasis was paid to ease out the maintenance certification constraint, which is a unique condition in aircraft maintenance. I proposed a novel concept termed variable crew assignment, which is a derivative of several management theories. The VCA strategy has two advantages over other methods. First, one being the crewmembers could maintain more than one type of aircraft during their tour of duty due to multi-skilled group concept. Next VCA assigns as low as possible crewmembers to fulfill the maintenance labour demand during a given job duration.

As any solution, this model too has its limitation. It is designed for planned maintenance and hence cannot handle the robustness in maintenance scheduling. When I solved the equations, I detected some anomalies in our prepositions, which was adjusted during data analysis. I believe this research would lead to many future researches such as robust maintenance scheduling for dynamic short-term lay over maintenance and stochastic maintenance demand forecasting for flight line maintenance demand.

V. REFERENCES

Alfares, H. K. (1999). Aircraft maintenance workforce scheduling A case study. *Journal of Quality in Maintenance Engineering*,

Barnhart, C., & Cohn, A. (2004). Airline Schedule Planning: Accomplishments and Opportunities. *Manufacturing & Service Operations Management*, 6(1), 3–22.

Dantzig, G. B. . (1954). A Comment on Edie ' s " Traffic Delays at Toll Booths " Author (s): George B . Dantzig Source : Journal of the Operations Research Society of America , Vol . 2 , No . 3 (Aug ., 1954), pp .

Deng, G.-F., & Lin, W.-T. (2011). Ant Colony Optimization-based Algorithm for Airline Crew Scheduling Problem.

Edie, L. C. (1954). Traffic Delays at Toll Booths. *Journal of the Operations Research Society of America*,

Ernst, a. T., Jiang, H., Krishnamoorthy, M., Owens, B., & Sier, D. (2004). An Annotated Bibliography of Personnel Scheduling and Rostering. Annals of Operations Research, 127, 21–144.

Gopalakrishnan, B., & Johnson, E. L. (2005). Airline crew scheduling: State-of-the-art. Annals of Operations Research, 140(1),

Jamili, A. (2017). A robust mathematical model and heuristic algorithms for integrated aircraft routing and scheduling, with consideration of fleet assignment problem. Journal of Air Transport Management,

Kasirzadeh, A., Saddoune, M., & Soumis, F. (2014). Airline crew scheduling: models, algorithms, and data sets. EURO Journal on Transportation and Logistics, 1–27. https://doi.org/10.1007/s13676-015-0080-x

Lavoie, S., Minoux, M., & Odier, E. (1988). A new approach for crew pairing problems by column generation with an application to air transportation. European Journal of Operational Research, 35(1), 45–58.

Medard, C. P., & Sawhney, N. (2007). Airline crew scheduling from planning to operations. European Journal of Operational Research,

Mercier, A., & Soumis, F. (2007). An integrated aircraft routing, crew scheduling and flight retiming model. Computers and Operations Research, 34(8),

PeriyarSelvam, U., Tamilselvan, T., Thilakan, S., & Shanmugaraja, M. (2013). Analysis on Costs for Aircraft Maintenance. Research India Publications,

Ryan, D. M. (1992). The Solution of Massive Generalized Set Partitioning Problems in Aircrew Rostering. Journal of the Operational Research Society,

Sasaki, D., & Nishi, T. (2016). Combinatorial auction algorithm with price-adjustment mechanism for airline crew scheduling problems. IEEE International Conference on Industrial Engineering and Engineering Management, https://doi.org/10.1109/IEEM.2015.7385834

Van Den Bergh, J., De Bruecker, P., Beliën, J., De Boeck, L., & Demeulemeester, E. (2013). A three-stage approach for aircraft line maintenance personnel rostering using MIP, discrete event simulation and DEA. Expert Systems with Applications,

Yan, S., & Chang, J. C. (2002). Airline cockpit crew scheduling. *European Journal of Operational Research*,