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Simulation Of C-Check Maintenance Task Card Distribution Using Vogel's Approximation Method

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Abstrak

Pemeliharaan sebuah pesawat terbang memang perlu manpower *yang andal dan bertanggung jawab.* Manpower *dan* manhour *ini sangat dibutuhkan untuk melakukan pemeliharaan terjadwal dan tidak terjadwal. Pemeliharaan* C-Check *ini memerlukan waktu yang cukup lama agar pesawat dapat beroperasi kembali. Oleh karena itu, diperlukan keoptimalan* task card *pada kelompok personel* maintenance *berdasarkan* manhour task card *yang diperlukan. Simulasi distribusi task card dibutuhkan untuk mencari kelompok pekerjaan C-Check yang optimum. Metode pada penelitian ini menggunakan metode* Vogel's Approximation Method (VAM) *sebagai perhitungan utama dan* Northwest Corner (NWC) *sebagai pembanding, dimana* VAM *dan* NWC *ini termasuk di dalam riset operasi. Penelitian ini bertujuan untuk menyimulasikan pendistribusian* task card *pemeliharaan* C-Check *dengan menyesuaikan* manhour *kelompok pekerja dan* manhour task card *yang diperlukan agar kelompok personel* maintenance *dapat mengerjakan tugas secara optimal. Hasil analisis yang diperoleh ialah menggunakan kebutuhan* manhour *pada kelompok* task card *sebagai permintaan* (demand)*, kemampuan tiap kelompok personel* maintenance *sebagai persediaan* (supply)*, dan faktor pengali antara aktual dan* maintenance program *sebagai biaya transportasi. Hasil perhitungan pendistribusian* manhour *menggunakan perhitungan* vogel's approximation method (VAM) *didapatkan total* manhours *sebesar 724.5* manhours *dan untuk perhitungan* northwest corner (NWC) *didapatkan total* manhours *sebesar 902.8* manhours*. Sehingga, perhitungan* VAM *menghasilkan biaya* manhour *lebih murah dibandingkan dengan perhitungan* NWC*.*

Kata Kunci*: Faktor Pengali*; Manhour; *Metode Transportasi*; Task Card; Vogel's Approximation Method

Abstract

Maintenance of an aircraft requires reliable and responsible manpower. Manpower and manhour are needed to perform scheduled and unscheduled maintenance. C-Check maintenance requires a long time for the aircraft to operate again. Therefore, it is necessary to optimize the task card in the maintenance personnel group based on the required task card manhour. Simulation of task card distribution is needed to find the optimum C-Check work group. The method in this study uses Vogel's Approximation Method (VAM) as the main calculation and Northwest Corner (NWC) as the comparison, where VAM and NWC are included in operations research. This study aims to simulate the distribution of C-Check maintenance task cards by adjusting the manhour of the personnel group and the manhour task card required so that the maintenance personnel group can perform the task optimally. The analysis results obtained are manhour requirements in the task card group as demand, the ability of each maintenance personnel group as supply, and the multiplying factor between actual and maintenance program as transportation costs. The results of the calculation of manhour distribution using the Vogel's approximation method (VAM) calculation obtained a total manhours of 724.5 manhours and for the northwest corner (NWC) calculation obtained a total manhours of 902.8 manhours. Thus, the VAM calculation results in cheaper manhour costs compared to the NWC calculation.

Keywords: Manhour; Multiplying Factor; Task Card; Transportation Method; Vogel's Approximation Method

1. Introduction

Aircraft Maintenance is the process or action to restore or maintain an aircraft system, components, and structures in a airworthy condition (Mora, 2012). These mechanical parts of an aircraft are subject to wear, corrosion, and fatigue which inevitably result in some deviation from when the item/part was new. Operationally, to keep the aircraft in a serviceable and reliable condition so as to generate revenue. The importance of scheduled maintenance is to overcome the failure process (Ackert, 2010).

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Those who have honesty, kindness, and discipline, should be able to complete the maintenance work on time (Britta, 2021). The workers must also be specialized to work on the maintenance of an aircraft or in other words, have a special license for aircraft maintenance. The more manpower a company has, the more manhour that can be utilized to make aircraft maintenance more efficient (Pemerintah, 2009). A manhour is the time of a worker when he is working on a job. Manhour, also called personhour, is a unit of measure used in project management to quantify the effort required to complete a task. 1 manhour equals completed in one hour of uninterrupted effort by the average worker. Calculating man-hours is the basis for being able to measure the cost per project of each type of expert and their contribution to the outcome. The total man-hours per task is obtained by multiplying the number of people assigned to a task by the total time required to complete it (Brian, 2018). Therefore, a document in the form of a task card is issued by the company/operator.

Task cards are used as a simple way to comply with regulations in performing maintenance, as well as recording maintenance. Task cards contain the Aircraft Maintenance Manual (AMM) which is used to reference detailed and concise procedural instructions, so as to organize and control maintenance activities while providing a means of ensuring compliance with the maintenance manual. Task cards are an easy way to ensure maintenance personnel follow proper procedures (Kinnison & Siddiqui, 2014).

This research uses Vogel's Approximation Method (VAM) which is found in the study of Operations Research. More precisely VAM is included in the transportation method where the transportation method is one of the models that can be used in operations research. Operations research itself is the application of scientific methods, techniques, and tools to solve problems that arise in company operations with the aim of finding optimal problem-solving alternatives (Takdir Syaifuddin, 2011). In other words, finding a solution to a problem in order to produce a more optimal solution than before. Operations research is starting to gain recognition as a useful subject in universities or colleges.

According to Morse and Kimball (1951), operations research is a scientific method that allows managers to make decisions about the activities they handle on a quantitative basis. Meanwhile, according to Miller and M.K. Star (1960), operations research is a management tool that brings together science, mathematics, and logic in order to solve problems faced daily, in the end the problem can be overcome optimally. In accordance with the definition above, operations research is concerned with making optimal decisions in designing system models that combine probabilistic and deterministic elements. There are many applications in government, business, engineering, economics, natural and social sciences that require limited resources. Operations research is very useful in dealing with problems, how to direct and coordinate operations or activities in an organization with all its limitations through a "search of optimality" procedure (Meflinda & Mahyarni, 2011).

Meflinda & Mahyarni (2011) stated that transportation method is a specialized part of the allocation process. Transportation method specifically discusses the determination of allocation from the initial location to the destination with the aim of reducing allocation or distribution costs as much as possible. Transportation methods have a variety of applications, especially in dealing with problems such as; Delivery schedules from factories to warehouse locations or marketing areas, Determination of factory location, Determination of sales area/region, Production schedule, Employee/machine assignment, Facility/machine layout placement, and Selection of projects and sub-contractors.

The characteristics of the transportation method includes (Rachman, 2016); a) Goods are moved from various sources to their respective destinations at the minimum possible cost. b) The source of the goods can provide the supply of a fixed amount and each destination has a fixed amount of demand. Thus, the amount of demand and supply must be the same.

In this case, to carry out aircraft maintenance, the airline must be able to distribute task cards to workers according to the manhours needed to make the aircraft airworthy. If the task cards are allocated properly, the workers can also work efficiently. So this research was conducted with the aim of distributing task cards to workers adjusted to the worker's manhour and the task card using Vogel's Approximation Method as the main calculation and Northwest Corner as the comparison. VAM is used because it is the most optimized calculation, unlike NWC which is the non-optimized calculation within the transport method (Das et al.,2014). Therefore, the comparison between the two will have a significant result.

Theoretically, the distribution of task cards using the calculation of Vogel's approximation method will reduce the aircraft maintenance time and use the worker group multiplication factor for better efficiency. Practically, it will need so much effort and discipline to use this method.

Previous research by Mahendra (Mahendra, 2022), explored a similar issue of allocating workers from multiple maintenance, repair and overhaul centres to other locations in the same company, with a focus on airline ticket prices. Finding the lowest and optimal price can be.

2. Research Methods

The research method used in this study is Vogel's Approximation Method and Northwest Corner. Both of these methods are used in the transportation method to allocate the suppliers manhour and the demand's manhour (Cook, 2022). The differences of these two are how they are allocated. After allocating the products according to their costs, each product is multiplied by its cost and the total cost is summed up, thus obtaining the minimum total cost of distribution. The minimum total cost formula for **Table 6** is (Tabroni & Komarudin, 2021):

$$Total\ Cost = (X_{11} \times C_{11}) + \cdots + (X_{ij} \times C_{ij}) \qquad (1)$$

Destription:
X_{ij} = Allocated/Distributed Manhour
C_{ij} = Manhour Cost

2.1. Vogel's Approximation Method

Vogel's Approximation Method (VAM) is one of the methods often used to find the minimum cost in transportation problems. This method usually provides a better solution than other methods (Kartika et al., 2019). The steps of this VAM method are as follows:

1. Find the two lowest costs from each row and column. Set the differences of the two lowest costs.
2. Select the largest cost difference in the row or column. If there is the same largest difference, then select the smallest distribution cost.
3. Allocate as many products as possible, adjusted for supply and demand in the cell that has the lowest cost in the row or column that has the largest cost difference.
4. Rows or columns that have been filled in cannot be re-included so delete the full row or column.
5. Perform steps 1 to 4 again, so that all products are allocated according to supply and demand.

2.2. Northwest Corner

The Northwest Corner (NWC) method is one of the most commonly known transportation methods. This method requires the calculation to start at the top left of the table and allocates units by looking at the supplies and demand's (Kartika et al., 2019). The steps are shown as follows:

1. Spend the supply in each row before moving to the next row.
2. Spend the demand of each column before moving to the next column on the right side.
3. Re-do steps 1 to 2, so that all products are allocated according to supply and demand.
4. Ensure that all supplies and demand's have been fulfilled.

2.3. Flowchart

The following are some of the steps that will be taken in the implementation of this research:

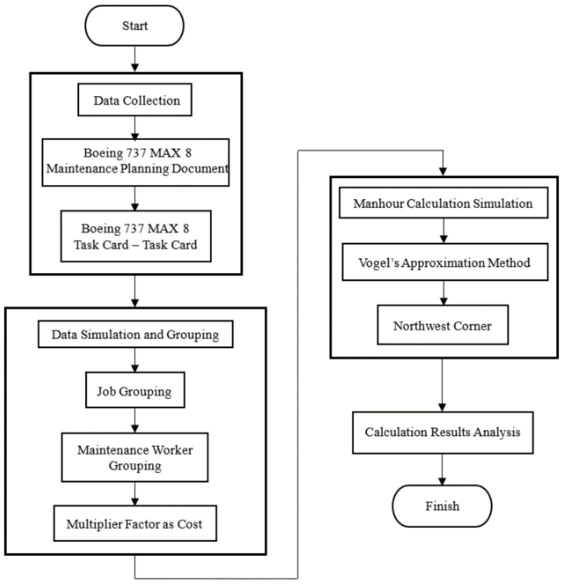


Figure 1: Study Flowchart

This research stage is a complete explanation of the research flowchart described above, with the following explanation:

1. Starting the research

Research begins with the identification of a topic to be researched. The title of the study is then determined by looking at the formulation of the problem that is the focus of the research, as well as looking for appropriate methods through discussion with the supervisor. A literature review is also carried out to find relevant theories and to broaden the understanding of the topic to be researched.

2. Data collection

Once the research topic has been identified, the next step is to collect data to help the research find answers to the problem formulation. The data collection process is carried out by observing the maintenance planning document and C-Check maintenance task card data for Boeing 737 MAX 8 aircraft.

3. Data simulation and grouping

At this stage, the raw data from the C-Check maintenance task card is grouped based on the components of the Boeing 737 MAX 8 aircraft (fuselage, empennage, wing, landing gear, engine). The maintenance personnel assigned to these aircraft components are also grouped. The distribution cost is then determined by applying a multiplication factor to the manhour cost.

4. Data calculation simulation

The fourth stage is the calculation process of the maintenance personnel group manhour and the manhour from the C-Check maintenance task card. This calculation process is carried out to determine the similarity of the maintenance group manhour determined with the manhour from the C-Check maintenance task card. Simulations use Vogel's Approximation Method and Northwest Corner to determine the optimality of the maintenance group allocation.

5. Analysis of data calculation

The analysis carried out is to compare Vogel's Approximation Method with Northwest Corner to determine the optimality of the allocation of maintenance personnel groups. Comparison of Vogel's Approximation Method with actual manhours on the entire collection of task cards.

6. Conclusions

The final stage is to draw conclusions based on the results of the research carried out in accordance with the research objectives.

3. Results and Discussion

This section describes collecting, simulating, and grouping data obtained to solve the problem and find the results accordingly.

3.1. Data Collection

The data sources that have been collected are Maintenance Planning Document (MPD) manhour data and task card manhours that have been done or performed at Company X. This data contains various information including MPD estimated manhours, actual manhour task cards that have been done, as well as descriptions and numbers. This collection of C-Check task card data is used to determine the manhours required for C-Check maintenance. The C-Check task card is used because it contains a lot of manhour work, so it can be used to allocate maintenance personnel groups.

The following is a comparison of manhours between the Maintenance Planning Document (MPD) and the Task Card of Company X **Table 1** below:

Table 1: Comparison of Manhours MPD and Task Card

TASK CARD C-CHECK B737-8				
No.	Task Card No.	Task Card Description	Est. Man Hours	Actual Manhours
1	737M-20-151-00-02-MLI	FUNCTIONALLY CHECK THE LIGHTNING/HIRF PROTECTION COMPONENTS (BY PERFORMING A LOOP RESISTANCE TEST) ON THE RIGHT REAR SPAR OF THE MAIN LANDING GEAR	0.83	2.07
2	737M-20-171-00-01-MLI	INSPECT (DETAILED) THE LIGHTNING/HIRF PROTECTION COMPONENTS ON THE LEFT STRUT MID FAIRING. THUMBNAIL FAIRING. INBOARD AND OUTBOARD OVER WING FAIRING FOIL-LINED PANELS AND UNDERLYING FOIL-LINED FAIRING SUPPORT STRUCTURE	1.40	1.75
3	737M-20-171-00-02-MLI	INSPECT (DETAILED) THE LIGHTNING/HIRF PROTECTION COMPONENTS ON THE RIGHT STRUT MID FAIRING. THUMBNAIL FAIRING. INBOARD AND OUTBOARD OVER WING FAIRING FOIL-LINED PANELS AND UNDERLYING FOIL-LINED FAIRING SUPPORT STRUCTURE	1.40	1.75
4	737M-20-174-00-02-MLI	FUNCTIONALLY CHECK THE LIGHTNING/HIRF PROTECTION COMPONENTS (BY PERFORMING A LOOP RESISTANCE TEST) IN THE RIGHT SIDE APU COMPARTMENT	0.51	3.30

It can be seen in **Table 1** above that there are categories which have been grouped together for ease of reading. Estimated Man Hours and Actual Man Hours are used to simulate the manpower and manhours of maintenance personnel. Task Card Number and Task Card Description are used to find out which tasks can be grouped using the ATA chapter.

3.2. Job Simulation and Grouping

After collecting the data in Section 3.1, the jobs are then grouped based on the data collected. The jobs are grouped by ATA chapter to facilitate the grouping of simulations. The following groups of jobs have been grouped by ATA chapter in **Table** 2:

Table 2: Groups According to ATA Chapters

ATA Chapter	Task Cards	Estimated Manhours	Actual Manhours
20 Standard Practices - Airframe	14	33.57	43.49
21 Air Conditioning	5	3.95	10.33
23 Communications	2	4.50	7.25
26 Fire Protection	8	8.01	24.00
27 Flight Controls	48	90.10	132.94
28 Fuel	8	8.84	16.76
29 Hydraulic Power	6	21.00	17.67
31 Indicating/Recording System	3	0.75	4.60
32 Landing Gear	8	14.41	33.90
34 Navigation	5	2.32	8.91
35 Oxygen	2	7.50	10.00
49 Auxiliary Power Unit	5	0.91	5.63
52 Doors	15	50.09	34.13

53 Fuselage	47	66.32	70.79
54 Nacelles/Pylons	10	28.06	40.54
55 Stabilizers	16	14.09	42.85
56 Windows	2	1.26	3.75
57 Wings	58	73.09	162.38
70 Standard Practices - Engines	8	16.72	16.03
72 Engine	6	15.30	17.41
78 Exhaust	47	139.44	159.80
Total	323	600	864

After grouping by the ATA chapters, it can be seen that the total number of task cards obtained is 323, the total number of estimated manhours obtained is 600 and the total number of actual manhours is 864. Estimated manhours and actual manhours have different meanings, namely estimated manhours to complete the work based on the Maintenance Planning Document (MPD) data from Company X, and actual manhours are real manhours when maintenance personnel perform the work and record the results of their work.

The work is grouped in more detail by setting the work area. The work areas defined for performing calculations and simulations are Wing, Upper Fuselage, Lower Fuselage, Empennage, Engine and Landing Gear. The work areas used are the majority of those contained in the task cards in the MPD. The work areas grouped for each of the estimated and actual manhours and their totals are shown in **Table 3** below:

Table 3: Groups According to the Work Area

Component Area	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear
Task Cards Total = 323	71	45	72	46	80	9
Estimated Manhours Total = 600	85	76	141	43	229	26
Actual Manhours Total = 864	183	81	189	95	282	34

Estimated manhours is what will be used for simulation calculations in this study, while actual manhours will be used for comparison in calculating simulation results. Therefore, the estimated manhours of the aircraft component area is what needs to be done (target), so it becomes the demand.

3.3. Maintenance Worker Simulation and Grouping

There are 5 (five) groups of personnel to be used in this research (Alpha, Beta, Charlie, Delta and Echo) containing different personnel positions, namely Junior Mechanic, Senior Mechanic and Engineer. The Junior Mechanic, Senior Mechanic and Engineer included in this grouping are the simulation results of the manhours of each personnel to carry out this research simulation. The manhour of each personnel is simulated as 1 person working for 5 working days. During 1 day, the staff works for 6 hours, so 1 staff has a total of 6 manhours per day. This means that for 1 week, 1 personnel has a total of 30 manhours per week, so the supply manhour is 30 manhours each. This manhour applies to all staff in this simulation. The staff groups total 20 manhours, as detailed in **Table 4** below:

Table 4: Maintenance Worker Groups

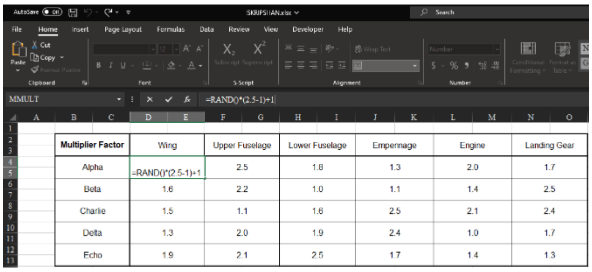
Position	Group				
	Alpha	Beta	Charlie	Delta	Echo
Engineer	1	1	1	1	1
Senior Mechanic	1	1	1	1	1
Junior Mechanic	-	4	3	1	2
Total = 20	2	6	5	3	4
Supply Manhour	60	180	150	90	120

After knowing the manhour in each group, the maintenance personnel group is what is needed to do the work (origin), so that it becomes the supply.

3.4. Multiplier Factor as Cost

The cost of maintaining an aircraft is made up of the cost of manhours and the cost of materials. Manhour cost is the number of manhours multiplied by the duration of the work. The calculated duration of the work is based on the actual duration of the work. The actual duration of the work is not necessarily the same as the planning based on the maintenance programme, this difference can be called a multiplier factor. For example, if the maintenance planning for 1 type of work is demonstrated by 2 people for 1 hour, it becomes 2 manhours. It turns out that during implementation it is still done by 2 people, but the implementation time becomes 1.5 hours (1.5), so the actual manhour is 3 manhours. This multiplier factor has several factors that affect the skills and abilities of the personnel, then the performance, the location of tools and materials to the workplace. The multiplier factor uses decimal numbers with values from 1.0 to 2.5 with a multiple of 0.1 (Materiedu9999, 2023).

These multipliers were simulated using Microsoft Excel software to find random values in each cell of the row and column. The Excel function used to find these values is shown in **Figure 2**:



Multiplier Factor	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear
Alpha	=RAND()*(2.5-1)+1	2.5	1.8	1.3	2.0	1.7
Beta	1.6	2.2	1.0	1.1	1.4	2.5
Charlie	1.5	1.1	1.6	2.5	2.1	2.4
Delta	1.3	2.0	1.9	2.4	1.0	1.7
Echo	1.9	2.1	2.5	1.7	1.4	1.3

Figure 2: Excel Function

The random function (=RAND()) is used to randomly find the values of the multiplier to simulate the manhour cost. The numbers 2.5 and 1 are the limits used in this multiplier simulation. The number 1 is the lower limit which indicates that the worker is proficient in his work and the number 2.5 is the upper limit which indicates that the worker is less proficient or has minimal ability and skill in his work. Thus, the multiplier factor as a manhour cost can be simulated as shown in **Table 5** below:

Table 5: Multiplying Factor as Manhour

Multiplier Factor	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear
Alpha	1.0	2.5	1.8	1.3	2.0	1.7
Beta	1.6	2.2	1.0	1.1	1.4	2.5
Charlie	1.5	1.1	1.6	2.5	2.1	2.4
Delta	1.3	2.0	1.9	2.4	1.0	1.7
Echo	1.9	2.1	2.5	1.7	1.4	1.3

The Alpha group has faster skills and abilities in the wing work area because they work on the wing area more often, so the multiplier factor is small (1.0) compared to the others. In the upper fuselage work area, there is a Charlie group that has faster skills and abilities than other groups. For the lower fuselage work area, there are several groups that can do it faster, but the Beta group is the fastest. There is also an empennage work area where the Beta group can do the work faster, so the multiplier factor is only 1.1. In the engine area, there is a Delta group that has faster skills. The ability and skill that is qualified on the landing gear is only for the echo group with a multiplier factor of 1.3.

3.5. Transportation Method Calculation

After determining the grouping of labor as demand, maintenance personnel as supply, and manhour as cost, the calculation method can be known. Simulation of manhour calculation using 2 (two) methods, namely the main method of Vogel's approximation method and its comparison with the northwest corner method. Simulation of transportation method calculation requires data on demand, supply and manhour cost as shown in **Table 6**:

Table 6: Transportation Table

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups
Alpha	$X_{A,WI}$ 1.0	$X_{A,UF}$ 2.5	$X_{A,LF}$ 1.8	$X_{A,EM}$ 1.3	$X_{A,EN}$ 2.0	$X_{A,LG}$ 1.7	60
Beta	$X_{B,WI}$ 1.6	$X_{B,UF}$ 2.2	$X_{B,LF}$ 1.0	$X_{B,EM}$ 1.1	$X_{B,EN}$ 1.4	$X_{B,LG}$ 2.5	180
Charlie	$X_{C,WI}$ 1.5	$X_{C,UF}$ 1.1	$X_{C,LF}$ 1.6	$X_{C,EM}$ 2.5	$X_{C,EN}$ 2.1	$X_{C,LG}$ 2.4	150
Delta	$X_{D,WI}$ 1.3	$X_{D,UF}$ 2.0	$X_{D,LF}$ 1.9	$X_{D,EM}$ 2.4	$X_{D,EN}$ 1.0	$X_{D,LG}$ 1.7	90
Echo	$X_{E,WI}$ 1.9	$X_{E,UF}$ 2.1	$X_{E,LF}$ 2.5	$X_{E,EM}$ 1.7	$X_{E,EN}$ 1.4	$X_{E,LG}$ 1.3	120
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600

Description :

X = Number of manhours to be allocated

A = Alpha Group
B = Beta Group
C = Charlie Group
D = Delta Group
E = Echo Group

WI = Wing
UF = Upper Fuselage
LF = Lower Fuselage
EM = Empennage
EN = Engine
LG = Landing Gear

3.6. Vogel's Approximation Method Simulation

This section first explains the VAM distribution calculation using the term conditions. These conditions are included in the first distribution calculation and will explain the process of using the Vogel's Approximation Method (VAM) distribution calculation. There are 6 conditions that must be followed in this VAM distribution calculation.

The first condition is to know the supply and demand and the cost of each cell. **Table 7** shows the first condition of VAM as follows:

Table 7: First Condition of VAM

Vogel's Approximation Method (VAM)								
To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0	2.5	1.8	1.3	2.0	1.7	60	
Beta	1.6	2.2	1.0	1.1	1.4	2.5	180	
Charlie	1.5	1.1	1.6	2.5	2.1	2.4	150	
Delta	1.3	2.0	1.9	2.4	1.0	1.7	90	
Echo	1.9	2.1	2.5	1.7	1.4	1.3	120	
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600	
Difference								

Table 8 below shows the second condition of VAM, which can be seen 2 minimum costs and the difference. In the first row, we can see that the minimums are 1.0 and 1.3, so the row difference is 0.3.

Table 8: Second Condition of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0	2.5	1.8	1.3	2.0	1.7	60	0.3
Beta	1.6	2.2	1.0	1.1	1.4	2.5	180	
Charlie	1.5	1.1	1.6	2.5	2.1	2.4	150	
Delta	1.3	2.0	1.9	2.4	1.0	1.7	90	
Echo	1.9	2.1	2.5	1.7	1.4	1.3	120	
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600	
Difference								

The next table shows the third VAM condition, where the row and column are filled with the difference, just as in the previous condition. Here is **Table 9** for the third VAM condition:

Table 9: Third Condition of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0	2.5	1.8	1.3	2.0	1.7	60	0.3
Beta	1.6	2.2	1.0	1.1	1.4	2.5	180	0.1
Charlie	1.5	1.1	1.6	2.5	2.1	2.4	150	0.4
Delta	1.3	2.0	1.9	2.4	1.0	1.7	90	0.3
Echo	1.9	2.1	2.5	1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600	
Difference	0.3	0.9	0.6	0.2	0.4	0.4		

The next step is to calculate the largest difference from the previous table. In the fourth condition table of VAM, **Table 10**, the largest difference is 0.9 (the difference between the lowest cost of 1.1 and 2.0) in the upper fuselage column as demand and there is the cheapest cost in the Charlie row.

Table 10: Fourth Condition of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0	2.5	1.8	1.3	2.0	1.7	60	0.3
Beta	1.6	2.2	1.0	1.1	1.4	2.5	180	0.1
Charlie	1.5	1.1	1.6	2.5	2.1	2.4	150	0.4
Delta	1.3	2.0	1.9	2.4	1.0	1.7	90	0.3
Echo	1.9	2.1	2.5	1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600	
Difference	0.3	0.9	0.6	0.2	0.4	0.4		

After obtaining the fourth condition, the next step is to make the first allocation to cell $X_{C,UF}$, which is 76 manhours, as shown in **Table 11**:

Table 11: Fifth Condition of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0	2.5	1.8	1.3	2.0	1.7	60	0.3
Beta	1.6	2.2	1.0	1.1	1.4	2.5	180	0.1
Charlie	1.5	1.1	1.6	2.5	2.1	2.4	150	0.4
Delta	1.3	2.0	1.9	2.4	1.0	1.7	90	0.3
Echo	1.9	2.1	2.5	1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85	76	141	43	229	26	600	
Difference	0.3	0.9	0.6	0.2	0.4	0.4	$X_{C,UF} = 76$	

For the sixth condition (**Table 12**), because the upper fuselage column as demand has been met (previously 76 manhours), the column is deleted and the Charlie row as supply was previously 150 manhours, leaving 74 manhours.

Table 12: Sixth Condition of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0		1.8	1.3	2.0	1.7	60	0.3
Beta	1.6		1.0	1.1	1.4	2.5	180	0.1
Charlie	1.5		1.6	2.5	2.1	2.4	74	0.1
Delta	1.3		1.9	2.4	1.0	1.7	90	0.3
Echo	1.9		2.5	1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85		141	43	229	26	524	
Difference	0.3		0.6	0.2	0.4	0.4		

After performing the above conditions, the next is to calculate the rest of the VAM distribution which is carried out similarly to conditions 1 to 6 above and is done until the calculation is complete.

The calculation of the VAM distribution will then be shown briefly. The following is **Table 13** for the calculation of the second distribution:

Table 13: Second Calculation of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0		1.8	1.3	2.0	1.7	60	0.3
Beta	1.6		1.0	1.1	1.4	2.5	180	0.1
Charlie	1.5		1.6	2.5	2.1	2.4	74	0.1
Delta	1.3		1.9	2.4	1.0	1.7	90	0.3
Echo	1.9		2.5	1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85		141	43	229	26	524	
Difference	0.3		0.6	0.2	0.4	0.4	$X_{B,LF} = 141$	

In **Table 13** above is the calculation of the second distribution of VAM, which shows the lower Fuselage column as the demand. It can be seen that the smallest are 1.0 and 1.6, so the column difference is 0.6. Shows the largest difference in the lower Fuselage column as demand and there is the cheapest cost in the Beta row. The second allocation in cell $X_{B,LF}$ is 141 manhours. Because the Lower Fuselage column as demand has been met, the column is removed and the Beta row as supply was previously 180 manhours, so there are 39 manhours left.

Table 14: Third Calculation of VAM

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0			1.3	2.0	1.7	60	0.3
Beta	1.6			1.1	1.4	2.5	39	0.3
Charlie	1.5			2.5	2.1	2.4	74	0.6
Delta	1.3			2.4	1.0	1.7	90	0.3
Echo	1.9			1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	85			43	229	26	383	
Difference	0.3			0.2	0.4	0.4	$X_{C,WI} = 74$	

In **Table 14** above is the calculation of the third distribution of VAM, which shows the Charlie line as the supply. It can be seen that the smallest is 1.5 and 2.1, so the row difference is 0.6. Shows the largest difference in the Charlie row as supply and there is the cheapest cost in the Wing column. The third allocation in cell $X_{C,WI}$ is 74 manhours. Because the Charlie row as supply has been met, the row is deleted and the Wing column as demand was previously 85 manhours, so there are 11 manhours left.

Table 15: Fourth Calculation of VAM

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0			1.3	2.0	1.7	60	0.3
Beta	1.6			1.1	1.4	2.5	39	0.3
Charlie								
Delta	1.3			2.4	1.0	1.7	90	0.3
Echo	1.9			1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*	11			43	229	26	309	
Difference	0.3			0.2	0.4	0.4	$X_{D,EN} = 90$	

In **Table 15** above is the calculation of the fourth distribution of VAM that shows the Engine column as demand. We can see that the smallest are 1.0 and 1.4, so the column difference is 0.4. The largest difference is shown in the Engine column as demand and the cheapest cost is shown in the Delta row. The fourth allocation in cell $X_{D,DE}$ is 90 manhours. Because the Delta row as supply has been met, the row is deleted and the Engine column as demand was previously 229 manhours, so there are 139 manhours left.

Table 16: Fifth Calculation of VAM

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha	1.0			1.3	2.0	1.7	60	0.3
Beta	1.6			1.1	1.4	2.5	39	0.3
Charlie								
Delta								
Echo	1.9			1.7	1.4	1.3	120	0.3
Demand (Manhours) *Task Card*	11			43	139	26	219	
Difference	0.6			0.2	0	0.4	$X_{A,WI} = 11$	

In **Table 16** above is the calculation of the fifth distribution of VAM, which shows the Wing column as demand. It can be seen that the smallest are 1.0 and 1.6, so the column difference is 0.6. Shows the largest difference in the Wing column as demand and there is the cheapest cost in row Alpha. The fifth allocation in cell $X_{A,WI}$ is 11 manhours. Because the Wing column as demand has been met, the column is removed and the Alpha row as supply was previously 60 manhours, so there are 49 manhours left.

Table 17: Sixth Calculation of VAM

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha				1.3	2.0	1.7	49	0.4
Beta				1.1	1.4	2.5	39	0.3
Charlie								
Delta								
Echo				1.7	1.4	1.3	120	0.1
Demand (Manhours) *Task Card*				43	139	26	208	
Difference				0.2	0	0.4	$X_{E,LG} = 26$	

In **Table 17** above is the calculation of the sixth distribution of VAM, which shows the Landing Gear column as demand. It can be seen that the smallest is 1.3 and 1.7, so the column difference is 0.4. Shows the largest difference in the Landing Gear column as demand and there is the cheapest cost in the Echo row. The sixth allocation in cell $X_{E,LG}$ is 26 labor hours. Since the Landing Gear column of demand has been met, the column is removed and the Echo row of supply was previously 120 manhours, leaving 94 manhours.

Table 18: Seventh Calculation of VAM

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha				1.3	2.0		49	0.7
Beta				1.1	1.4		39	0.3
Charlie								
Delta								
Echo				1.7	1.4		94	0.3
Demand (Manhours) *Task Card*				43	139		182	
Difference				0.2	0		$X_{A,EM} = 43$	

In **Table 18** above is the calculation of the seventh distribution of VAM, which shows the Alpha row as the supply. It can be seen that the smallest is 1.3 and 2.0 so the row difference is 0.7. Shows the largest difference in the Alpha row as supply and there is the cheapest cost in the Empennage column. The seventh allocation in cell $X_{A,EM}$ is 43 manhours. Since the Empennage column as demand has been met, the column is removed and the Alpha row as supply was previously 49 manhours, so there are 6 manhours left.

Table 19: Eight Calculation of VAM

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	*Supply (Manhours)* Worker Groups	Difference
Alpha					2.0		6	2.0
Beta					1.4		39	1.4
Charlie								
Delta								
Echo					1.4		94	1.4
Demand (Manhours) *Task Card*					139		139	
Difference					0		$X_{A,EN} = 6$; $X_{B,EN} = 39$; $X_{E,EN} = 94$	

In **Table 19** above, the calculation of the distribution of the eight VAMs shows the last column, which is the Engine column, as demand. The column difference is 0 and the row differences are 2.0, 1.4 and 1.4. Since this is the last distribution calculation, the remaining cells $X_{A,EN}$ are 6 manhours, $X_{B,EN}$ is 39 manhours, and $X_{E,EN}$ is 94 manhours.

Since this is the final distribution calculation, simply enter the manhours for each cell in **Table 6** to calculate the total minimum distribution cost. **Table 20** shows the final results of the Vogel's Approximation Method distribution calculation from **Table 7** through **Table 19**.

Table 20: Final Results for VAM

From \ To	Wing		Upper Fuselage		Lower Fuselage		Empennage		Engine		Landing Gear		*Supply (Manhours)* Worker Groups
Alpha	11	1.0		2.5		1.8	43	1.3	6	2.0		1.7	60
Beta		1.6		2.2	141	1.0		1.1	39	1.4		2.5	180
Charlie	74	1.5	76	1.1		1.6		2.5		2.1		2.4	150
Delta		1.3		2.0		1.9		2.4	90	1.0		1.7	90
Echo		1.9		2.1		2.5		1.7	94	1.4	26	1.3	120
Demand (Manhours) *Task Card*	85		76		141		43		229		26		600

Below is **Table 21**, which shows the simplified results of the VAM calculation results table in **Table 20**. With the explanation that the Alpha group is working on the wing area with a manhour distribution of 11 manhours, the empennage with 43 manhours, and the engine with 6 manhours. It is then multiplied by its manhour costs of 1.0, 1.3, and 2.0. And so on with other groups to get the total cost. After that, the total minimum cost of distribution can be calculated.

Table 21: VAM Manhour Cost

VAM		Work Area	Manhour Distribution	Manhour Cost
Groups	Alpha	Wing	11	1.0
		Empennage	43	1.3
		Engine	6	2.0
	Beta	Lower Fuselage	141	1.0
		Engine	39	1.4
	Charlie	Wing	74	1.5
		Upper Fuselage	76	1.1
	Delta	Engine	90	1.0
	Echo	Engine	94	1.4
		Landing Gear	26	1.3

By using the formula (1), the total distribution cost of manhours for Vogel's approximation method calculation is 724.5 Manhours.

3.7. Northwest Corner Simulation

The first step in using the Northwest Corner (NWC) is to distribute the top left corner first in terms of supply and demand. The NWC should first deplete its supply, when it is depleted, move to the next row. Second, deplete the demand, when it is depleted, move to the next column. Continue to deplete supply and demand in the above manner until they are all depleted. The following table shows the result in a simplified form.

In **Table 22** below, we see that the upper left corner is the Alpha row as Supply and the Wing column as Demand, which is filled with 60 manhours, so the Alpha row as Supply is fulfilled and must move to the bottom row. Therefore, the Wing column, which previously contained 85 manhours, is left with 25 manhours.

Table 22: First Calculation of NWC

North West Corner (NWC)								
From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	(1.6)	(2.2)	(1.0)	(1.1)	(1.4)	(2.5)	180	180
Charlie	(1.5)	(1.1)	(1.6)	(2.5)	(2.1)	(2.4)	150	150
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	25	76	141	43	229	26		

In **Table 23** below, the Beta row for Supply and the Wing column for Demand are filled with 25 manhours, so the Wing column for Demand is fulfilled and must move to the right column. Therefore, the Beta row, which previously had 180 manhours, is left with 155 manhours.

Table 23: Second Calculation of NWC

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	(2.2)	(1.0)	(1.1)	(1.4)	(2.5)	180	155
Charlie	(1.5)	(1.1)	(1.6)	(2.5)	(2.1)	(2.4)	150	150
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	76	141	43	229	26		

In **Table 24** below, the Beta row as Supply and the Upper Fuselage column as Demand are filled with 76 manhours, so the Upper Fuselage column as Demand is fulfilled and must move to the right column. Therefore, the Beta row, which was previously 155 manhours, is left with 79 manhours.

Table 24: Third Calculation of NWC

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	(1.0)	(1.1)	(1.4)	(2.5)	180	79
Charlie	(1.5)	(1.1)	(1.6)	(2.5)	(2.1)	(2.4)	150	150
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	141	43	229	26		

In **Table 25** below, the Beta Supply row and the Bottom Fuselage Demand column are filled with 79 manhours, so the Beta Supply row is fulfilled and must move to the bottom row. Therefore, the lower fuselage column, which previously had 141 manhours, is left with 62 manhours.

Table 25: Fourth Calculation of NWC

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	(1.6)	(2.5)	(2.1)	(2.4)	150	150
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	62	43	229	26		

In **Table 26** below, which shows the Charlie row as Supply and the Lower Fuselage column as Demand, 62 manhours are filled, so the Lower Fuselage column as Demand is fulfilled and must move to the right column. Therefore, the Charlie row, which previously had 150 manhours, is left with 88 manhours.

Table 26: Fifth Calculation of NWC

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	(2.5)	(2.1)	(2.4)	150	88
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	43	229	26		

In **Table 27** below, the Charlie row as Supply and the Empennage column as Demand are filled with 43 manhours, so the Empennage column as Demand has been fulfilled and must move to its right column. Therefore, the Charlie row, which was previously 88 manhours, is left with 45 manhours.

Table 27: Sixth Calculation of NWC

From \ To	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	(2.1)	(2.4)	150	45
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	0	229	26		

In **Table 28** below, the Charlie row as Supply and the Engine column as Demand are filled with 45 manhours, so the Charlie row as Supply is fulfilled and must move to the bottom row. Therefore, the Engine column, which previously contained 229 manhours, is left with 184 manhours.

Table 28: Seventh Calculation of NWC

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	45 (2.1)	(2.4)	150	0
Delta	(1.3)	(2.0)	(1.9)	(2.4)	(1.0)	(1.7)	90	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	0	184	26		

In **Table 29** below, the Delta row as Supply and the Engine column as Demand are filled with 90 manhours, so the Delta row as Supply is fulfilled and must move to the bottom row. Therefore, the Engine column, which previously had 184 manhours, is left with 94 manhours.

Table 29: Eigth Calculation of NWC

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	45 (2.1)	(2.4)	150	0
Delta	(1.3)	(2.0)	(1.9)	(2.4)	90 (1.0)	(1.7)	90	0
Echo	(1.9)	(2.1)	(2.5)	(1.7)	(1.4)	(1.3)	120	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	0	94	26		

In **Table 30** below, the Echo row as Supply and the Engine column as Demand are filled with 94 manhours, so the Engine column as Demand is fulfilled and must move to the right column. Therefore, the Echo row, which previously contained 120 manhours, is left with 26 manhours.

Table 30: Ninth Calculation of NWC

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	45 (2.1)	(2.4)	150	0
Delta	(1.3)	(2.0)	(1.9)	(2.4)	90 (1.0)	(1.7)	90	0
Echo	(1.9)	(2.1)	(2.5)	(1.7)	94 (1.4)	(1.3)	120	26
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	0	0	26		

In **Table 31** below, the Echo row as Supply and the Landing Gear column as Demand are filled with 26 manhours, so the Landing Gear column as Demand and the Echo row as Supply are satisfied. Therefore, this tenth distribution calculation is the last distribution calculation.

Table 31: Tenth Calculation of NWC

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups	Remaining
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60	0
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180	0
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	45 (2.1)	(2.4)	150	0
Delta	(1.3)	(2.0)	(1.9)	(2.4)	90 (1.0)	(1.7)	90	0
Echo	(1.9)	(2.1)	(2.5)	(1.7)	94 (1.4)	26 (1.3)	120	0
Demand (Manhours) Task Card	85	76	141	43	229	26	600	
Remaining	0	0	0	0	0	0		

Since this is the final distribution calculation, simply fill in the manhours for each cell in **Table 6** to calculate the total minimum distribution cost. **Table 32** below shows the final result of the distribution calculation for the northwest corner from **Table 22** through **Table 31**.

Table 32: Final Results for NWC

To / From	Wing	Upper Fuselage	Lower Fuselage	Empennage	Engine	Landing Gear	Supply (Manhours) Worker Groups
Alpha	60 (1.0)	(2.5)	(1.8)	(1.3)	(2.0)	(1.7)	60
Beta	25 (1.6)	76 (2.2)	79 (1.0)	(1.1)	(1.4)	(2.5)	180
Charlie	(1.5)	(1.1)	62 (1.6)	43 (2.5)	45 (2.1)	(2.4)	150
Delta	(1.3)	(2.0)	(1.9)	(2.4)	90 (1.0)	(1.7)	90
Echo	(1.9)	(2.1)	(2.5)	(1.7)	94 (1.4)	26 (1.3)	120
Demand (Manhours) Task Card	85	76	141	43	229	26	600

Below is **Table 33**, which shows the simplified results of the NWC calculation results table in **Table 32**. With the explanation that this NWC calculation works the Alpha group on the wing area with a manhour distribution of 60 manhours, after which it is multiplied by its manhour cost of 1.0. And so on with the other groups to get the total cost. The total minimum cost of the distribution can then be calculated.

Table 33: NWC Manhour Cost

NWC		Work Area	Manhour Distribution	Manhour Cost
Groups	Alpha	Wing	60	1.0
	Beta	Wing	25	1.6
		Upper Fuselage	76	2.2
		Lower Fuselage	79	1.0
	Charlie	Lower Fuselage	62	1.6
		Empennage	43	2.5
		Engine	45	2.1
	Delta	Engine	90	1.0
	Echo	Engine	94	1.4
		Landing Gear	26	1.3

By using the formula (1), the total distribution cost of manhours for northwest corner calculation is 902.8 Manhours.

3.8. Analysis Result

The results of this analysis are based on the results of the Vogel's Approximation Method (VAM) and Northwest Corner (NWC) calculations in the previous section, which can be seen in **Table 34** below:

Table 34: VAM and NWC Analysis Results

VAM		Work Area	Manhour Distribution	Manhour Cost	Manhour Total
Groups	Alpha	Wing	11	1.0	724.5
		Empennage	43	1.3	
		Engine	6	2.0	
	Beta	Lower Fuselage	141	1.0	
		Engine	39	1.4	
	Charlie	Wing	74	1.5	
		Upper Fuselage	76	1.1	
	Delta	Engine	90	1.0	
	Echo	Engine	94	1.4	
		Landing Gear	26	1.3	
NWC		**Work Area**	**Manhour Distribution**	**Manhour Cost**	**Manhour Total**
Groups	Alpha	Wing	60	1.0	902.8
	Beta	Wing	25	1.6	
		Upper Fuselage	76	2.2	
		Lower Fuselage	79	1.0	
	Charlie	Lower Fuselage	62	1.6	
		Empennage	43	2.5	
		Engine	45	2.1	
	Delta	Engine	90	1.0	
	Echo	Engine	94	1.4	
		Landing Gear	26	1.3	

The VAM calculation gives a total of 724.5 manhours and the NWC is 902.8 manhours. The difference in the calculations is 178.3 manhours, therefore the VAM method produces an optimum value because the C-Check work can be completed in a shorter time. Hangar task card assignments are generally based on the availability of manpower and task cards that are ready to be completed, so the Northwest Corner Method approach is more similar. The use of VAM for optimization is expected to result in a more optimal and efficient work time.

In the Maintenance Planning Document (MPD) data, there is a collection of task cards performed by maintenance personnel totaling 864 actual manhours. These results are compared to the results of the VAM and NWC calculations. The C-Check work is completed 139.5 manhours faster when the VAM calculation is used. With the NWC calculation, the C-Check work gets an additional 38.8 manhours, so it increases the work time.

There are advantages and disadvantages to calculating maintenance manhours using the VAM method when implemented with a multiplier factor as the manhour cost. The advantages are that the VAM calculation shows the results of the manhour cost faster than the actual manhours on the task card collection, and the VAM calculation shows the lowest cost results compared to the NWC. The disadvantages are; this method can be done if the value of the multiplier factor is accurately known. It is necessary to collect data from previous C-Check experiences for each group of personnel in order to calculate the multiplier value.

4. Conclusion

The conclusions obtained after performing simulations and calculations is carried out by using the manhour requirement in the task card group as the demand, the capability of each group of maintenance personnel as the supply, and the multiplication factor between actual and maintenance programs as the transportation cost. From the results of the analysis of the optimum allocation using Vogel's Approximation Method, the calculation results obtained are 724.5 manhours and for the Northwest Corner calculation obtained by 902.8 manhours, so there is a difference of 178.3 manhours, thus the calculation of Vogel's Approximation Method obtains optimum results.

Based on the research that has been done, the suggestions that can be given for further research are, the calculations in this study only simulate existing or non-actual problems, so this research needs to be developed again with actual cases based on how they are distributed in the airline hangar. Future research can use different transportation methods or multiplying factor data.

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References

Ackert, S. P. (2010). *Basics of Aircraft Maintenance Programs for Financiers.* http://aircraftmonitor.com/uploads/1/5/9/9/15993320/basics_of_aircraft_maintenance_programs_for_financiers___v1.pdf

Brian, A. (2018). Aplikasi Man Hours Dalam Aktifitas Proyek Untuk Penerapan Manajemen Biaya Proyek Dalam PMBOK. *Jurnal Teknik: Universitas Muhammadiyah Tangerang*, Vol. 7 (1), pp 26-35.

Britta, M. (2021). Mengenal Lebih Jauh Pengertian serta Fungsi Manpower Planning.

https://staffinc.co/post/fungsi-manpower-planning

Cook, B. (2022). Supply and Demand Definition: What is Supply and Demand?. https://tipalti.com/procurement-hub/supply-and-demand/

Das, U. K., Babu, A., Khan, A. R., & Uddin, S. (2014). Advanced Vogel's Approximation Method (AVAM): A New Approach to Determine Penalty Cost for Better Feasible Solution of Transportation Problem. *International Journal of Engineering Research & Technology (IJERT)*. Vol. 3 (1), pp 182-187.

Kartika, R., Basari, M. A., Iskandar, Y., & Adhitia, L. (2019). Optimasi Distribusi Dengan Metode Transportasi. *Jurnal Ilmu Manajemen*. Fakultas Ekonomi Universitas Galuh, pp 189-206.

Kinnison, H. A., & Siddiqui, T. (2014). *Aviation Maintenance Management, Second Edition*. Mc. GrawHill Book Company, New York.

Mahendra, M. R. (2022). Simulasi Distribusi Manpower Pemeliharaan Maskapai X Dengan Metode Northwest Corner, Least Cost, dan Vogel's Approximation Method. *Skripsi*. Universitas Dirgantara Marsekal Suryadarma. Jakarta.

Materiedu9999 (2023). Faktor Pengali: Mengenal Konsep dan Pentingnya dalam Matematika. https://www.caracek.net/faktor-pengali-mengenal-konsep-dan-pentingnya-dalam-matematika/

Meflinda, A., & Mahyarni (2011). *Operations Research (Riset Operasi)*. UR Press, Pekanbaru.

Mora, M. (2012). Literature Review On Aircraft Maintenance Program. Jurnal Penelitian Perhubungan Udara Warta Ardhia, Vol. 38 (4), Hal. 356-372. http://dx.doi.org/10.25104/wa.v38i4.205.356-372

Tabroni, H., Komarudin, M. (2021). *Riset Operasi Penyelesaian Model Transportasi Dengan Cara Manual Dan Software*. Serang, Banten: CV. AA. RIZKY. Hal. 76

Takdir Syaifuddin, D. (2011). *Riset Operasi (Aplikasi Quantitative Analysis For Management)*. Malang: CV Citra Malang. Hal. 147.

Pemerintah, RI. (2009). Undang-Undang No. 13 Tahun 2003 Tentang Penerbangan.

Rachman, T. (2016). Riset Operasional Metode transportasi. http://taufiqurrachman.weblog.esaunggul.ac.id.

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