**END 395 - Operations Research II**

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**PROJECT**

**Cargo Plane Weight Optimization**

**Group 09**

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**ABSTRACT**

Our project focuses on efficiently loading pallets onto aircraft while ensuring weight limits, cumulative weight limits, pallet type compatibility and “Blue Envelope” constraints. We developed an integer model that successfully loads the aircraft with given pallets. Our approach divides the project into 4 parts. First, we loaded pallets to a suitable position in the aircraft. Then, we ensured that the pallets were placed so that they did not overlap each other. After that we took into account the cumulative weight limits. Finally, we calculated the total weight of the aircraft and ensured that the aircraft remained within the Blue Envelope limits. Our model effectively optimizes cargo allocation within the aircraft, maximizing payload capacity based on the provided pallet list.

**Keywords:** Cumulative Weights, Center of Gravity (CG) Intervals, Overlapping

**1. Introduction**

This project aims to address the two-dimensional pallet placement problem for an air cargo company, which currently relies on manual assessments by load-masters. The goal is to develop a mathematical model to automate and streamline this process while enhancing efficiency. The model will consider specific constraints related to pallet placement, aiming to optimize cargo loading for transportation.

* 1. **Characteristics of the Aircraft and Pallets**

The primary pallet types utilized in cargo loading are denoted as PAG and PMC, distinguished by their respective base dimensions of 88" x 125" and 96" x 125".

Cargo aircraft feature main and lower decks, The main deck offers "Single Row" and "Side-by-Side" loading alternatives, while the lower deck has a singular main loading type. Both loading alternatives can become compatible for each pallet type. Each position has a starting lock and an ending lock which secures each pallet to its assigned position.

For each position, the distance from the position’s center to the aircraft’s nose is expressed as the h-arm of the position. Each position for each loading type is associated with specific weight limits and h-arm values for each pallet type.

In addition to the individual weight limits of positions, there is a maximum cumulative weight limit for each position, calculated separately for the front and aft sections. These limits are determined by adding the weights of each position, multiplied by its coefficient, either from smallest h-arm value to the center for the front section or in reverse for the aft section.

The total index is obtained by summing the indices of loaded pallets, while the total weight is obtained by summing the weights of the pallets loaded to that section. These calculations help ensure proper weight distribution and balance throughout the aircraft, crucial for flight safety. For safe and balanced flight, the total weight and total index of the loaded aircraft should fall within a shaded region, referred to as the "Blue Envelope"

**1.2. Overview of Approach**

In this project, we are trying to fill the pallets we have into the aircraft in a way that maximizes the weight carried by the aircraft. While doing this, we are careful to stay within various constraints. The constraints we have can be listed as follows:

* Weight limit should not be exceeded
* The type of pallet and position must be the same
* Pallets should not overlap
* Cumulative weight limit should not be exceeded
* Must stay within the boundaries of Blue Envelope

Before we started working on the model, we decided to divide the model into 4 parts. In this way, we reduced the complexity of the model and approached each step more carefully. Each part has its own scope of topics. Those parts can be listed as follows:

1. Placement
2. Collision
3. Cumulative
4. Blue Envelope

Placement part ensures that we place each pallet into a suitable position, ignoring other pallets' existence. We also make sure that there is at most 1 pallet in each position, and each pallet is at most in 1 position.

Collision part makes sure that pallets do not overlap. This is trickier than it sounds, because the main part of the plane includes “Single Row” and “Side by Side” loading types, each can be adjusted for each pallet type. The data about locks of positions is crucial for this part.

In the cumulative part, we calculate the cumulative weight of each position and ensure that this limit is not exceeded. For the front and aft part, we use different calculations.

The Blue Envelope part ensures safety and balance. For this, we calculated the total weight and total index of the plane. We made sure that total weight and total index falls into the feasible region of safety and balance standards model.

**2. Method**

Our model is as follows

***Sets:***

*= Set of Main Deck position indexes sorted by h-arm values*

*= Set of Lower Deck position indexes sorted by h-arm values*

*= Set of position indexes which is PM concatenated by PL*

*S = pallet indexes*

***Parameters:***

*= Lock1 position of Main Deck position i*

*= Lock2 position of Main Deck position i*

*= Lock1 position of Lower Deck position i*

*= Lock2 position of Lower Deck position i*

*=* *h-arm value of Main Deck position i*

*= h-arm value of Lower Deck position i*

*= cumulative weight of Main Deck position i*

*= cumulative weight of Lower Deck position i*

*= coefficient of Main Deck position i*

*= coefficient of Lower Deck position i*

*= type of Main Deck position i*

*= type of Lower Deck position i*

*= weight of pallet j*

*= type of pallet j*

*Dry Operating Weight*

*Dry Operating Index*

*= weight limit of Main Deck position i*

*= weight limit of Lower Deck position i*

***Decision Variables:***

*= weight of position i*

*= index of position i*

*= total weight*

*= total index*

***Objective Function:***

***Constraints:***

*Part 1:*

*//Ensures That At Max 1 Pallet Could Be Assigned To Each Position*

*//Ensures That Pallets Do Not Exceed The Weight Limit For Each Position.*

*//Ensures That A Pallet Could Be Assigned Only One Positions*

*Main Deck PAG And PMC control*

*Part 2*

*Part3*

Part4

//Calculates Weights And Indices Of Each Position.

This flow chart outlines our models implementation on Python.

A diagram of a flowchart

Description automatically generated

**3. Results and Alternative Solutions**

For each given pallet list, the optimal solutions are follows:

**Pallets 1**

|  |  |
| --- | --- |
| Objective Function Value | 57350 |
| Solution Time | 12 seconds average |
| Percentage Gap | 100% |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pallets** | **Positions** |  | **Pallets** | **Positions** |
| PMC22 | ABR(96) |  | PAG29 | STL(88) |
| PMC3 | ABL(96) |  | PAG8 | U |
| PMC21 | CC |  | PMC30 | UU |
| PMC19 | EFL(96) |  | PMC2 | VV |
| PAG10 | G |  | PMC1 | 11P(96) |
| PMC17 | HJR(96) |  | PMC5 | 12P(96) |
| PAG12 | HJL(88) |  | PAG25 | 21P(88) |
| PMC20 | JKR(96) |  | PAG23 | 22P(88) |
| PAG6 | JKL(88) |  | PMC13 | 23P(96) |
| PAG28 | KMR(88) |  | PAG24 | 24P(88) |
| PMC16 | KML(96) |  | PMC15 | 31P(96) |
| PAG9 | MPL(88) |  | PAG27 | 32P(88) |
| PAG26 | PSR(88) |  | PMC14 | 33P(96) |
| PAG11 | PSL(88) |  | PMC18 | 41P(96) |
| PMC4 | STR(96) |  | PAG7 | 42P(88) |

**Pallets 2**

|  |  |
| --- | --- |
| Objective Function Value | 62300 |
| Solution Time | 24 seconds average |
| Percentage Gap | 96.875% |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pallets** | **Positions** |  | **Pallets** | **Positions** |
| PAG1 | PSL(88) |  | PMC17 | 23P(96) |
| PAG2 | CER(88) |  | PMC18 |  |
| PAG3 | STR(88) |  | PMC19 | 41P(96) |
| PAG4 | STL(88) |  | PMC20 | VV |
| PAG5 | FHR(88) |  | PAG21 | V |
| PAG6 | 42P(88) |  | PAG22 | 24P(88) |
| PMC7 | FHL(96) |  | PAG23 | BCR(88) |
| PMC8 | MPL(96) |  | PAG24 | KMR(88) |
| PMC9 | 33P(96) |  | PAG25 | KML(88) |
| PMC10 | EE |  | PAG26 | ABL(88) |
| PMC11 | SS |  | PMC27 | 22P(96) |
| PAG12 | 12P(88) |  | PMC28 | 21P(96) |
| PAG13 | JKR(88) |  | PMC29 | 31P(96) |
| PAG14 | JKL(88) |  | PMC30 | MPR(96) |
| PAG15 | PSR(88) |  | PMC31 | HJL(96) |
| PAG16 | 32P(88) |  | PMC32 | HJR(96) |

**Pallets 3**

|  |  |
| --- | --- |
| Objective Function Value | 49900.0 |
| Solution Time | 8 seconds average |
| Percentage Gap | 92.5% |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pallets** | **Positions** |  | **Pallets** | **Positions** |
| PAG1 | 41P(88) |  | PAG21 | FHR(88) |
| PAG2 | MPR(88) |  | PAG22 | BCR(88) |
| PAG3 | KML(88) |  | PAG23 | BCL(88) |
| PAG4 | 21P88) |  | PAG24 | KMR(88) |
| PAG5 | PSR(88) |  | PAG25 | 11P(88) |
| PAG6 | PSL(88) |  | PAG26 | HJL(88) |
| PMC7 | TT |  | PMC27 | SS |
| PMC8 | JKR(96) |  | PMC28 | ABR(96) |
| PMC9 | 33P(96) |  | PMC29 | FHL(96) |
| PMC10 | 23P(96) |  | PMC30 | EFR(96) |
| PMC11 | 24P(96) |  | PMC31 | 32P(96) |
| PAG12 | HJR(88) |  | PMC32 | STL(96) |
| PAG13 | Y |  | PMC33 | EFL(96) |
| PAG14 | MPL(88) |  | PMC34 | CER(96) |
| PAG15 | 42P(88) |  | PMC35 | ABL(96) |
| PAG16 | JKL(88) |  | PMC36 | UU |
| PMC17 |  |  | PMC37 |  |
| PMC18 |  |  | PMC38 | 12P(96) |
| PMC19 | STR(96) |  | PMC39 | 31P(96) |
| PMC20 | CEL(96) |  | PMC40 | 22P(96) |

**4. Conclusions and Recommendations**

**4.1. Conclusions**

The main purpose of our developed model is to address the pallet placement problem for an air cargo company. This entails automating and streamlining the pallet placement process while enhancing efficiency and adhering to specific constraints related to aircraft characteristics.

By carefully considering various constraints like pallet dimensions, loading options, safety standards, and weight limits, we've built a thorough framework for optimizing cargo loading. Our model guarantees balanced weight distribution across the aircraft, boosting efficiency and safety in air cargo transport.

Drawing from existing literature and research, we analyzed various approaches and optimization techniques relevant to pallet placement. This foundational knowledge informed the design and formulation of our mathematical model.

We collected and analyzed relevant data on aircraft characteristics, such as pallet dimensions, deck layouts and weight limits to inform the development of our model. Leveraging computational tools and software, we implemented and tested the model to ensure its accuracy and reliability in handling different scenarios and constraints.

We used a comprehensive process that included analysis, modeling, and implementation to create a strong framework for optimizing pallet placement. Our model addresses the unique constraints of air cargo companies, improving efficiency and safety in pallet operations.

In summary, our model efficiently solves the complex task of placing pallets in two-dimensional spaces for air cargo companies. We've automated and improved the process using a mixed integer model, ensuring all constraints are met.

**4.1. Recommendations**

Even though our model solves the pallet placement problem, there are still some constraints we have not considered yet. Such as right-left balance, chemical pallets, importance of pallets depending on where they should be unloaded. Future studies may expand the model by taking such constraints into account. Our model is suitable to extend the constraints for such situations.

This model we created is only valid for a single aircraft. Future studies may adapt this model for different types of aircraft, and even trains and cargo ships. These applications will be crucial in easing the load on the transportation sector, which stands as one of the largest sectors in the 21st century.