END395
Operations Research II
Term Project
Spring 2024

In this project, you will work on a two-dimensional pallet placement problem of an air cargo company that transports variety of cargo loaded pallets. Presently, the company relies on manual assessments by load-masters to determine the placement of each pallet based on specific constraints. Your task is to develop a comprehensive mathematical model that not only streamlines this process but also enhances its efficiency.

Air cargo companies employ a diverse fleet of aircraft, many of which were initially intended for passenger transport (with the potential inclusion of dedicated air cargo freighter aircraft). The loading process requires careful consideration of a series of intricate constraints, encompassing both load-specific and aircraft-specific considerations. This involves accommodating pallets with diverse priorities, sizes, weights, and unique properties such as chemical, radioactive, or live freight. These constraints are summarized as follows.

PAG and PMC represent the primary pallet types employed in cargo loading, characterized by base dimensions of 88" x 125" and 96" x 125", respectively. Notably, this problem focuses exclusively on the two-dimensional aspects of these pallets, with height being disregarded. Compatibility with specific loading types (as described in the next paragraph) is essential for the successful loading of these pallets.

Cargo aircraft feature main and lower decks, as depicted in Figure 1. Each type of aircraft deck is equipped with distinct loading types. The main deck offers "Single Row" and "Side-by-Side" loading alternatives, while the lower deck has a singular main loading type. It's crucial to adhere to compatibility rules, where, for instance, a PAG pallet fits on Single Row (88" x 125") but not on Single Row (96" x 125"). This principle applies consistently across all loading types, whether on the main or lower deck. For each loading type, there exist non-overlapping positions where pallets can be securely loaded and locked. Figure 2 visually outlines these positions for each loading type, accompanied by the upper weight limit (max. load in kg.s) for the loaded pallet to each position.

While positions within the same loading types are compatible, ensuring no overlap, certain positions across different loading types may intersect due to interconnected position locks (refer to Figure 3). For instance, in a cargo flight, one PAG (88" x 125") pallet might be assigned to position A through the Single Row loading type. Simultaneously, a distinct PMC (96" x 125") pallet can be loaded onto position BCL using the Side By Side Loading type in the same cargo flight, given

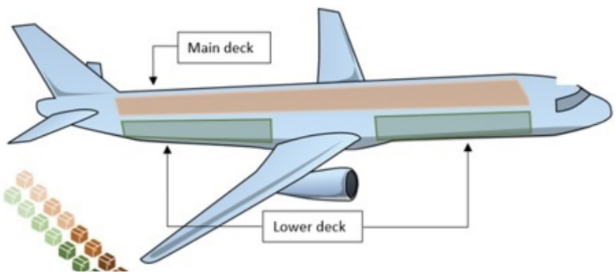


Figure 1: An air cargo aircraft.

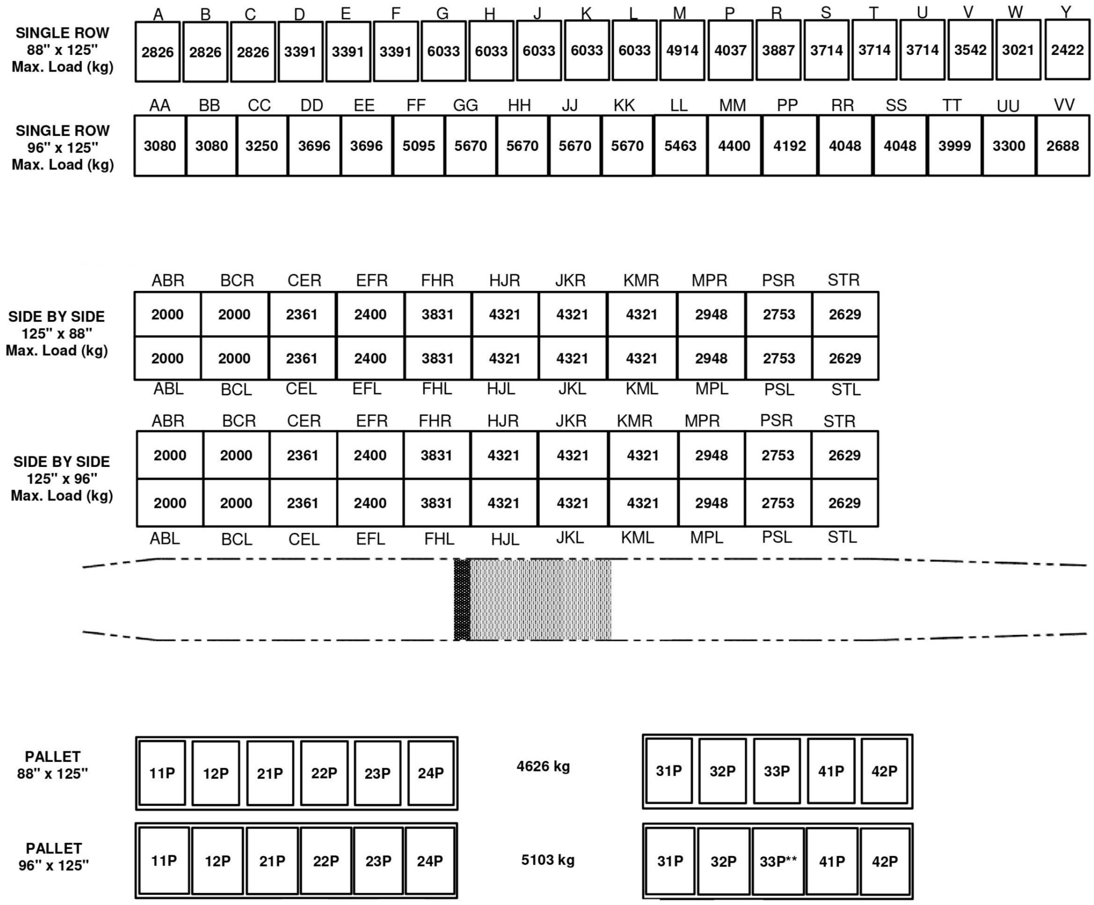


Figure 2: Detailed demonstration of positions for each loading type and their weight limits.

that these two positions do not overlap. This highlights that both the loading type and position decisions are specific to each pallet. To secure each pallet to its assigned position, each position has a starting lock and an ending lock, represented by their distances to the aircraft's nose in meters. The determination of overlapping positions relies on the distances of these locks to the aircraft's nose. Specifically, if any position's starting lock (or ending lock) is between the starting and ending locks of another position, then these two positions overlap. Additionally, for each position, the distance from the position's center to the aircraft's nose is expressed as the **h-arm** of the position.

Given the potential for overlap between positions of different loading types and recognizing the pallet-specific nature of loading type and position decisions, it is crucial to avoid assigning two pallets to positions that may overlap. To summarize, **each position for each loading type is associated with specific weight limits and h-arm values for each pallet type. Assigning available pallets to positions is contingent on factors such as pallet type compatibility, adherence to weight limit constraints, and careful consideration of potential overlapping issues. It is pivotal to emphasize that each loaded pallet should be assigned to exactly one position**.

In addition to the individual weight limits of positions, there is **a maximum cumulative weight limit for each position**. This cumulative weight limit is calculated separately for the front and aft sections of the aircraft. In the front section, the cumulative weight is obtained by summing the weights of each position, multiplied by its coefficient, from the one with the smallest h-arm value to the highest, moving towards the center. Conversely, the cumulative weight for the aft section is calculated in reverse, from the highest h-arm value to the center. **It is crucial to ensure that the cumulative weight of each loaded position stays within its limits.**

Figure 3: Inside of an empty cargo aircraft with a clear view of locks for each position

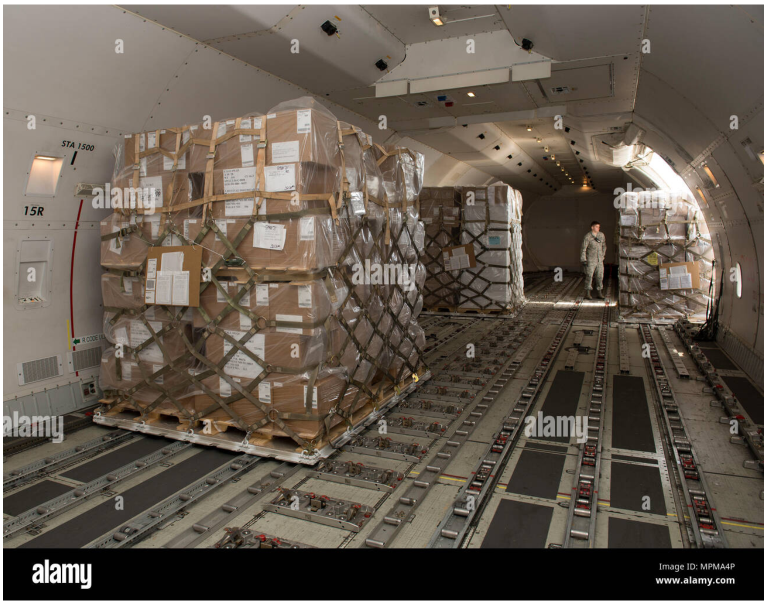


Figure 4: Pallet loading process: Third pallet is being transferred to its assigned position.

(**Note 1:** Cumulative weight limit check will not be considered for positions in the center part of the aircraft. In the dataset, you can identify these positions with "0" for both cumulative limit and coefficient.)

(**Note 2:** The front side of the aircraft includes positions from position "A" to position "J," ordered by h-arm values. Every position after position "J" is considered in the aft section.)

To ensure a safe flight through a balanced loading, the following index calculations and further weight and index based limits should also be ensured. The index value of each position p is calculated based on the formula provided in Equation 1 using the pallet's weight (denoted as w_p) loaded to that position and the position's h-arm value (h_p^{arm}). Summing the indices and weights of the pallets loaded to the front, total index and total weight of front section should be calculated as $I^{(F)}$ and $W^{(F)}$, respectively. Similarly, by summing the the indices and weights of the pallets loaded to the front, the total index and total weight of aft section should be calculated as $I^{(A)}$ and $W^{(A)}$. While calculating total weight (W) and total index (I) of the aircraft, the aircraft's dry operating weight, indicated by $w^{(DOW)}$ and the aircraft's dry operating index, indicated by $i^{(DOI)}$, must be included according to Equations 2 and 3, respectively. For safe and balanced flight, the weight and index of the loaded aircraft should fall within the shaded region, referred to as the "Blue Envelope" (see Figure 5).

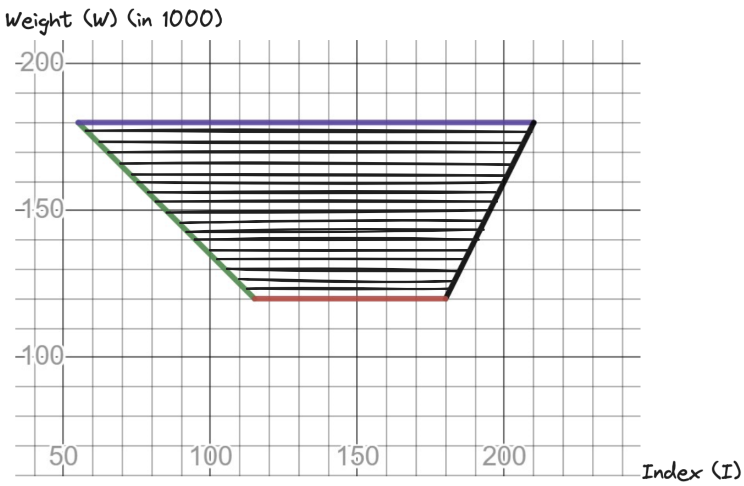
$$i_p = \frac{(h_p^{arm} - 36.3495)w_p}{2500} \tag{1}$$

$$W = W^{(F)} + W^{(A)} + w^{(DOW)} \tag{2}$$

$$I = I^{(F)} + I^{(A)} + i^{(DOI)} \tag{3}$$

$$\tag{4}$$

Figure 5: Blue Envelope (Vertical axis = Aircraft Weight x 1000, Horizontal axis = Index)



The main objective is to maximize the loaded pallet weight considering all these constraints.

Part I

- Deadline: March, 15, 2024 - Friday 18:30 (**A maximum of three days of latency is permitted, with a penalty of 20 points for each day beyond the deadline.**)
- **Formulate the problem as a mixed integer problem (MIP)** where the objective is to maximize the total weight of pallets loaded on the aircraft for a given pallet list. Note that, few pallets in the list may not be loaded. The project report should provide a clear description of
  - the decision variables,
  - the objective function, and
  - constraints
- **Time schedule and submission requirements:** The data for three problem instances are provided. In the project report, provide the following results of each instance in a Results table
  - the objective function value of the best found solution,
  - the solution time (CPU time) of your model, and
  - the percentage gap attained at the end of the run (if you couldn't obtain the optimal solution)
- Project report should be prepared in English and should include all the necessary information specified above. Report format will be announced later and you should prepare your reports in the correct format to get full credit.

- You must submit all your project files (including data sets you used) in a described format. The format will be announced later.
- Submissions and all project related questions should be sent to the course e-mail address. Mails that are sent to the individual e-mail addresses of TA's will not be responded.

Part II

- Deadline: April, 5, 2024 - Friday 18:30 (**A maximum of two days of latency is permitted, with a penalty of 25 points for each day beyond the deadline.**)
- In this part of the project, you will assume all the pallets can be loaded. Recalling from previous cumulative weight check constraint, you were checking only one cumulative limit per position. In this part, there are four possible maximum cumulative weight limits corresponding to four Center of Gravity (CG) Intervals. However, only one interval can be selected for each run. Two separate positions cannot have a different cumulative limits from different intervals. For example, if "CG Interval 3" is selected for this run, all positions' cumulative limit must satisfy the limits of "CG Interval 3".
- In terms of fuel consumption, the CG interval order from best to worst is "2", "1", "3", "4". Your goal is to find a loading configuration that optimizes the fuel consumption.
- You may consider two of the following additional features separately to receive extra points. You can receive extra points only if your part II model covers all requirements.

  - **Bonus 1 (10 points): Pallet-Specific Loading Type-Position-Location Restrictions**

    In the first part of the project, pallets can be placed in any position or location. However, in this variant, certain pallets may have restrictions, such as loading type, position, or location (e.g., front-lower, aft-main). For instance, "pallet1" can only be loaded through the side-by-side (SBS) loading type, "pallet2" can only be loaded using the single-row (SR) loading type, "pallet3" is restricted to position ABR(96), "pallet4" is restricted to position SS, "pallet5" is designated for the front side of the lower deck, and "pallet6" is designated for the aft side of the lower deck.

  - **Bonus 2 (10 points): Neighboring Pallets**

    In the first part of the project, there was no constraint regarding binding two pallets together. However, in this variant, there may be a requirement for two pallets to be loaded together, and they cannot be separated. For instance, consider "pallet1" and "pallet2" as neighboring pallets. If "pallet1" is loaded in position "BB," then "pallet2" must be loaded in either position "AA" or "CC," and different loading types are not permitted in this scenario.

- Data instances for this part and the bonus variants will be provided later.
- **For Part II, please explicitly specify the modifications made to the original MIP model submitted in Part I and present a comprehensive formulation of the modified model. Additionally, include detailed explanations for any modifications made for bonuses if achieved.** The project report should provide a clear description of **adjustments** or **augmentations** in the **decision variables, objective function, and/or constraints.**

- **In the project report, you must provide:**
  - the following results of each instance in a Results table
    - the objective function value of the best found solution
    - the solution time (CPU time) of your model
    - the "% gap" attained at the end of the corresponding run
  - a discussion on the difficulty of the instances based on the results in your Results table