FACULTY OF COMPUTER SCIENCE AND INFORMATION TECHNOLOGY

CSC4202

DESIGN AND ANALYSIS OF ALGORITHM

GROUP PROJECT:

JOB SCHEDULING FOR MAXIMUM PROFIT

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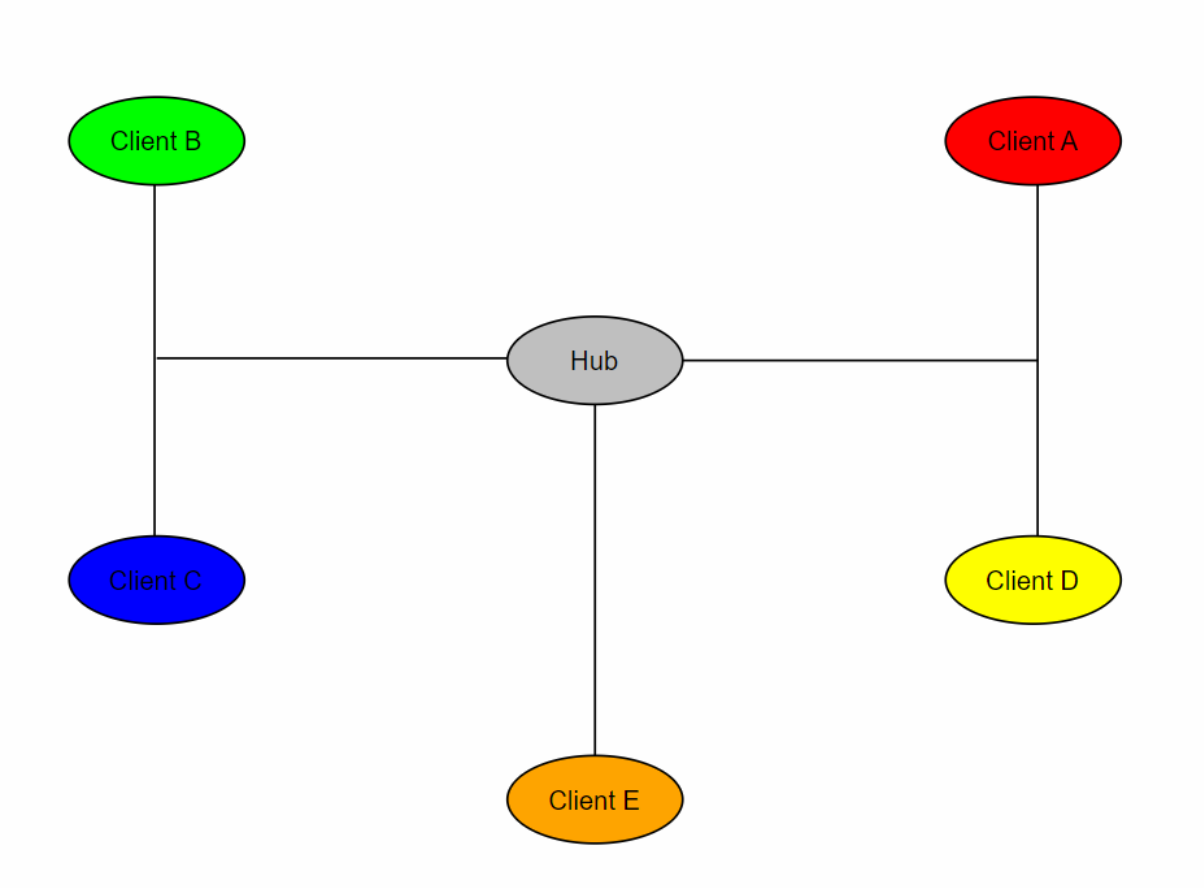
1.0 Problem Scenario



Hub:

- Central point where drones start their delivery routes.
- All delivery jobs originate from the Hub.

Clients:

- **Client A**: Located to the northeast of the Hub.
- **Client B**: Located to the northwest of the Hub.
- **Client C**: Located to the southwest of the Hub.
- **Client D**: Located to the southeast of the Hub.
- **Client E**: Located directly south of the Hub.

Routes:

- Straight lines represent the delivery routes from the Hub to each client.
- Connections illustrate the possible paths the drones can take to deliver to each client.

In a bustling metropolitan area, a drone delivery service company, "QuickDrop," operates to ensure packages are delivered promptly and efficiently. Each delivery job has a deadline (by when it must be completed) and a profit associated with it. The company aims to maximize its total profit by optimally scheduling deliveries within their respective deadlines.

Geographical Setting: The city is divided into several zones, each with varying traffic conditions and distances. The scheduling must account for these factors to ensure timely deliveries.

Type of Disaster: Not applicable in this scenario.

Damage Impact: Delays in deliveries can lead to customer dissatisfaction, loss of future business, and reduced profits.

Importance: Finding an optimal solution for this scenario is crucial because it maximizes the company's revenue, ensures timely deliveries, enhances customer satisfaction, and improves operational efficiency.

Goal and Expected Output: The goal is to develop an algorithm that schedules jobs to maximize total profit while meeting all deadlines. The expected output is a schedule that lists the jobs to be completed within their deadlines and the total profit achieved.

2.0 Development of a Model

2.1 Data Types:

- Jobs: Represented as an array of Job objects, each containing (jobId, deadline, profit). For example:
    - jobId (String)
    - deadline (int)
    - profit (int)
- Example:
    - Job 1: ('A001', 2, 100)
    - Job 2: ('B002', 1, 50)
    - Job 3: ('C003', 2, 150)

2.2 Objective Function:

- Maximize Total Profit: To maximize the total profit by selecting jobs that can be completed within their deadlines.

2.3 Constraints:

- Deadline Constraint: Each job must be completed by its deadline.
    - Example: If a job has a deadline of 2, it can only be scheduled in time slots 1 or 2.
- Non-Overlapping Constraint: No two jobs can be scheduled at the same time slot.
    - Ensures that only one job is assigned per time slot.

2.4 Other Requirements:

- Space Constraint:
    - Use space proportional to the number of jobs and the maximum deadline O(n + d).
    - Includes arrays to store jobs and scheduled jobs.
- Time Constraint:
    - Sorting: O(n log n) for sorting jobs by profit.
    - Scheduling: O(n * d) for scheduling jobs up to their deadlines.
- Value Constraint:
    - Profits and deadlines must be positive integers.

Example:

- Profit Values: All job profits are positive integers.
- Deadlines: All deadlines are positive integers.

2.5 Simple Example:

Job ID	Client	Deadline (time units)	Profit
A001	Client A	3	100
B002	Client B	2	80
C003	Client C	1	60
D004	Client D	2	40
E005	Client E	1	20

Scheduling Algorithm Explanation

A **Greedy Algorithm** is used to prioritize jobs based on profit and schedules them within their deadlines. This approach ensures the maximum profit while adhering to job deadlines and operational constraints.

Example Scheduling Using Greedy Algorithm

1. **Sort Jobs by Profit**:
    - Jobs sorted by profit: 1, 2, 3, 4, 5

2. **Schedule Jobs**:
    - **Slot 1**: Job 3 (Client C, Deadline = 1, Profit = 60)
    - **Slot 2**: Job 2 (Client B, Deadline = 2, Profit = 80)
    - **Slot 3**: Job 1 (Client A, Deadline = 3, Profit = 100)

3. **Total Profit Calculation**:
    - Total Profit = 60 (Job 3) + 80 (Job 2) + 100 (Job 3) = 240

Scheduled Jobs	Total Profit	Scheduled Time Slots
['3', '2', '1']	240	['3' at Slot 1, '2' at Slot 2, '1' at Slot 3]

3.0 Specification of an Algorithm

3.1 Comparison with Other Algorithms:

	Strengths	**Weakness**
Divide and Conquer (DAC)	Efficient for certain types of problems, easy to parallelize.	Not suitable for problems requiring global optimization.
Dynamic Programming (DP)	Provides optimal solutions by considering all possible solutions.	High memory and time complexity.
Greedy Algorithm	Simple to implement, efficient for many problems, provides good approximate solutions.	May not always provide the optimal solution.
Graph Algorithms	Suitable for network flow and connectivity problems.	Complex implementation for job scheduling problems.

3.1.1 Divide and Conquer (DAC):

- Strengths: DAC is highly effective for problems that can be broken down into smaller subproblems, solved independently, and then combined to form the solution for the original problem. Examples include sorting algorithms like QuickSort and MergeSort.
- Weaknesses: DAC may not be the best choice for problems requiring global optimization, like job scheduling, where the solution to a subproblem depends on the solutions to other subproblems. It can fail to consider dependencies between subproblems, leading to suboptimal solutions.

3.1.2 Dynamic Programming (DP):

- Strengths: DP systematically explores all possible solutions by storing the results of subproblems, ensuring that the optimal solution is found. It is effective for optimization problems where overlapping subproblems and optimal substructure are present.
- Weaknesses: DP often requires significant memory to store the results of subproblems, which can be problematic for large-scale problems.

3.1.3 Greedy Algorithm:

- Strengths: Greedy algorithms are typically straightforward to design and implement, making them accessible for a wide range of problems.
- Weaknesses: Greedy algorithms make decisions based on local optimization, which can sometimes lead to suboptimal global solutions. They are not guaranteed to find the best solution for all problems.

3.1.4 Graph Algorithm:

- Strengths: Graph algorithms excel in solving problems related to network flow, shortest paths, and connectivity. They are powerful tools for a wide range of applications, from internet routing to social network analysis.
- Weaknesses: While graph algorithms can be used for scheduling problems by modelling jobs and dependencies as graphs, the implementation can be complex. It often involves sophisticated data structures and a deep understanding of graph theory.

3.2 Chosen Algorithm: Greedy Algorithm

1. Suitability for Job Scheduling: Greedy algorithms are particularly well-suited for job scheduling problems where jobs need to be selected based on specific criteria (e.g., profit) and fit within given constraints (e.g., deadlines).
2. Efficiency: The greedy approach allows for quick decision-making, which is crucial for operational efficiency in a real-time environment like drone delivery.
3. Implementation: The implementation of a greedy algorithm is straightforward, making it easier to develop, test, and maintain compared to more complex algorithms like dynamic programming or graph-based approaches.
4. Good Approximation: While not always optimal, the greedy algorithm often yields solutions that are very close to the best possible outcome, especially in scenarios where making the locally optimal choice leads to a near-optimal global solution

4.0 Designing an Algorithm

4.1 Algorithm Paradigm Explanation

This paradigm involves making the locally optimal choice at each step with the hope of finding a global optimum.

4.1.1 Key Components

1. Sorting Jobs by Profit: - Purpose: To prioritize jobs with the highest profit. - Process: Jobs are sorted in descending order based on their profit.

2. Iterative Scheduling: - Purpose: To schedule jobs in the available time slots up to their deadlines. - Process: - Iterate through the sorted jobs. - For each job, find the latest available time slot before its deadline. - If an available slot is found, schedule the job and update the total profit.

4.1.2 Recurrence and Optimization

- Recurrence: There is no explicit recurrence relation in this greedy approach. *Instead, the algorithm iteratively makes the best local decision (highest profit job that fits) and moves on to the next job.
- Optimization Function: The optimization function here is the total profit, which is incrementally updated as jobs are scheduled.

```
for (int j = Math.min(maxDeadline - 1, jobs[i].deadline - 1); j >= 0; j--) {
      if (result[j] == null) {
          result[j] = jobs[i];
          totalProfit += jobs[i].profit; (Optimization Part)
          break;
      }
 }
```

4.2 Code Breakdown

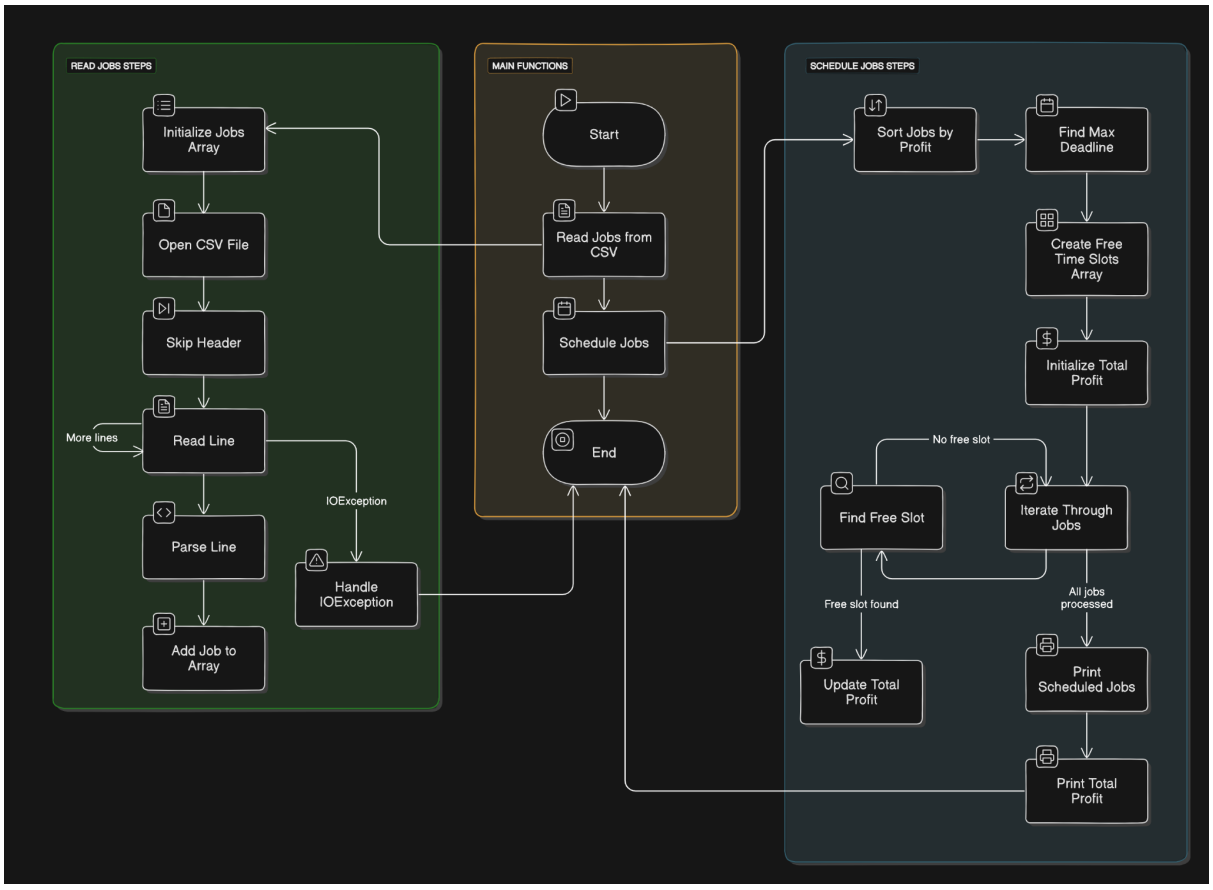
- Sorting: Arrays.sort(jobs, (a, b) -> b.profit - a.profit);
    - Time Complexity: O(n log n)
- Scheduling: Iterate through each job and find a free slot from its deadline backward.

- For each job:

```
for (int j = Math.min(maxDeadline - 1, jobs[i].deadline - 1); j >= 0; j--
    if (result[j] == null) {
        result[j] = jobs[i];
        totalProfit += jobs[i].profit;
        break;
    }
}
```

- Time Complexity: (×), where d is the maximum deadline.

4.3 Flowchart



5.0 Checking the Correctness of an Algorithm

5.1 Greedy Choice Property

The greedy choice property ensures that making a locally optimal choice (choosing the highest profit job that fits within its deadline) leads to a globally optimal solution.

5.2 Optimal Substructure

Optimal substructure means that an optimal solution to the problem contains optimal solutions to its subproblems. For the job scheduling problem, this implies that if we schedule the most profitable jobs first, the remaining jobs will still form an optimal schedule for the remaining slots.

5.3 Steps in the Code:

1. Reading Jobs from CSV File:
    - This part of the code reads jobs from a CSV file and stores them in an array.
    - Time Complexity: O(n), where n is the number of jobs (assuming the file reading and parsing are linear operations).

2. Sorting Jobs by Profit:
    - The jobs are sorted in descending order of profit.
    - Time Complexity: O(n log n), as the sorting operation (using Arrays.sort) is based on a comparison-based sorting algorithm.

3. Finding the Maximum Deadline:
    - The maximum deadline among all jobs is determined by iterating through the jobs array.
    - Time Complexity: O(n).

4. Scheduling Jobs:
    - An array is used to keep track of free time slots.
    - The algorithm iterates through the sorted jobs and tries to schedule each job in the latest possible slot before its deadline.
    - For each job, it checks up to the maximum deadline slots to find a free slot.
    - Time Complexity: O(n • d), where d is the maximum deadline.

5. Printing Results:
    - The scheduled jobs and total profit are printed.
    - Time Complexity: O(d), since it prints based on the number of time slots (maximum deadline).

5.4 Combined Time Complexity:

The overall time complexity of the algorithm is determined by the dominant terms from each step:

1. Reading Jobs: O(n)
2. Sorting Jobs: O(n log n)
3. Finding Maximum Deadline: O(n)
4. Scheduling Jobs: O(n • d)
5. Printing Results: O(d)

The total time complexity is the sum of these complexities:
I (n) = 0(n) + O(n log n) + O(n) + O(n •d) + 0(d)
Since O(n log n) and On • d) are the dominant terms, the final time complexity is:
T (n) = 0(n log n) + O(n•d)

5.5 Recurrence Relation:

The recurrence relation describes how the time complexity grows with the input size. The code doesn't have a recursive structure, so instead, we derive the relation based on the iterative steps:

1. Sorting step:
T_{sort} (n) = O(nlogn)

2. Scheduling step:
$T_{schedule}$ (n, d) = O(n • d)

Combining these, we get the overall time complexity:
T(n, d) = O(n log n) + O(n •d)

5.4 Summary

- Asymptotic Time Complexity: O(n log n) + O(n.d)
- Recurrence Relation: T(n,d) = O(n log n) + O(n.d)

6.0 Analysis of an Algorithm Growth of Function for Worst, Best, Average Analysis

6.1 Worst-Case Analysis

- The worst-case scenario occurs when the algorithm has to perform the maximum number of operations.
    - For the job scheduling algorithm, this happens when:
        - Sorting Jobs by Profit: This is always (log) because sorting needs to be done irrespective of the job deadlines or profits.
        - Finding the Maximum Deadline: This is ( ) as it requires scanning through all jobs.
        - Scheduling Jobs: In the worst case, each job needs to be checked against all deadlines to find an available slot. This involves nested loops where the outer loop runs times (for each job) and the inner loop runs up to times (the maximum deadline).
- Thus, the worst-case time complexity is: ( )( ) = (log) + ( ) + ( ) = (log +)

6.2 Best-Case Analysis

- The best-case scenario happens when each job can be placed in its slot immediately without needing to check multiple slots.
    - However, since the algorithm always sorts the jobs, the best-case time complexity is still influenced by the sorting step:
        - Sorting Jobs by Profit: This is (log)
        - Finding the Maximum Deadline: This is ( ).
        - Scheduling Jobs: Each job is placed in its slot without conflicts. This is still ( ) as it needs to check each slot to confirm it's free, even if it's optimal.
- Thus, the best-case time complexity is: ( )( ) = (log) + ( ) + ( ) = (log +)

6.3 Average-Case Analysis

- The average-case scenario is typically more complex to analyze theoretically because it involves the expected number of operations over all possible inputs
    - However, for this algorithm, it also involves sorting and scheduling which are influenced similarly to the worst and best cases:
        - Sorting Jobs by Profit: This is (log)
        - Finding the Maximum Deadline: This is ( ).
        - Scheduling Jobs: On average, we still need to check multiple slots for each job, but this number is generally around half the maximum deadline.
- Thus, the best-case time complexity is: ( )( ) = (log) + ( ) + ( ) = (log +)

6.7 Table Comparing the Worst-Case, Best-Case, and Average-Case

Analysis Type	Sorting Jobs by Profit	Finding the Maximum Deadline	Scheduling Jobs	Overall Time Complexity	Where it Happens
Worst-Case	O(n log n)	O(n)	O(n·d)	O(nlogn+n·d)	When each job must be checked against all deadlines
Best-Case	O(n log n)	O(n)	O(n·d)	O(nlogn+n·d)	When each job is placed in its slot without conflicts
Average-Case	O(n log n)	O(n)	O(n·d)	O(nlogn+n·d)	Generally half the maximum deadline slots checked

The reason the time complexity (log +) remains the same in the worst-case, best-case, and average-case scenarios is because of the nature of the operations involved

- Consistency Across Cases:
  - Sorting always takes (log)
  - Finding the maximum deadline is ( )
  - Scheduling jobs, in the worst case, needs to check up to slots for each job, resulting in ( )

7.0 Implementation of an Algorithm

// Job.java

```
public class Job {
  String jobId;
  int deadline;
  int profit;
```

```
public Job(String jobId, int deadline, int profit) {
    this.jobId = jobId;
    this.deadline = deadline;
    this.profit = profit;
}
}
```

// JobScheduler.java

```
import java.io.BufferedReader;
import java.io.FileReader;
import java.io.IOException;
import java.util.Arrays;

public class JobScheduler {

  //Function to schedule jobs to maximize total profit
  public static void scheduleJobs(Job[] jobs) {
      // Sort jobs by profit in descending order
      Arrays.sort(jobs, (a, b) -> b.profit - a.profit);

      int n = jobs.length;

      // Find the maximum deadline
      int maxDeadline = 0;
      for (Job job : jobs) {
          if (job.deadline > maxDeadline) {
              maxDeadline = job.deadline;
          }
      }

      // Create an array to keep track of free time slots
      Job[] result = new Job[maxDeadline];
      int[] timeSlots = new int[maxDeadline];

      // Keep track of total profit
      int totalProfit = 0;

      // Iterate through all given jobs
      for (int i = 0; i < n; i++) {
          // Find a free time slot for this job (start from the last possible slot)
          for (int j = Math.min(maxDeadline - 1, jobs[i].deadline - 1); j >= 0; j--) {
              // Free slot found
              if (result[j] == null) {
                  result[j] = jobs[i];
                  timeSlots[j] = j + 1; // record the slot (1-based index)
                  totalProfit += jobs[i].profit;
                  break;
              }
          }
      }
```

```
        // Print the scheduled jobs
        System.out.println("Scheduled Jobs:");
        for (int i = 0; i < maxDeadline; i++) {
            if (result[i] != null) {
                System.out.println("Job ID: " + result[i].jobId + ", Profit: " + result[i].profit + ", Scheduled Time
Slot: " + timeSlots[i]);
            }
        }

        // Print the total profit
        System.out.println("Total Profit: " + totalProfit);
    }

    public static Job[] readJobsFromCSV(String filePath) {
        Job[] jobs = new Job[50];
        String line;
        int index = 0;

        try (BufferedReader br = new BufferedReader(new FileReader(filePath))) {
            br.readLine(); // Skip header
            while ((line = br.readLine()) != null) {
                String[] values = line.split(",");
                jobs[index++] = new Job(values[0], Integer.parseInt(values[1]), Integer.parseInt(values[2]));
            }
        } catch (IOException e) {
            e.printStackTrace();
        }

        return Arrays.copyOf(jobs, index); // Adjust size of array to actual number of jobs read
    }

    public static void main(String[] args) {
        String filePath = "data\\jobs_dataset.csv"; // Update with the actual path to the CSV file
        Job[] jobs = readJobsFromCSV(filePath);
        scheduleJobs(jobs);
    }
}
```

8.0 Sample Output

```
Scheduled Jobs:
Job ID: E056, Profit: 50, Scheduled Time Slot: 1
Job ID: R090, Profit: 55, Scheduled Time Slot: 2
Job ID: X056, Profit: 55, Scheduled Time Slot: 3
Job ID: O060, Profit: 60, Scheduled Time Slot: 4
Job ID: Y078, Profit: 65, Scheduled Time Slot: 5
Job ID: X600, Profit: 60, Scheduled Time Slot: 6
Job ID: T056, Profit: 60, Scheduled Time Slot: 7
Job ID: B200, Profit: 70, Scheduled Time Slot: 8
Total Profit: 475
```

8.1 Output Explanation:

- Job ID: E056, Profit: 50, Scheduled Time Slot: 1
    - This job with a profit of 50 is scheduled at the earliest available slot, which is slot 1.
- Job ID: R090, Profit: 55, Scheduled Time Slot: 2
    - This job with a profit of 55 is scheduled in slot 2.
- Job ID: X056, Profit: 55, Scheduled Time Slot: 3
    - This job with a profit of 55 is scheduled in slot 3.
- Job ID: O060, Profit: 60, Scheduled Time Slot: 4
    - This job with a profit of 60 is scheduled in slot 4.
- Job ID: Y078, Profit: 65, Scheduled Time Slot: 5
    - This job with a profit of 65 is scheduled in slot 5.
- Job ID: X600, Profit: 60, Scheduled Time Slot: 6
    - This job with a profit of 60 is scheduled in slot 6.
- Job ID: T056, Profit: 60, Scheduled Time Slot: 7
    - This job with a profit of 60 is scheduled in slot 7.
- Job ID: B200, Profit: 70, Scheduled Time Slot: 8
    - This job with a profit of 70 is scheduled in slot 8.

Total Profit: 475

- The sum of the profits of the scheduled jobs: (50 + 55 + 55 + 60 + 65 + 60 + 60 + 70 = 475).

8.2 Explanation of Scheduling:

The algorithm follows these steps:

1. Sort Jobs by Profit in Descending Order:
    - Jobs are sorted based on their profit, with the highest profit job considered first. This is why the job with the highest profit (B200, profit 70) is considered before others.
2. Schedule Jobs:
    - The algorithm schedules each job in the latest possible slot before its deadline. It starts from the highest profit job and tries to place it in the nearest available slot to its deadline, moving backward if needed.

For example, let's take a closer look at the first few jobs in the sorted order and how they were scheduled:

- Job B200 with a profit of 70 is scheduled in slot 8.
- Job Y078 with a profit of 65 is scheduled in slot 5.
- Job T056 with a profit of 60 is scheduled in slot 7.
- Job X600 with a profit of 60 is scheduled in slot 6.
- Job O060 with a profit of 60 is scheduled in slot 4.
- Job R090 with a profit of 55 is scheduled in slot 2.
- Job X056 with a profit of 55 is scheduled in slot 3.
- Job E056 with a profit of 50 is scheduled in slot 1.

Each job is placed in the latest available time slot before its deadline to maximize the profit without conflicting with other jobs.

8.3 Summary

The output shows that the algorithm successfully schedules jobs to maximize the total profit while adhering to their respective deadlines. The total profit of 475 is the sum of the profits of the scheduled jobs, and each job is placed in a time slot that allows it to be completed on time.

9.0 Discussion and Improvement

- Non-Overlapping Constraint:
    - Current Approach: The algorithm ensures no two jobs are scheduled in the same time slot by checking each time slot from the latest possible back to the earliest.
    - Issue: This greedy approach is optimal for individual slots but might not be globally optimal when multiple jobs have the same deadline.
    - Improvement: Use more advanced optimization techniques like dynamic programming to handle complex dependencies between jobs more efficiently.

- Multiple Drones:
    - Current Approach: The algorithm assumes only one drone is available, which is sufficient for simple scenarios.
    - Issue: If multiple drones (e.g., 5 drones) are available, the problem becomes similar to a knapsack problem where each drone can be considered as a separate "knapsack" with time slots as capacity.
    - Improvement: Modify the algorithm to handle multiple drones by using a priority queue to keep track of the next available time slot for each drone.