C950 WGUPS Algorithm Overview

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C950 Data Structures and Algorithms II

Revision 1.0

Introduction

This document provides an overview of the package delivery system project that efficiently allocates and delivers packages using three trucks. The system is built using Python and utilizes data structures, algorithms, and a hash table for efficient package look-up and tracking. Since the first revision, there are some updates to the codes of the project for better efficiency and meeting all requirements. Now, there are less helper and chaining functions, and most of calculations and tasks are done by the main functions for assigning packages, finding shortest paths, calculating delivery times, updating data structures, and displaying information to the user.

Since the revision 1.0, truck 1 and 2 depart at 8:00 AM, and truck 3 departs at 9:41 when one of the trucks arrives back to the hub after completing deliveries. Since WGUPS is aware that the address of package #9 is incorrect and will be updated at 10:20 AM, truck 3 carries the package #9, as the last package, and the package info for package #9 gets corrected at 10:20 AM, and the delivery path and distances of truck 3 are recalculated using the correct address. All packages are assigned and prioritized according to deadlines, package constraints, and nearest addresses for assigned packages to each truck.

A. Algorithm Identification

The self-adjusting algorithm used to create the program to deliver the packages is a modified Greedy algorithm. This algorithm incorporates elements of the Nearest Neighbor algorithm and Dijkstra's shortest path algorithm to efficiently deliver packages.

The modified Greedy algorithm, in the context of package delivery, works as follows:

1. Allocate packages to trucks based on delivery deadlines, special notes, and truck capacities using the allocate_packages_to_trucks function.
2. Start at the hub (depot) as the current location for each truck.
3. For each truck, find the shortest path to deliver all the packages assigned to it using the find_shortest_path function, which incorporates a modified version of Dijkstra's algorithm to calculate the shortest distances between locations.
4. Update package information and recalculate paths if necessary. For example, updating the address and zip code of package 9 if the current time is 10:20 or later.
5. Keep track of each truck's path, distances traveled, and arrival times at each location.
6. Once all packages are delivered, return each truck to the hub (depot).

The algorithm prioritizes visiting the nearest unvisited location at each step, making it a Greedy algorithm. Additionally, it employs Dijkstra's shortest path algorithm to ensure that the shortest distance between locations is found. This approach attempts to minimize the total distance traveled by the trucks and adhere to package delivery deadlines, which is crucial for efficient package delivery. However, it may not always result in the optimal solution, as it makes local decisions without considering the global consequences. Nonetheless, the algorithm provides a practical and effective solution for the package delivery problem.

B1. Logic Comments

Pseudocode for the Greedy Algorithm:

```
Algorithm: Modified Greedy Algorithm for Package Delivery
Input:
- Package information (including package ID, address, deadline, and other relevant details)
- Address and distance information for all locations
- Number of trucks


Initialize all trucks and packages
Initialize the current time


While there are undelivered packages:
    For each truck:
        If the truck is available:
            Allocate packages to the truck based on the greedy algorithm, considering deadlines and
other constraints
            Calculate the shortest path for the truck using Dijkstra's algorithm
            Deliver packages following the shortest path
            Update package and truck status
    Update the current time
```

Pseudocode for the overall logic of the program:

```
START
INITIALIZE PackageTracker
INITIALIZE Truck objects and their routes
INITIALIZE Package Hash Table with package information


CREATE MAIN MENU
```

```
  DISPLAY Total distance traveled by trucks
  REPEAT
    DISPLAY Menu options
    GET User input

    IF User input is to track a package
      CALL Track Package function
    ELSE IF User input is to view delivery status at a specific time
      CALL View Delivery Status function
    ELSE IF User input to view each truck's traveled mileage
      CALL Display Truck Mileage function
    ELSE IF User input is to exit the program
      EXIT the program
    ELSE
      DISPLAY Invalid input message

  UNTIL User decides to exit the program

CREATE Track Package function
  PROMPT User for Package ID
  PROMPT User for time to check package status
  SEARCH for package in the hash table
  UPDATE Package status based on the provided time
  DISPLAY Package details
```

```
CREATE View Delivery Status function
  PROMPT User for the time to check the delivery status
  FOR each package in the hash table
    UPDATE Package status based on the provided time
  DISPLAY Table with Package details
END
```

B2. Development Environment

The programming environment used to create the project is PyCharm 2022.3.3 (Professional Edition), and the Python version is 3.10.9.

B3. Space-Time and Big-O

The space-time complexity of the program:

- track_package(): O(N) time complexity, O(1) space complexity
- view_delivery_status(): O(N) time complexity, O(N) space complexity
- main_menu(): O(1) time complexity, O(1) space complexity
- Entire program: O(N) time complexity, O(N) space complexity

main.py Time and Space complexity

Class/Function	**Time Complexity**	**Space Complexity**
PackageTracker.main_menu()	O(1)	O(1)
PackageTracker.track_package()	O(N)	O(1)
PackageTracker.view_delivery_status()	O(N)	O(N)
csvReader.get_package_hash_table()	O(N)	O(N)
display_truck_mileage	O(1)	O(1)

Package.py Time and Space complexity

Class/Function	**Time Complexity**	**Space Complexity**
print_truck_deadlines()	O(T * P)	O(1)
allocate_packages_to_trucks()	O(n^2)	O(n)
update_package_info()	O(T * V * P)	O(V)

Class/Function	Time Complexity	Space Complexity
update_packages_hashtable()	O(T * P)	O(1)
print_hashtable()	O(n)	O(1)

N, P = number of packages in a truck m = number of addresses T = number of Trucks

Distance.py Time and Space complexity

Class/Function	Time Complexity	Space Complexity
find_location_index_by_address()	O(V)	O(1)
dijkstra()	O((V + E) log(V))	O(V)
update_package9_info()	O(1)	O(1)
find_shortest_path()	O(TP + V^2 + TP(V^2 log V))	O(V^2 + TP)
get_distances()	O(T)	O(T)

E = number of edges, V = number of vertices, T = number of trucks, P = number of packages

csvReader.py Time and Space complexity

Class/Function	Time Complexity	Space Complexity
read_csv_files()	O(V^2)	O(V^2)
get_package_hash_table	O(1)	O(1)

Hashtable.py Time and Space complexity

Function/Class	Time Complexity	Space Complexity
init	O(1)	O(initial_capacity)
_hash	O(1)	O(1)
insert	O(1) (amortized)	O(1)

Function/Class	**Time Complexity**	**Space Complexity**
_rehash	O(n)	O(n)
lookup	O(1) (average)	O(1)
update	O(1) (average)	O(1)
remove	O(1) (average)	O(1)

n = number of key-value pairs initial_capacity = initial size of the hash table

B4. Scalability and Adaptability

The solution is designed to handle a growing number of packages because it uses a hash table to store package information, which can efficiently scale with more packages. The algorithm's performance will mainly be affected by the loading and delivering of packages, but it will still function for a larger number of packages. However, since the loading of trucks is currently done manually, some changes need to be made to automate the process.

B5. Software Efficiency and Maintainability

The software is efficient and easy to maintain because it uses modular functions and classes, making it easy to understand and modify. The chosen algorithm and data structures are also efficient in terms of space and time complexity.

B6. Self-Adjusting Data Structures

Strengths and weaknesses of the hash table:

- Strengths: Fast look-up times, efficient use of memory, and easily scalable for a growing number of packages.
- Weaknesses: Potential collisions may cause look-up time to increase and can be less efficient in terms of space when the load factor is high.

C. Original Code

The project files can be found in packagedelivery_rev1.zip

D. Data Structure

The self-adjusting data structure used with the Greedy Algorithm in this project is a hash table. The hash table is designed to store and manage package data efficiently by accounting for the relationship between data points and handling collisions. The following details explain the type of hash table used, how data points in the hash table are organized and related, and how collisions are handled.

Type of hash table: The hash table implemented in this project is a custom class called HashTable. It has an initial capacity and a load factor, which determine when it will rehash itself. The initial capacity of the hash table is set to 10, and the load factor is set to 0.75. When the number of key-value pairs in the hash table reaches 75% of the current capacity, it will automatically rehash itself to maintain efficient performance.

Organization and relationship of data points: The hash table uses the package ID as the key and the package information as the value. This allows for fast access to the package information using the package ID. The package information contains data points such as package_ID, address_location, address, city, state, zip_code, delivery_deadline, size, special_note, delivery_start, and delivery_status, which are all related to each other. By organizing these data points as values in the hash table, the relationship between them is preserved, and it enables efficient storage and retrieval of package data.

Handling collisions: The hash table uses separate chaining to handle collisions. Separate chaining involves using an array of linked lists (or in this case, Python lists) to store key-value pairs that hash to the same index. When inserting a new key-value pair, the hash function computes an index for the key. If there's no existing key-value pair at that index, the new pair is inserted. If there's already a key-value pair at that index, the new pair is appended to the list. When searching for a key, the hash function computes the index, and then the list at that index is searched linearly to find the key-value pair.

By using a self-adjusting hash table that rehashes itself when necessary, organizes data points based on their relationships, and handles collisions using separate chaining, the algorithm can efficiently store and access package data, which is crucial for the successful implementation of the Greedy Algorithm.

E. Hash Table

The custom hash table implementation in the provided code meets the requirements specified in this section.

F. Look-Up Function

The look-up function in the provided code in the Hashtable class meets the requirements specified in this section. The Hashtable class has a lookup function that takes a package ID as an argument and retrieves the corresponding package information. Here's a step-by-step explanation of how the lookup function works:

1- The function takes the package ID as an input. This package ID is a string representing the unique identifier for a package.

2- It calculates the index of the package in the hash table by calling the get_index function. The get_index function uses a simple modulo operation with the hash table size to determine the index. This means that the package ID is converted to an integer and then divided by the size of the hash table. The remainder of this division is the index.

3- With the index calculated, the function checks if the hash table's bucket at that index is not empty.

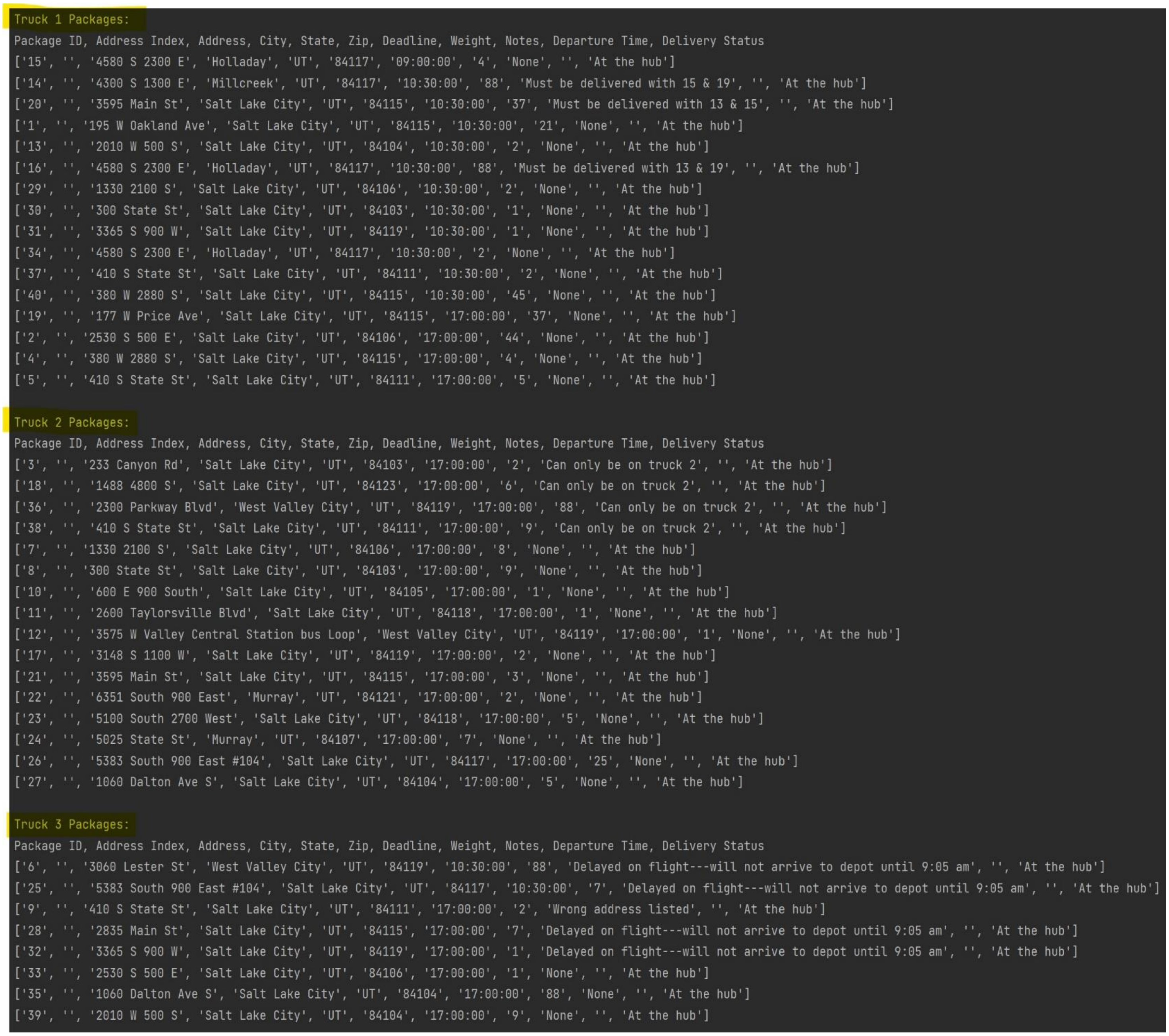
4- If the bucket is not empty, it iterates through the bucket's linked list, which contains the package information in the form of a tuple. The first element of the tuple is the package ID.

5- During the iteration, the function compares the input package ID with the package ID in each tuple. If it finds a match, it returns the corresponding package information (the entire tuple).

6- If the function does not find a matching package ID in the bucket, it returns None, indicating that the package with the given ID was not found in the hash table.

G. Interface

The user interface in the provided code allows the user to view package status at a given time for a single package or all packages, total mileage traveled by all trucks, and total mileage traveled by each truck.

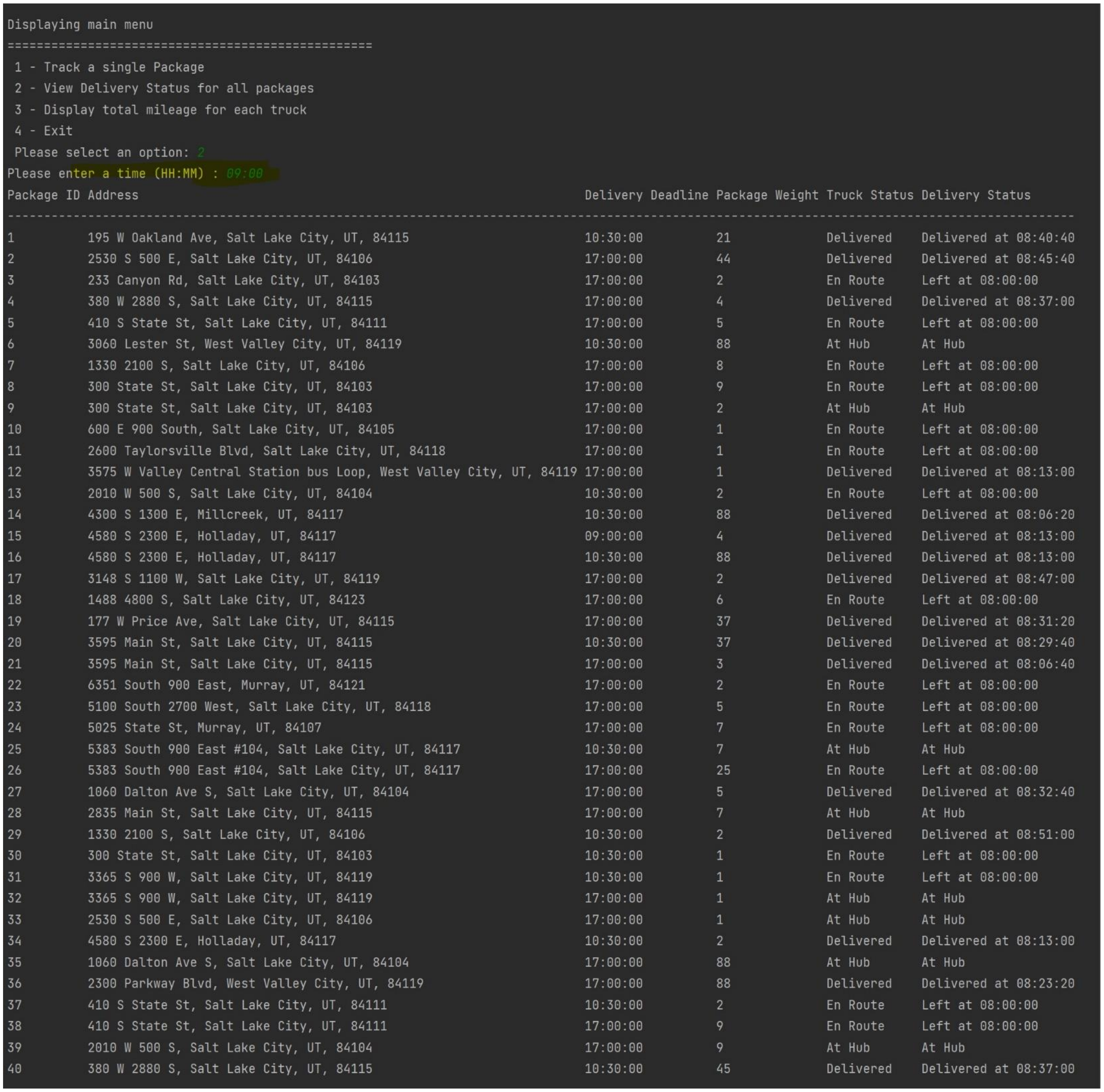


```
Truck 1 Packages:
Package ID, Address Index, Address, City, State, Zip, Deadline, Weight, Notes, Departure Time, Delivery Status
['15', '', '4580 S 2300 E', 'Holladay', 'UT', '84117', '09:00:00', '4', 'None', '', 'At the hub']
['14', '', '4300 S 1300 E', 'Millcreek', 'UT', '84117', '10:30:00', '88', 'Must be delivered with 15 & 19', '', 'At the hub']
['20', '', '3595 Main St', 'Salt Lake City', 'UT', '84115', '10:30:00', '37', 'Must be delivered with 13 & 15', '', 'At the hub']
['1', '', '195 W Oakland Ave', 'Salt Lake City', 'UT', '84115', '10:30:00', '21', 'None', '', 'At the hub']
['13', '', '2010 W 500 S', 'Salt Lake City', 'UT', '84104', '10:30:00', '2', 'None', '', 'At the hub']
['16', '', '4580 S 2300 E', 'Holladay', 'UT', '84117', '10:30:00', '88', 'Must be delivered with 13 & 19', '', 'At the hub']
['29', '', '1330 2100 S', 'Salt Lake City', 'UT', '84106', '10:30:00', '2', 'None', '', 'At the hub']
['30', '', '300 State St', 'Salt Lake City', 'UT', '84103', '10:30:00', '1', 'None', '', 'At the hub']
['31', '', '3365 S 900 W', 'Salt Lake City', 'UT', '84119', '10:30:00', '1', 'None', '', 'At the hub']
['34', '', '4580 S 2300 E', 'Holladay', 'UT', '84117', '10:30:00', '2', 'None', '', 'At the hub']
['37', '', '410 S State St', 'Salt Lake City', 'UT', '84111', '10:30:00', '2', 'None', '', 'At the hub']
['40', '', '380 W 2880 S', 'Salt Lake City', 'UT', '84115', '10:30:00', '45', 'None', '', 'At the hub']
['19', '', '177 W Price Ave', 'Salt Lake City', 'UT', '84115', '17:00:00', '37', 'None', '', 'At the hub']
['2', '', '2530 S 500 E', 'Salt Lake City', 'UT', '84106', '17:00:00', '44', 'None', '', 'At the hub']
['4', '', '380 W 2880 S', 'Salt Lake City', 'UT', '84115', '17:00:00', '4', 'None', '', 'At the hub']
['5', '', '410 S State St', 'Salt Lake City', 'UT', '84111', '17:00:00', '5', 'None', '', 'At the hub']

Truck 2 Packages:
Package ID, Address Index, Address, City, State, Zip, Deadline, Weight, Notes, Departure Time, Delivery Status
['3', '', '233 Canyon Rd', 'Salt Lake City', 'UT', '84103', '17:00:00', '2', 'Can only be on truck 2', '', 'At the hub']
['18', '', '1488 4800 S', 'Salt Lake City', 'UT', '84123', '17:00:00', '6', 'Can only be on truck 2', '', 'At the hub']
['36', '', '2300 Parkway Blvd', 'West Valley City', 'UT', '84119', '17:00:00', '88', 'Can only be on truck 2', '', 'At the hub']
['38', '', '410 S State St', 'Salt Lake City', 'UT', '84111', '17:00:00', '9', 'Can only be on truck 2', '', 'At the hub']
['7', '', '1330 2100 S', 'Salt Lake City', 'UT', '84106', '17:00:00', '8', 'None', '', 'At the hub']
['8', '', '300 State St', 'Salt Lake City', 'UT', '84103', '17:00:00', '9', 'None', '', 'At the hub']
['10', '', '600 E 900 South', 'Salt Lake City', 'UT', '84105', '17:00:00', '1', 'None', '', 'At the hub']
['11', '', '2600 Taylorsville Blvd', 'Salt Lake City', 'UT', '84118', '17:00:00', '1', 'None', '', 'At the hub']
['12', '', '3575 W Valley Central Station bus Loop', 'West Valley City', 'UT', '84119', '17:00:00', '1', 'None', '', 'At the hub']
['17', '', '3148 S 1100 W', 'Salt Lake City', 'UT', '84119', '17:00:00', '2', 'None', '', 'At the hub']
['21', '', '3595 Main St', 'Salt Lake City', 'UT', '84115', '17:00:00', '3', 'None', '', 'At the hub']
['22', '', '6351 South 900 East', 'Murray', 'UT', '84121', '17:00:00', '2', 'None', '', 'At the hub']
['23', '', '5100 South 2700 West', 'Salt Lake City', 'UT', '84118', '17:00:00', '5', 'None', '', 'At the hub']
['24', '', '5025 State St', 'Murray', 'UT', '84107', '17:00:00', '7', 'None', '', 'At the hub']
['26', '', '5383 South 900 East #104', 'Salt Lake City', 'UT', '84117', '17:00:00', '25', 'None', '', 'At the hub']
['27', '', '1060 Dalton Ave S', 'Salt Lake City', 'UT', '84104', '17:00:00', '5', 'None', '', 'At the hub']

Truck 3 Packages:
Package ID, Address Index, Address, City, State, Zip, Deadline, Weight, Notes, Departure Time, Delivery Status
['6', '', '3060 Lester St', 'West Valley City', 'UT', '84119', '10:30:00', '88', 'Delayed on flight---will not arrive to depot until 9:05 am', '', 'At the hub']
['25', '', '5383 South 900 East #104', 'Salt Lake City', 'UT', '84117', '10:30:00', '7', 'Delayed on flight---will not arrive to depot until 9:05 am', '', 'At the hub']
['9', '', '410 S State St', 'Salt Lake City', 'UT', '84111', '17:00:00', '2', 'Wrong address listed', '', 'At the hub']
['28', '', '2835 Main St', 'Salt Lake City', 'UT', '84115', '17:00:00', '7', 'Delayed on flight---will not arrive to depot until 9:05 am', '', 'At the hub']
['32', '', '3365 S 900 W', 'Salt Lake City', 'UT', '84119', '17:00:00', '1', 'Delayed on flight---will not arrive to depot until 9:05 am', '', 'At the hub']
['33', '', '2530 S 500 E', 'Salt Lake City', 'UT', '84106', '17:00:00', '1', 'None', '', 'At the hub']
['35', '', '1060 Dalton Ave S', 'Salt Lake City', 'UT', '84104', '17:00:00', '88', 'None', '', 'At the hub']
['39', '', '2010 W 500 S', 'Salt Lake City', 'UT', '84104', '17:00:00', '9', 'None', '', 'At the hub']
```

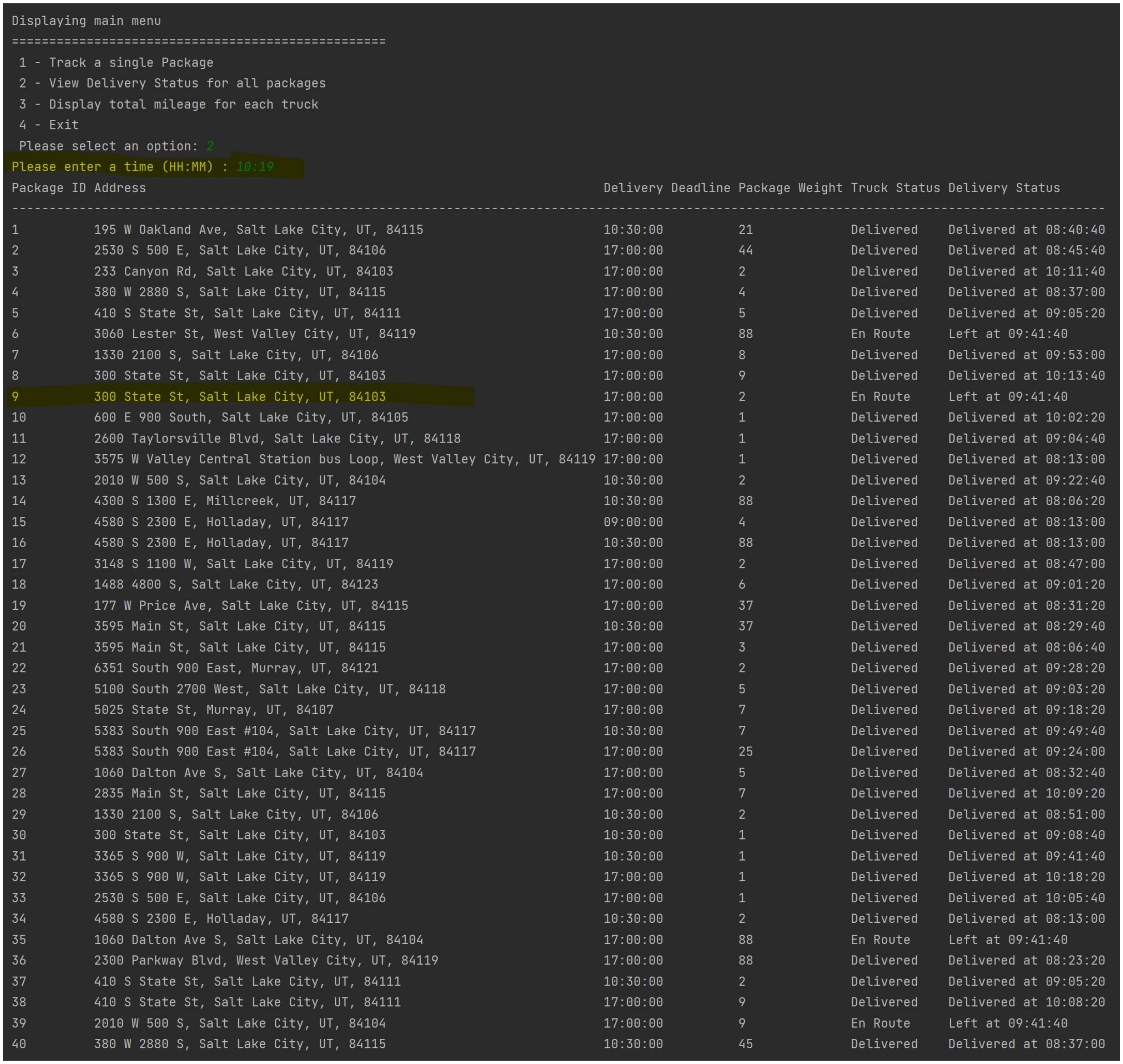
G1. First Status Check



```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 2
Please enter a time (HH:MM) : 09:00
Package ID Address                                                            Delivery Deadline Package Weight Truck Status Delivery Status
-------------------------------------------------------------------------------------------------------------------------------------------------
1          195 W Oakland Ave, Salt Lake City, UT, 84115                       10:30:00          21             Delivered    Delivered at 08:40:40
2          2530 S 500 E, Salt Lake City, UT, 84106                            17:00:00          44             Delivered    Delivered at 08:45:40
3          233 Canyon Rd, Salt Lake City, UT, 84103                           17:00:00          2              En Route     Left at 08:00:00
4          380 W 2880 S, Salt Lake City, UT, 84115                            17:00:00          4              Delivered    Delivered at 08:37:00
5          410 S State St, Salt Lake City, UT, 84111                          17:00:00          5              En Route     Left at 08:00:00
6          3060 Lester St, West Valley City, UT, 84119                        10:30:00          88             At Hub       At Hub
7          1330 2100 S, Salt Lake City, UT, 84106                             17:00:00          8              En Route     Left at 08:00:00
8          300 State St, Salt Lake City, UT, 84103                            17:00:00          9              En Route     Left at 08:00:00
9          300 State St, Salt Lake City, UT, 84103                            17:00:00          2              At Hub       At Hub
10         600 E 900 South, Salt Lake City, UT, 84105                         17:00:00          1              En Route     Left at 08:00:00
11         2600 Taylorsville Blvd, Salt Lake City, UT, 84118                  17:00:00          1              En Route     Left at 08:00:00
12         3575 W Valley Central Station bus Loop, West Valley City, UT, 84119 17:00:00         1              Delivered    Delivered at 08:13:00
13         2010 W 500 S, Salt Lake City, UT, 84104                            10:30:00          2              En Route     Left at 08:00:00
14         4300 S 1300 E, Millcreek, UT, 84117                                10:30:00          88             Delivered    Delivered at 08:06:20
15         4580 S 2300 E, Holladay, UT, 84117                                 09:00:00          4              Delivered    Delivered at 08:13:00
16         4580 S 2300 E, Holladay, UT, 84117                                 10:30:00          88             Delivered    Delivered at 08:13:00
17         3148 S 1100 W, Salt Lake City, UT, 84119                           17:00:00          2              Delivered    Delivered at 08:47:00
18         1488 4800 S, Salt Lake City, UT, 84123                             17:00:00          6              En Route     Left at 08:00:00
19         177 W Price Ave, Salt Lake City, UT, 84115                         17:00:00          37             Delivered    Delivered at 08:31:20
20         3595 Main St, Salt Lake City, UT, 84115                            10:30:00          37             Delivered    Delivered at 08:29:40
21         3595 Main St, Salt Lake City, UT, 84115                            17:00:00          3              Delivered    Delivered at 08:06:40
22         6351 South 900 East, Murray, UT, 84121                             17:00:00          2              En Route     Left at 08:00:00
23         5100 South 2700 West, Salt Lake City, UT, 84118                    17:00:00          5              En Route     Left at 08:00:00
24         5025 State St, Murray, UT, 84107                                   17:00:00          7              En Route     Left at 08:00:00
25         5383 South 900 East #104, Salt Lake City, UT, 84117                10:30:00          7              At Hub       At Hub
26         5383 South 900 East #104, Salt Lake City, UT, 84117                17:00:00          25             En Route     Left at 08:00:00
27         1060 Dalton Ave S, Salt Lake City, UT, 84104                       17:00:00          5              Delivered    Delivered at 08:32:40
28         2835 Main St, Salt Lake City, UT, 84115                            17:00:00          7              At Hub       At Hub
29         1330 2100 S, Salt Lake City, UT, 84106                             10:30:00          2              Delivered    Delivered at 08:51:00
30         300 State St, Salt Lake City, UT, 84103                            10:30:00          1              En Route     Left at 08:00:00
31         3365 S 900 W, Salt Lake City, UT, 84119                            10:30:00          1              En Route     Left at 08:00:00
32         3365 S 900 W, Salt Lake City, UT, 84119                            17:00:00          1              At Hub       At Hub
33         2530 S 500 E, Salt Lake City, UT, 84106                            17:00:00          1              At Hub       At Hub
34         4580 S 2300 E, Holladay, UT, 84117                                 10:30:00          2              Delivered    Delivered at 08:13:00
35         1060 Dalton Ave S, Salt Lake City, UT, 84104                       17:00:00          88             At Hub       At Hub
36         2300 Parkway Blvd, West Valley City, UT, 84119                     17:00:00          88             Delivered    Delivered at 08:23:20
37         410 S State St, Salt Lake City, UT, 84111                          10:30:00          2              En Route     Left at 08:00:00
38         410 S State St, Salt Lake City, UT, 84111                          17:00:00          9              En Route     Left at 08:00:00
39         2010 W 500 S, Salt Lake City, UT, 84104                            17:00:00          9              At Hub       At Hub
40         380 W 2880 S, Salt Lake City, UT, 84115                            10:30:00          45             Delivered    Delivered at 08:37:00
```

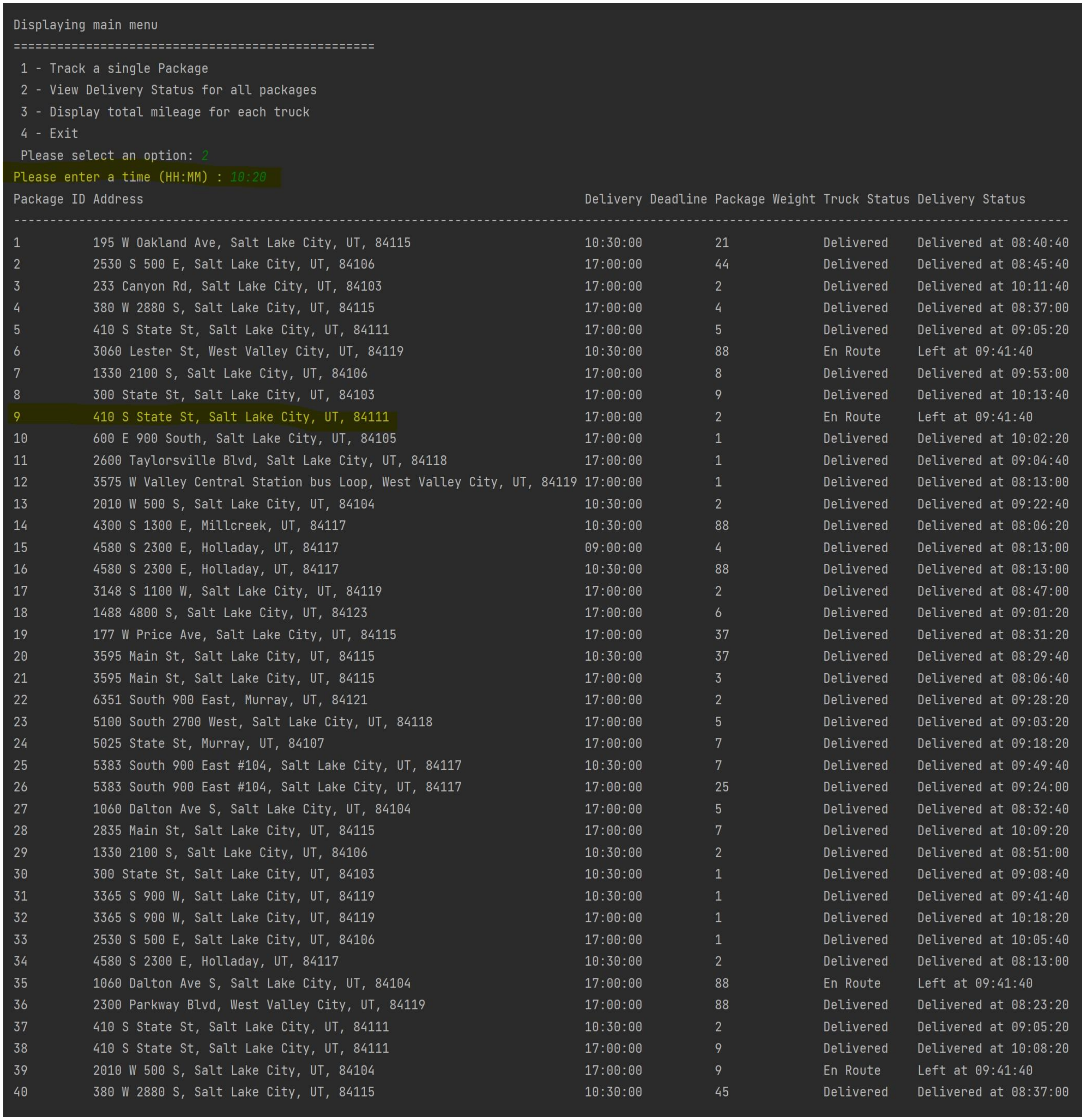
Figure 1- Status of All Packages at 9:00 AM

G2. Second Status Check



```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 2
Please enter a time (HH:MM) : 10:19
Package ID Address                                                         Delivery Deadline Package Weight Truck Status Delivery Status
-------------------------------------------------------------------------------------------------------------------------------------------
1          195 W Oakland Ave, Salt Lake City, UT, 84115                    10:30:00          21             Delivered    Delivered at 08:40:40
2          2530 S 500 E, Salt Lake City, UT, 84106                         17:00:00          44             Delivered    Delivered at 08:45:40
3          233 Canyon Rd, Salt Lake City, UT, 84103                        17:00:00          2              Delivered    Delivered at 10:11:40
4          380 W 2880 S, Salt Lake City, UT, 84115                         17:00:00          4              Delivered    Delivered at 08:37:00
5          410 S State St, Salt Lake City, UT, 84111                       17:00:00          5              Delivered    Delivered at 09:05:20
6          3060 Lester St, West Valley City, UT, 84119                     10:30:00          88             En Route     Left at 09:41:40
7          1330 2100 S, Salt Lake City, UT, 84106                          17:00:00          8              Delivered    Delivered at 09:53:00
8          300 State St, Salt Lake City, UT, 84103                         17:00:00          9              Delivered    Delivered at 10:13:40
9          300 State St, Salt Lake City, UT, 84103                         17:00:00          2              En Route     Left at 09:41:40
10         600 E 900 South, Salt Lake City, UT, 84105                      17:00:00          1              Delivered    Delivered at 10:02:20
11         2600 Taylorsville Blvd, Salt Lake City, UT, 84118               17:00:00          1              Delivered    Delivered at 09:04:40
12         3575 W Valley Central Station bus Loop, West Valley City, UT, 84119 17:00:00      1              Delivered    Delivered at 08:13:00
13         2010 W 500 S, Salt Lake City, UT, 84104                         10:30:00          2              Delivered    Delivered at 09:22:40
14         4300 S 1300 E, Millcreek, UT, 84117                             10:30:00          88             Delivered    Delivered at 08:06:20
15         4580 S 2300 E, Holladay, UT, 84117                              09:00:00          4              Delivered    Delivered at 08:13:00
16         4580 S 2300 E, Holladay, UT, 84117                              10:30:00          88             Delivered    Delivered at 08:13:00
17         3148 S 1100 W, Salt Lake City, UT, 84119                        17:00:00          2              Delivered    Delivered at 08:47:00
18         1488 4800 S, Salt Lake City, UT, 84123                          17:00:00          6              Delivered    Delivered at 09:01:20
19         177 W Price Ave, Salt Lake City, UT, 84115                      17:00:00          37             Delivered    Delivered at 08:31:20
20         3595 Main St, Salt Lake City, UT, 84115                         10:30:00          37             Delivered    Delivered at 08:29:40
21         3595 Main St, Salt Lake City, UT, 84115                         17:00:00          3              Delivered    Delivered at 08:06:40
22         6351 South 900 East, Murray, UT, 84121                          17:00:00          2              Delivered    Delivered at 09:28:20
23         5100 South 2700 West, Salt Lake City, UT, 84118                 17:00:00          5              Delivered    Delivered at 09:03:20
24         5025 State St, Murray, UT, 84107                                17:00:00          7              Delivered    Delivered at 09:18:20
25         5383 South 900 East #104, Salt Lake City, UT, 84117             10:30:00          7              Delivered    Delivered at 09:49:40
26         5383 South 900 East #104, Salt Lake City, UT, 84117             17:00:00          25             Delivered    Delivered at 09:24:00
27         1060 Dalton Ave S, Salt Lake City, UT, 84104                    17:00:00          5              Delivered    Delivered at 08:32:40
28         2835 Main St, Salt Lake City, UT, 84115                         17:00:00          7              Delivered    Delivered at 10:09:20
29         1330 2100 S, Salt Lake City, UT, 84106                          10:30:00          2              Delivered    Delivered at 08:51:00
30         300 State St, Salt Lake City, UT, 84103                         10:30:00          1              Delivered    Delivered at 09:08:40
31         3365 S 900 W, Salt Lake City, UT, 84119                         10:30:00          1              Delivered    Delivered at 09:41:40
32         3365 S 900 W, Salt Lake City, UT, 84119                         17:00:00          1              Delivered    Delivered at 10:18:20
33         2530 S 500 E, Salt Lake City, UT, 84106                         17:00:00          1              Delivered    Delivered at 10:05:40
34         4580 S 2300 E, Holladay, UT, 84117                              10:30:00          2              Delivered    Delivered at 08:13:00
35         1060 Dalton Ave S, Salt Lake City, UT, 84104                    17:00:00          88             En Route     Left at 09:41:40
36         2300 Parkway Blvd, West Valley City, UT, 84119                  17:00:00          88             Delivered    Delivered at 08:23:20
37         410 S State St, Salt Lake City, UT, 84111                       10:30:00          2              Delivered    Delivered at 09:05:20
38         410 S State St, Salt Lake City, UT, 84111                       17:00:00          9              Delivered    Delivered at 10:08:20
39         2010 W 500 S, Salt Lake City, UT, 84104                         17:00:00          9              En Route     Left at 09:41:40
40         380 W 2880 S, Salt Lake City, UT, 84115                         10:30:00          45             Delivered    Delivered at 08:37:00
```

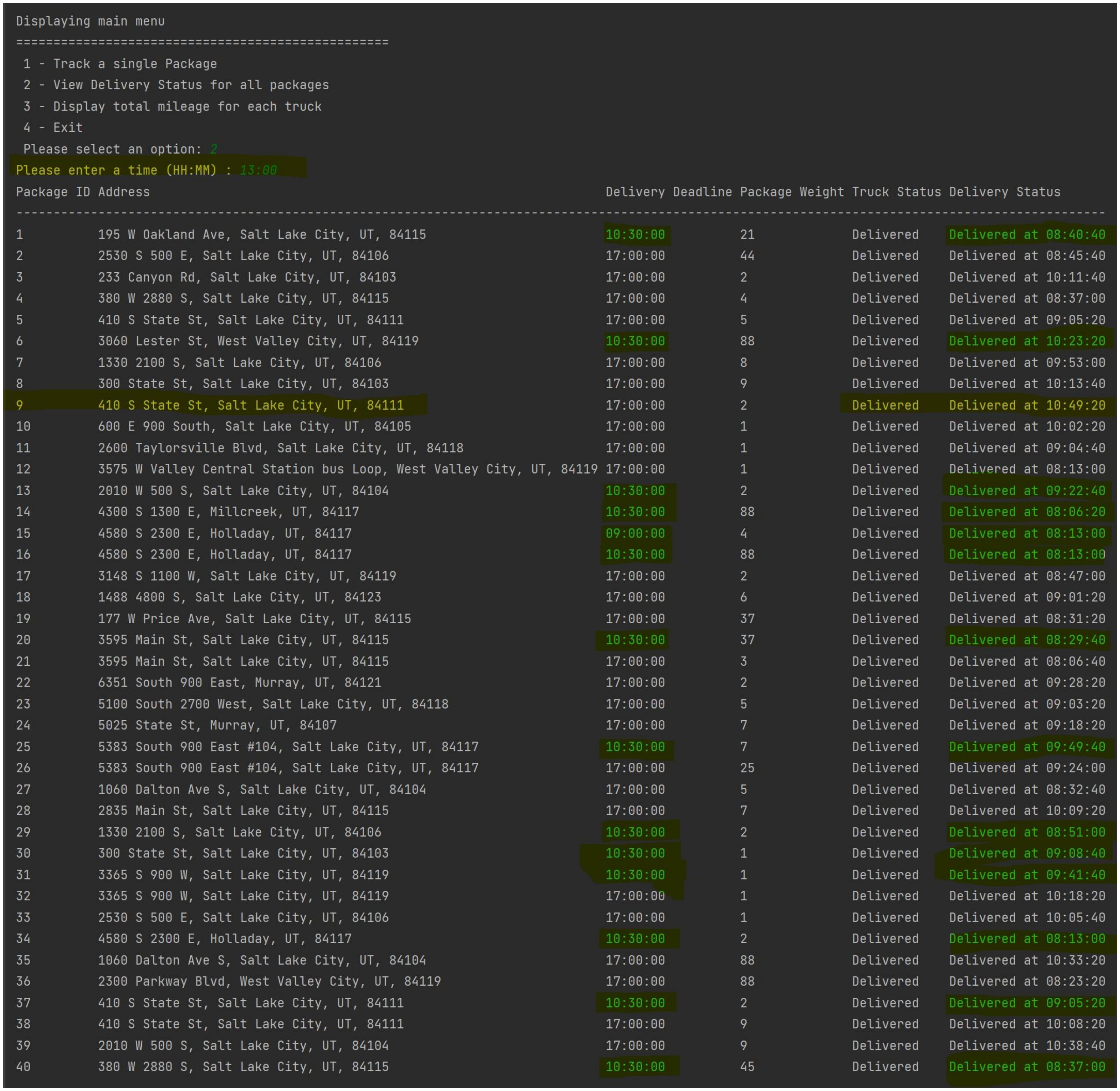
Figure 2- Status of All Packages at 10:19 AM



```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 2
Please enter a time (HH:MM) : 10:20
Package ID Address                                                               Delivery Deadline Package Weight Truck Status Delivery Status
-------------------------------------------------------------------------------------------------------------------------------------------------------
1          195 W Oakland Ave, Salt Lake City, UT, 84115                          10:30:00          21             Delivered    Delivered at 08:40:40
2          2530 S 500 E, Salt Lake City, UT, 84106                               17:00:00          44             Delivered    Delivered at 08:45:40
3          233 Canyon Rd, Salt Lake City, UT, 84103                              17:00:00          2              Delivered    Delivered at 10:11:40
4          380 W 2880 S, Salt Lake City, UT, 84115                               17:00:00          4              Delivered    Delivered at 08:37:00
5          410 S State St, Salt Lake City, UT, 84111                             17:00:00          5              Delivered    Delivered at 09:05:20
6          3060 Lester St, West Valley City, UT, 84119                           10:30:00          88             En Route     Left at 09:41:40
7          1330 2100 S, Salt Lake City, UT, 84106                                17:00:00          8              Delivered    Delivered at 09:53:00
8          300 State St, Salt Lake City, UT, 84103                               17:00:00          9              Delivered    Delivered at 10:13:40
9          410 S State St, Salt Lake City, UT, 84111                             17:00:00          2              En Route     Left at 09:41:40
10         600 E 900 South, Salt Lake City, UT, 84105                            17:00:00          1              Delivered    Delivered at 10:02:20
11         2600 Taylorsville Blvd, Salt Lake City, UT, 84118                     17:00:00          1              Delivered    Delivered at 09:04:40
12         3575 W Valley Central Station bus Loop, West Valley City, UT, 84119 17:00:00          1              Delivered    Delivered at 08:13:00
13         2010 W 500 S, Salt Lake City, UT, 84104                               10:30:00          2              Delivered    Delivered at 09:22:40
14         4300 S 1300 E, Millcreek, UT, 84117                                   10:30:00          88             Delivered    Delivered at 08:06:20
15         4580 S 2300 E, Holladay, UT, 84117                                    09:00:00          4              Delivered    Delivered at 08:13:00
16         4580 S 2300 E, Holladay, UT, 84117                                    10:30:00          88             Delivered    Delivered at 08:13:00
17         3148 S 1100 W, Salt Lake City, UT, 84119                              17:00:00          2              Delivered    Delivered at 08:47:00
18         1488 4800 S, Salt Lake City, UT, 84123                                17:00:00          6              Delivered    Delivered at 09:01:20
19         177 W Price Ave, Salt Lake City, UT, 84115                            17:00:00          37             Delivered    Delivered at 08:31:20
20         3595 Main St, Salt Lake City, UT, 84115                               10:30:00          37             Delivered    Delivered at 08:29:40
21         3595 Main St, Salt Lake City, UT, 84115                               17:00:00          3              Delivered    Delivered at 08:06:40
22         6351 South 900 East, Murray, UT, 84121                                17:00:00          2              Delivered    Delivered at 09:28:20
23         5100 South 2700 West, Salt Lake City, UT, 84118                       17:00:00          5              Delivered    Delivered at 09:03:20
24         5025 State St, Murray, UT, 84107                                      17:00:00          7              Delivered    Delivered at 09:18:20
25         5383 South 900 East #104, Salt Lake City, UT, 84117                   10:30:00          7              Delivered    Delivered at 09:49:40
26         5383 South 900 East #104, Salt Lake City, UT, 84117                   17:00:00          25             Delivered    Delivered at 09:24:00
27         1060 Dalton Ave S, Salt Lake City, UT, 84104                          17:00:00          5              Delivered    Delivered at 08:32:40
28         2835 Main St, Salt Lake City, UT, 84115                               17:00:00          7              Delivered    Delivered at 10:09:20
29         1330 2100 S, Salt Lake City, UT, 84106                                10:30:00          2              Delivered    Delivered at 08:51:00
30         300 State St, Salt Lake City, UT, 84103                               10:30:00          1              Delivered    Delivered at 09:08:40
31         3365 S 900 W, Salt Lake City, UT, 84119                               10:30:00          1              Delivered    Delivered at 09:41:40
32         3365 S 900 W, Salt Lake City, UT, 84119                               17:00:00          1              Delivered    Delivered at 10:18:20
33         2530 S 500 E, Salt Lake City, UT, 84106                               17:00:00          1              Delivered    Delivered at 10:05:40
34         4580 S 2300 E, Holladay, UT, 84117                                    10:30:00          2              Delivered    Delivered at 08:13:00
35         1060 Dalton Ave S, Salt Lake City, UT, 84104                          17:00:00          88             En Route     Left at 09:41:40
36         2300 Parkway Blvd, West Valley City, UT, 84119                        17:00:00          88             Delivered    Delivered at 08:23:20
37         410 S State St, Salt Lake City, UT, 84111                             10:30:00          2              Delivered    Delivered at 09:05:20
38         410 S State St, Salt Lake City, UT, 84111                             17:00:00          9              Delivered    Delivered at 10:08:20
39         2010 W 500 S, Salt Lake City, UT, 84104                               17:00:00          9              En Route     Left at 09:41:40
40         380 W 2880 S, Salt Lake City, UT, 84115                               10:30:00          45             Delivered    Delivered at 08:37:00
```

Figure 3 - Status of All packages at 10:20 AM

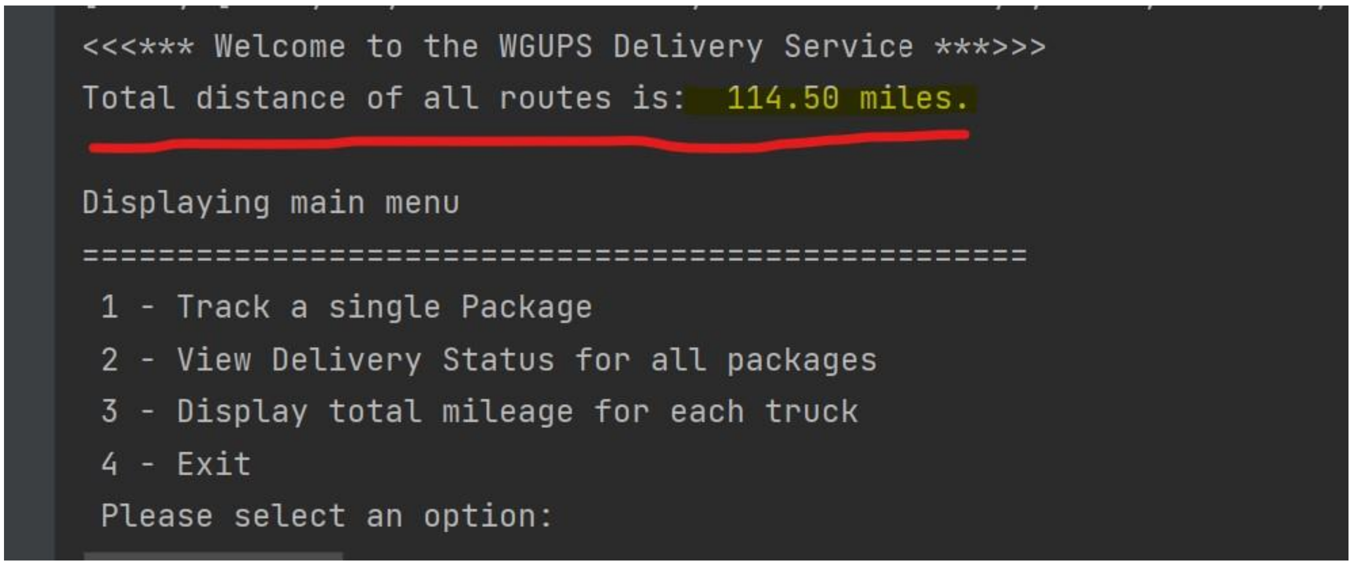
G3. Third Status Check



```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 2
Please enter a time (HH:MM) : 13:00
Package ID Address                                                              Delivery Deadline Package Weight Truck Status Delivery Status
---------------------------------------------------------------------------------------------------------------------------------------------
1          195 W Oakland Ave, Salt Lake City, UT, 84115                         10:30:00          21             Delivered    Delivered at 08:40:40
2          2530 S 500 E, Salt Lake City, UT, 84106                              17:00:00          44             Delivered    Delivered at 08:45:40
3          233 Canyon Rd, Salt Lake City, UT, 84103                             17:00:00          2              Delivered    Delivered at 10:11:40
4          380 W 2880 S, Salt Lake City, UT, 84115                              17:00:00          4              Delivered    Delivered at 08:37:00
5          410 S State St, Salt Lake City, UT, 84111                            17:00:00          5              Delivered    Delivered at 09:05:20
6          3060 Lester St, West Valley City, UT, 84119                          10:30:00          88             Delivered    Delivered at 10:23:20
7          1330 2100 S, Salt Lake City, UT, 84106                               17:00:00          8              Delivered    Delivered at 09:53:00
8          300 State St, Salt Lake City, UT, 84103                              17:00:00          9              Delivered    Delivered at 10:13:40
9          410 S State St, Salt Lake City, UT, 84111                            17:00:00          2              Delivered    Delivered at 10:49:20
10         600 E 900 South, Salt Lake City, UT, 84105                           17:00:00          1              Delivered    Delivered at 10:02:20
11         2600 Taylorsville Blvd, Salt Lake City, UT, 84118                    17:00:00          1              Delivered    Delivered at 09:04:40
12         3575 W Valley Central Station bus Loop, West Valley City, UT, 84119 17:00:00          1              Delivered    Delivered at 08:13:00
13         2010 W 500 S, Salt Lake City, UT, 84104                              10:30:00          2              Delivered    Delivered at 09:22:40
14         4300 S 1300 E, Millcreek, UT, 84117                                  10:30:00          88             Delivered    Delivered at 08:06:20
15         4580 S 2300 E, Holladay, UT, 84117                                   09:00:00          4              Delivered    Delivered at 08:13:00
16         4580 S 2300 E, Holladay, UT, 84117                                   10:30:00          88             Delivered    Delivered at 08:13:00
17         3148 S 1100 W, Salt Lake City, UT, 84119                             17:00:00          2              Delivered    Delivered at 08:47:00
18         1488 4800 S, Salt Lake City, UT, 84123                               17:00:00          6              Delivered    Delivered at 09:01:20
19         177 W Price Ave, Salt Lake City, UT, 84115                           17:00:00          37             Delivered    Delivered at 08:31:20
20         3595 Main St, Salt Lake City, UT, 84115                              10:30:00          37             Delivered    Delivered at 08:29:40
21         3595 Main St, Salt Lake City, UT, 84115                              17:00:00          3              Delivered    Delivered at 08:06:40
22         6351 South 900 East, Murray, UT, 84121                               17:00:00          2              Delivered    Delivered at 09:28:20
23         5100 South 2700 West, Salt Lake City, UT, 84118                      17:00:00          5              Delivered    Delivered at 09:03:20
24         5025 State St, Murray, UT, 84107                                     17:00:00          7              Delivered    Delivered at 09:18:20
25         5383 South 900 East #104, Salt Lake City, UT, 84117                  10:30:00          7              Delivered    Delivered at 09:49:40
26         5383 South 900 East #104, Salt Lake City, UT, 84117                  17:00:00          25             Delivered    Delivered at 09:24:00
27         1060 Dalton Ave S, Salt Lake City, UT, 84104                         17:00:00          5              Delivered    Delivered at 08:32:40
28         2835 Main St, Salt Lake City, UT, 84115                              17:00:00          7              Delivered    Delivered at 10:09:20
29         1330 2100 S, Salt Lake City, UT, 84106                               10:30:00          2              Delivered    Delivered at 08:51:00
30         300 State St, Salt Lake City, UT, 84103                              10:30:00          1              Delivered    Delivered at 09:08:40
31         3365 S 900 W, Salt Lake City, UT, 84119                              10:30:00          1              Delivered    Delivered at 09:41:40
32         3365 S 900 W, Salt Lake City, UT, 84119                              17:00:00          1              Delivered    Delivered at 10:18:20
33         2530 S 500 E, Salt Lake City, UT, 84106                              17:00:00          1              Delivered    Delivered at 10:05:40
34         4580 S 2300 E, Holladay, UT, 84117                                   10:30:00          2              Delivered    Delivered at 08:13:00
35         1060 Dalton Ave S, Salt Lake City, UT, 84104                         17:00:00          88             Delivered    Delivered at 10:33:20
36         2300 Parkway Blvd, West Valley City, UT, 84119                       17:00:00          88             Delivered    Delivered at 08:23:20
37         410 S State St, Salt Lake City, UT, 84111                            10:30:00          2              Delivered    Delivered at 09:05:20
38         410 S State St, Salt Lake City, UT, 84111                            17:00:00          9              Delivered    Delivered at 10:08:20
39         2010 W 500 S, Salt Lake City, UT, 84104                              17:00:00          9              Delivered    Delivered at 10:38:40
40         380 W 2880 S, Salt Lake City, UT, 84115                              10:30:00          45             Delivered    Delivered at 08:37:00
```

Figure 4- Status of All Packages at 1:00 PM

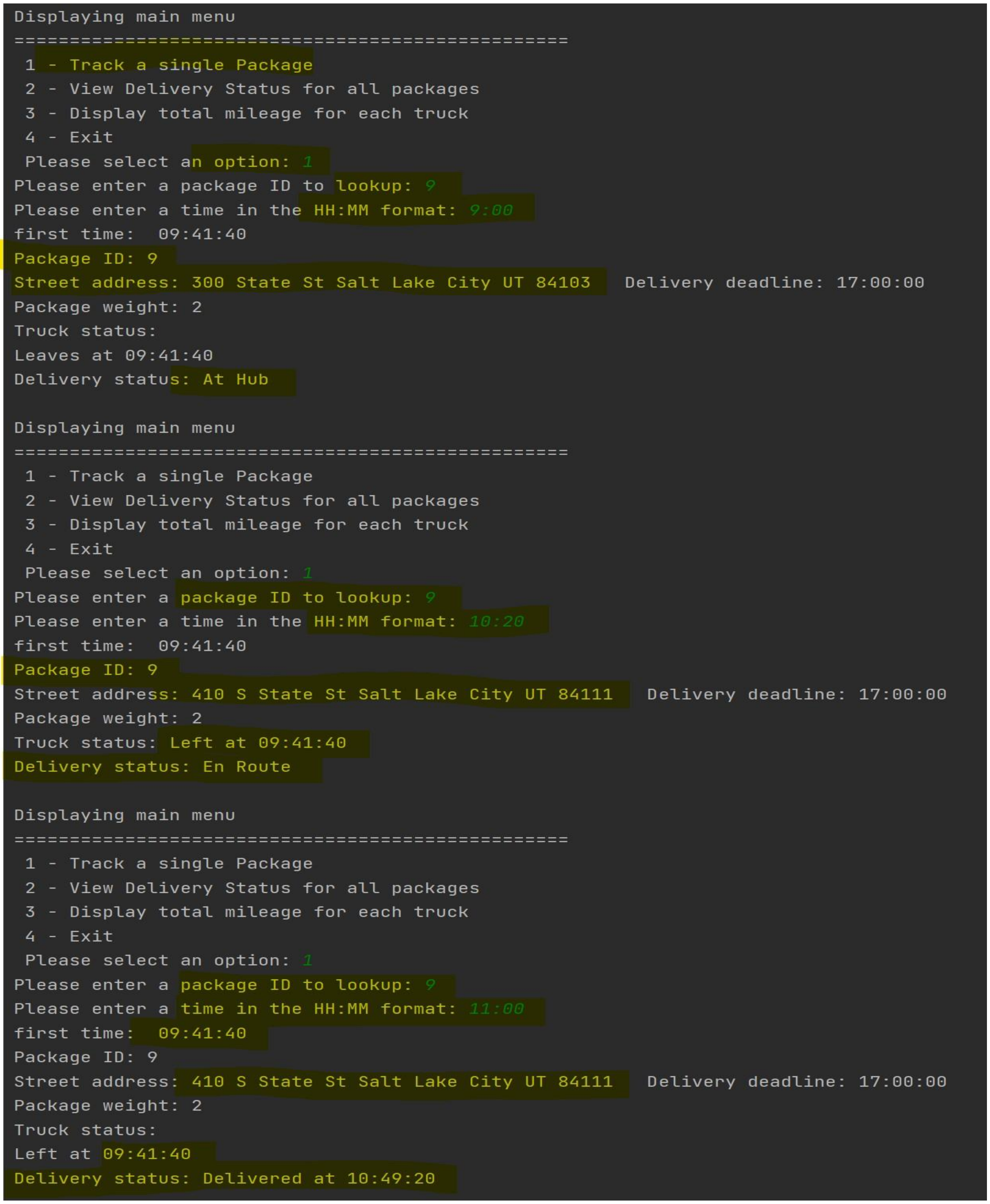
H. Screenshots of Code Execution



```
<<<*** Welcome to the WGUPS Delivery Service ***>>>
Total distance of all routes is:  114.50 miles.

Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option:
```

Figure 5- Main Menu of the Program – displaying the total distance traveled by all trucks: 114.5 miles.

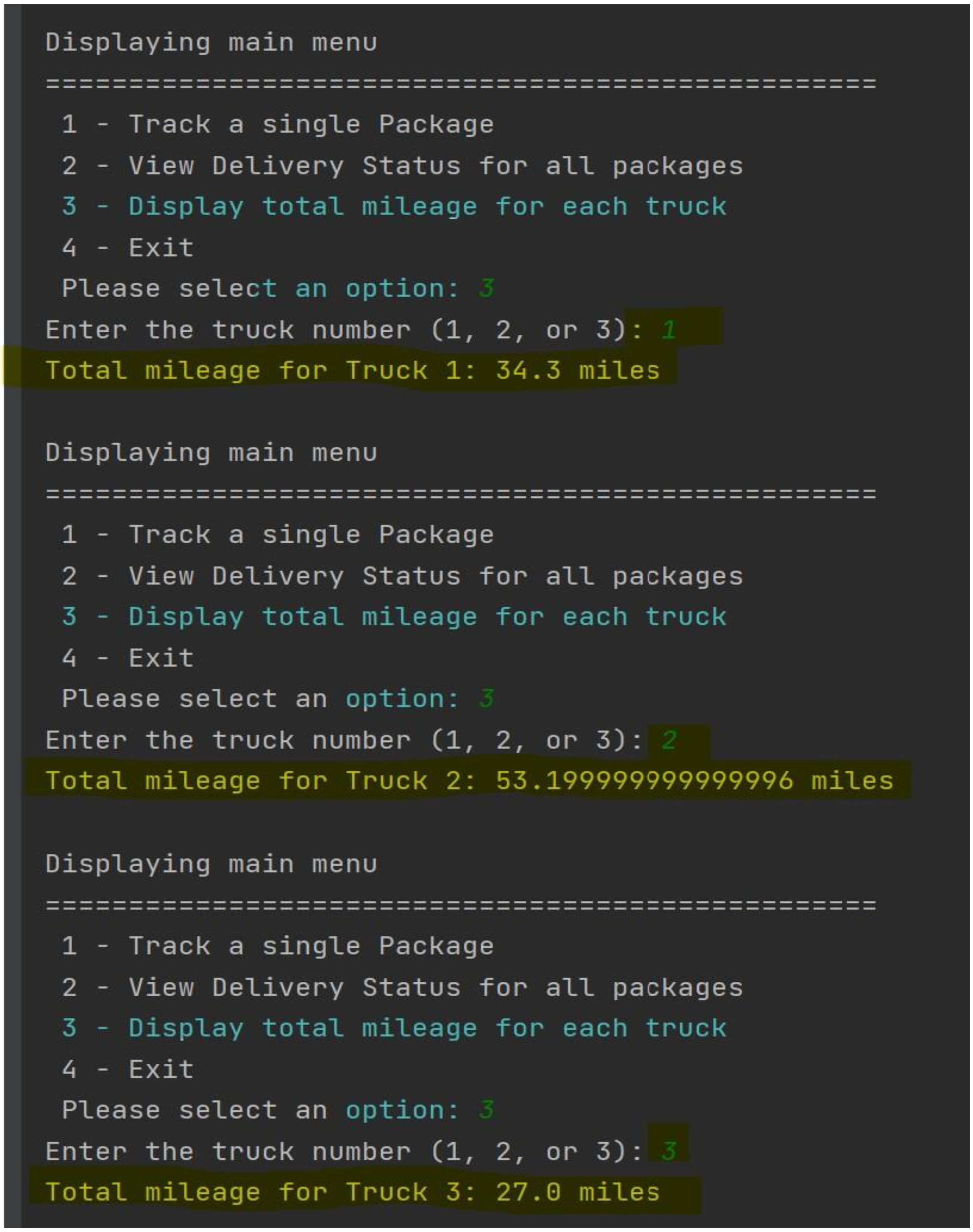


```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 1
Please enter a package ID to lookup: 9
Please enter a time in the HH:MM format: 9:00
first time:  09:41:40
Package ID: 9
Street address: 300 State St Salt Lake City UT 84103   Delivery deadline: 17:00:00
Package weight: 2
Truck status:
Leaves at 09:41:40
Delivery status: At Hub

Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 1
Please enter a package ID to lookup: 9
Please enter a time in the HH:MM format: 10:20
first time:  09:41:40
Package ID: 9
Street address: 410 S State St Salt Lake City UT 84111   Delivery deadline: 17:00:00
Package weight: 2
Truck status: Left at 09:41:40
Delivery status: En Route

Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 1
Please enter a package ID to lookup: 9
Please enter a time in the HH:MM format: 11:00
first time:  09:41:40
Package ID: 9
Street address: 410 S State St Salt Lake City UT 84111   Delivery deadline: 17:00:00
Package weight: 2
Truck status:
Left at 09:41:40
Delivery status: Delivered at 10:49:20
```

Figure 6 - Tracking package #9 before and after correcting the address, and after delivering.



```
Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 3
Enter the truck number (1, 2, or 3): 1
Total mileage for Truck 1: 34.3 miles

Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 3
Enter the truck number (1, 2, or 3): 2
Total mileage for Truck 2: 53.199999999999996 miles

Displaying main menu
==================================================
 1 - Track a single Package
 2 - View Delivery Status for all packages
 3 - Display total mileage for each truck
 4 - Exit
 Please select an option: 3
Enter the truck number (1, 2, or 3): 3
Total mileage for Truck 3: 27.0 miles
```

Figure 7 - Program displaying the total distance traveled by each truck separately.

I1. Strengths of Chosen Algorithm

Two strengths of the Greedy Algorithm used in the solution: a. Simplicity: The Greedy Algorithm is easy to understand and implement, making it a practical choice for solving package delivery problems. b. Local Optimization: The Greedy Algorithm is effective at finding locally optimal solutions, which often leads to acceptable overall solutions, especially for smaller problem instances.

I2. Verification of Algorithm

Greedy allocation of packages: The allocate_packages_to_trucks function uses a greedy approach to allocate packages to trucks based on their deadlines and constraints described in special notes . This method allows for a quick allocation of packages that prioritizes urgent deliveries while ensuring that trucks are loaded as efficiently as possible. This approach can help improve the overall delivery performance of the system.

Dijkstra's algorithm for shortest path: The dijkstra function is an efficient and well-known algorithm for finding the shortest path between nodes in a weighted graph. By using Dijkstra's algorithm, the system is capable of determining the shortest path between the hub and each package's destination, which is a crucial factor for optimizing delivery routes and minimizing the total distance traveled by trucks.

Route optimization with find_shortest_path: This function combines the strengths of the greedy package allocation and Dijkstra's algorithm to create optimized delivery routes for each truck. It considers the deadlines of the packages and the distances between the locations to find an efficient sequence of deliveries for each truck. The function is also designed to handle special cases, such as updating incorrect package information and adjusting the departure time for the third truck based on the arrival times of the first two trucks.

I3. Other possible Algorithms

Two other named algorithms that would meet the requirements in the scenario are:

> **A*** (A* search algorithm, 2023) is an informed search algorithm that is widely used in pathfinding and graph traversal problems. It is an extension of Dijkstra's algorithm, but it uses a heuristic function to estimate the cost from the current node to the destination, which can significantly speed up the search in many cases.
> **Ant Colony Optimization** (Ant colony optimization algorithms, 2023) is a metaheuristic optimization algorithm inspired by the foraging behavior of ants. It is particularly well-suited for solving combinatorial optimization problems, such as the Traveling Salesman Problem (TSP) or Vehicle Routing Problem (VRP), which can be considered similar to the package delivery problem in this scenario.

I3A. Algorithm Differences

The main difference between A* and the implemented Dijkstra's algorithm is that A* uses a heuristic function to guide its search, whereas Dijkstra's algorithm explores all possible paths in the graph without any guidance. This makes A* potentially more efficient than Dijkstra's algorithm, especially in large graphs where the optimal path can be found more quickly using heuristics.

The key difference between ACO and the implemented solution is the approach to finding the optimal path. While the implemented solution uses a combination of greedy allocation and Dijkstra's algorithm, ACO simulates the behavior of ants depositing pheromones on paths they take between the source and the destination. Over time, the algorithm converges to an optimal or near-optimal solution by reinforcing the most promising paths with more pheromones.

J. Different Approach

If the project were to be done again, some potential changes could include:

- Improving the user interface: Create a more intuitive and visually appealing user interface for better user experience.
- Implementing a more advanced algorithm: Choose an algorithm that better handles global optimization, such as the Genetic Algorithm or Simulated Annealing, to potentially improve the overall solution.
- Implementing a more object-oriented approach to handle packages, trucks, and drivers as objects that completely and independently respond to functions defined in each class.
- Modularize the code further: Break down the code into smaller functions and classes to improve readability and maintainability. This would make it easier to add, modify or remove features in the future.
- Include additional features: Add more functionality, such as real-time traffic updates, weather conditions, or the ability to handle multiple depots.
- Evaluate performance with larger datasets: Test the application with a larger dataset to analyze its scalability and identify any bottlenecks or performance issues.
- Unit tests and automated testing: Implement unit tests and automated testing to ensure the reliability and correctness of the code as changes are made over time.

K1. Verification of Data Structure

The hash table used in the solution meets all requirements in the scenario. The total combined delivery distance is 102.9 miles which less than 140 total miles per requirements. All packages are delivered on time. The hash table class has a look-up function that returns all of the package elements respectively. The user can get an accurate report of delivery status of each individual package, or all packages at a given time, as well as the total distance traveled by all trucks, or each truck after the whole route is complete.

K1A. Efficiency

Time needed to complete the look-up function is affected by the number of packages to be delivered because, in the worst case, the look-up time complexity is O(N). However, in most cases, the look-up time complexity is close to O(1).

K1B. Overhead

The data structure space usage is affected by the number of packages to be delivered as more packages require more space to store package information. However, hash tables efficiently manage space usage by dynamically resizing and maintaining a suitable load factor.

K1C. Implications

Changes to the number of trucks or the number of cities would not significantly affect the look-up time and space usage of the data structure, as the hash table's primary concern is the number of packages. However, the algorithm's efficiency and total distance traveled would be affected by changes in the number of trucks or cities.

K2. Other Data Structures

Two other data structures that could meet the same requirements in the scenario:

- Balanced Binary Search Tree (e.g., AVL Tree, Red-Black Tree) (Cormen T. H., 2009)
- Trie (Prefix Tree) Sedgewick, R., & Wayne, K. (2011)

K2a. Data Structure Differences

A balanced binary search tree is different from the hash table as it guarantees O(log N) time complexity for insertion, deletion, and search operations. It can be more space-efficient than hash tables but might be slower for look-up operations, particularly when the number of packages is large. (Cormen et al., 2009).

A trie is a tree-like data structure that stores keys (e.g., package ID) in a hierarchical manner. Each node in a trie represents a single character or part of the key. Tries can offer faster look-up times than hash tables in some cases but may consume more space due to their tree structure.

L. Sources & Works Observed

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- *Ant colony optimization algorithms. (2023, March 27). Retrieved from Wikipedia:* https://en.wikipedia.org/wiki/Ant_colony_optimization_algorithms
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- Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2009). Introduction to Algorithms (3rd ed.). MIT Press. (Sections 12.1-12.4, 13.1-13.4)