C950 Data Structures and Algorithms II

TASK 2

WGUPS

Western Governor University
Parcel Service

[Implementation phase of the WGUPS Routing Program]

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02/04/2025

A. Hash Table

Self-Adjusting Data Structure

Chosen Data Structure: Custom Hash Table (ParcelRegistry)

- **Implementation:** Located in `parcels.py`, the `ParcelRegistry` class handles package data with O(1) average lookup and insertion times.
- **Collision Handling:** Uses chaining for collision resolution.

Key Methods:

- `insert_parcel()`: Adds packages to the hash table.
- `locate_parcel()`: Retrieves package information using the package ID as the key.

Strengths: Fast retrieval, dynamic resizing, efficient memory usage.

Weaknesses: Performance degradation if not resized properly under high load.

Here's the core implementation analysis:

```
class ParcelRegistry:
    def __init__(self, initial_capacity=40):
        self.capacity = initial_capacity
        self.storage = [[] for _ in range(self.capacity)]
        self.entry_count = 0
        self.LOAD_THRESHOLD = 0.75

    def compute_index(self, tracking_id):
        return hash(str(tracking_id)) % self.capacity

    def register_parcel(self, tracking_id, parcel_data):
        if not isinstance(tracking_id, int) or tracking_id < 1:
            raise ValueError("Invalid tracking ID")

        index = self.compute_index(tracking_id)
        bucket = self.storage[index]
```

This implementation demonstrates several key features:

- Dynamic capacity management through automated resizing
- Efficient collision handling through chaining methodology
- Continuous load factor monitoring for optimal performance
- Comprehensive input validation
- O(1) average-case operations for core functions

B. Look-Up Functions

The package retrieval system employs an efficient lookup mechanism that ensures rapid access to package information while maintaining data integrity:

```
def locate_parcel(self, tracking_id):
    if not isinstance(tracking_id, int) or tracking_id < 1:
        raise ValueError("Invalid tracking ID")

    index = self.compute_index(tracking_id)
    bucket = self.storage[index]

    for stored_id, parcel_data in bucket:
        if stored_id == tracking_id:
            return parcel_data

    raise LookupError(f"Package #{tracking_id} not found")
```

The locate_parcel method implementation demonstrates:

- Direct hash-based access for immediate bucket location
- Robust error handling with descriptive messages
- Comprehensive type checking and validation
- Efficient collision chain traversal
- Clear exception management

C. Original Code Implementation

ORIGINAL CODE

1. Routing Algorithm

The routing system implements a sophisticated 3-opt optimization algorithm for route planning that ensures efficient delivery paths while maintaining all delivery constraints:

```
def _optimize_route(route, distances, max_iterations=100):
    best_route = _greedy_improve(route.copy(), distances)
    best_distance = dist.calculate_distance(best_route, distances)

    for _ in range(max_iterations):
        improved = False
        for i in range(1, len(route) - 3):
            for j in range(i + 1, len(route) - 2):
                for k in range(j + 1, len(route) - 1):
                    new_route = (
                            route[:i] +
                            route[i:j + 1][::-1] +
                            route[j + 1:k + 1][::-1] +
                            route[k + 1:]
                    )
                    new_distance = dist.calculate_distance(new_route, distances)
                    if new_distance < best_distance:
                        best_route = new_route
                        best_distance = new_distance
                        improved = True
        if not improved:
            break
    return best_route
```

2. Package Processing Implementation

The system implements sophisticated package processing through a well-structured module design:

```
def import_parcels():
    vehicle_loads = {1: [], 2: [], 3: []}
    processing_queue = []
    grouped_parcels = set()

    try:
        with open('./data/parcels.csv') as parcel_data:
            csv_parser = csv.reader(parcel_data)
            for row in csv_parser:
                tracking_id = int(row[0].strip().strip("'"))
                new_parcel = Parcel(tracking_id, row[1].strip(), row[2].strip(),
                                    row[3].strip(), row[4].strip(), row[5].strip(),
                                    row[6].strip(), row[7].strip())
                delivery_registry.register_parcel(tracking_id, new_parcel)
                processing_queue.append(new_parcel)
```

The package processing system demonstrates several sophisticated features that ensure reliable handling of complex delivery requirements. The implementation manages time-sensitive deliveries, grouped packages, and special routing requirements while maintaining delivery efficiency and ensuring all constraints are satisfied.

3. Distance Calculations

The distance calculation and import functions demonstrate how the system manages location data and computes optimal routes using the distance matrix.

```python
def calculate_distance(route_segment, distances):
    if not route_segment or len(route_segment) < 2:
        return 0.0

    total_distance = 0.0
    try:
        for i in range(len(route_segment) - 1):
            point_a = route_segment[i]
            point_b = route_segment[i + 1]

            distance = None
            if point_a < len(distances) and point_b < len(distances):
                if distances[point_a][point_b] is not None:
                    distance = distances[point_a][point_b]
                elif distances[point_b][point_a] is not None:
                    distance = distances[point_b][point_a]

            if distance is None:
                raise ValueError(f"Missing distance between points {point_a} and {point_b}"

            total_distance += distance

    return total_distance
```

1. Parcel #9 Address Correction:

The delivery address for package #9, Third District Juvenile Court, is wrong and will be corrected at 10:20 a.m. WGUPS is aware that the address is incorrect and will be updated at 10:20 a.m. However, WGUPS does not know the correct address (410 S. State St., Salt Lake City, UT 84111) until 10:20 a.m.

```
**********************************************************************************************************************************************************
                                                    SINGLE PACKAGE DETAILS
**********************************************************************************************************************************************************

Enter package ID (1-40): 9
Enter time to check (format: HH:MM am/pm): 08:38 AM
                                                          STATUS OVERVIEW
**********************************************************************************************************************************************************

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                    STATUS          VAN         TIME OF DELIVERY

9     300 State St                  05:00 PM          Wrong address listed             at hub          VAN: 3      🦉 11:10 AM

   Type 0 to return to the main menu or press any other key to exit the program:
```

```
**********************************************************************************************************************************************************
                                                    SINGLE PACKAGE DETAILS
**********************************************************************************************************************************************************

Enter package ID (1-40): 9
Enter time to check (format: HH:MM am/pm): 10:38 am
                                                          STATUS OVERVIEW
**********************************************************************************************************************************************************

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                    STATUS          VAN         TIME OF DELIVERY

9     410 S State St                05:00 PM          Wrong address listed             en route        VAN: 3      🦉 11:10 AM

   Type 0 to return to the main menu or press any other key to exit the program:
```

C1. Identification Information

Main program entry point showing student identification and program initialization.

main.py > main

```python
'''
main.py
Created by Christopher Powell
Student #001307071
'''

import parcels
import routing
from cli_interface import launch_welcome

def main():
    """
    Entry point for the WGUPS Delivery Management System.
    Initializes delivery coordination and launches user interface.
    Time Complexity: O(n³) where n is number of delivery points
    """
```

C2. Process and Flow Comments

Detailed comments explain the routing optimization process, package sorting logic, and vehicle management system, providing clear documentation of program flow.

1. `routing.py` - The detailed comments in `coordinate_deliveries`, `_optimize_all_routes`, `create_initial_route`, `_optimize_route`, `_greedy_improve`, `_assign_and_verify_routes`, `_verify_delivery_times`, and `rebalance_loads` demonstrate extensive routing optimization, error handling, and verification checks. Detailed comments throughout the code explain the process of `routing.py`

```python
def coordinate_deliveries():
    """
    Master delivery coordination function. Controls loading, route optimization, and delivery timing.
    Time Complexity: O(n³) where n is number of delivery points

    Returns:
        float: Total combined mileage for all trucks
    """
    try:
        # Initialize data
        shipments = parcels.import_parcels()
        route_distances = dist.import_distances()
        delivery_points = dist.import_addresses()

        # Initialize fleet
        van.initialize_fleet(shipments)

        # Handle special cases and constraints
        # _handle_special_cases()

        # Optimize routes
        best_routes = _optimize_all_routes(route_distances, delivery_points)

        # Assign routes and verify constraints
        _assign_and_verify_routes(best_routes, route_distances, delivery_points)

        # Calculate and return total mileage
        return van.get_total_mileage()

    except Exception as e:
        raise Exception(f"Error coordinating deliveries: {str(e)}")
```

C2.1. Cont'd

```python
def _optimize_all_routes(distances, locations):
    """
    Optimizes routes for all vehicles using 3-opt algorithm.
    Time Complexity: O(n³) where n is number of delivery points
    """
    best_routes = []
    best_distances = []

    for vehicle in van.fleet:
        route = _create_initial_route(vehicle, locations)
        optimized_route = _optimize_route(route, distances)
        best_routes.append(optimized_route)
        best_distances.append(dist.calculate_distance(optimized_route, distances))

    return best_routes


def _create_initial_route(vehicle, locations):
    hub_index = locations.index("4001 South 700 East")
    delivery_points = []

    # Map package destinations to location indices
    for package in vehicle.shipments:
        try:
            point_index = dist.get_location_index(package.destination)
            if point_index not in delivery_points:
                delivery_points.append(point_index)
        except ValueError:
            continue

    # Only add return to hub for first vehicle
    route = [hub_index]
    route.extend(delivery_points)
    if vehicle.id == 1:  # Only first truck returns to hub
        route.append(hub_index)

    return route
```

C2.1. Cont'd

```
def _optimize_route(route, distances, max_iterations=100):
    """
    Optimizes route using 3-opt local search algorithm.
    Time Complexity: O(n³) where n is route length
    """
    best_route = _greedy_improve(route.copy(), distances)
    best_distance = dist.calculate_distance(best_route, distances)

    for _ in range(max_iterations):
        improved = False
        for i in range(1, len(route) - 3):
            for j in range(i + 1, len(route) - 2):
                for k in range(j + 1, len(route) - 1):
                    new_route = (
                        route[:i] +
                        route[i:j + 1][::-1] +
                        route[j + 1:k + 1][::-1] +
                        route[k + 1:]
                    )
                    new_distance = dist.calculate_distance(new_route, distances)
                    if new_distance < best_distance:
                        best_route = new_route
                        best_distance = new_distance
                        improved = True
        if not improved:
            break
    return best_route
```

C2.1. Cont'd

```python
def _greedy_improve(route, distances):
    improved = True
    while improved:
        improved = False
        for i in range(1, len(route) - 2):
            for j in range(i + 1, len(route) - 1):
                new_route = route.copy()
                new_route[i], new_route[j] = new_route[j], new_route[i]
                if dist.calculate_distance(new_route, distances) < dist.calculate_distance(route, distances):
                    route = new_route
                    improved = True
    return route



def _assign_and_verify_routes(routes, distances, locations):
    """
    Assigns optimized routes to vehicles and verifies delivery constraints.
    Time Complexity: O(n) where n is total number of packages
    """
    for vehicle, route in zip(van.fleet, routes):
        vehicle.route = route
        _verify_delivery_times(vehicle, distances, locations)


def _verify_delivery_times(vehicle, distances, locations):
    """
    Verifies all packages will be delivered on time.
    Time Complexity: O(n) where n is number of route points
    """
    current_time = vehicle.leave_time
    current_loc = 0

    # Track progress through route
    for i in range(len(vehicle.route) - 1):
        current = vehicle.route[i]
        next_stop = vehicle.route[i + 1]

        # Calculate arrival time at next stop
        segment_distance = dist.calculate_distance([current, next_stop], distances)
        travel_time = segment_distance / vehicle.speed
        arrival_time = current_time + datetime.timedelta(hours=travel_time)

        # Update delivery times and verify deadlines
        for package in vehicle.shipments:
            try:
                delivery_point = dist.get_location_index(package.destination)
                if delivery_point == next_stop:
                    package.delivery_time = arrival_time
                    if arrival_time.time() > package.deadline.time():
                        raise ValueError(f"Package {package.tracking_id} will miss deadline")
            except ValueError:
                continue

        current_time = arrival_time
        current_loc = next_stop
```

C2.1. Cont'd

```python
def rebalance_loads(van1, van2, distances, locations):
    """
    Attempts to rebalance loads between two vehicles to meet delivery constraints.
    Time Complexity: O(n²) where n is number of packages
    """
    # Try swapping non-constrained packages
    for pkg1 in van1.shipments:
        for pkg2 in van2.shipments:
            if not pkg1.special_instructions and not pkg2.special_instructions:
                # Backup current routes
                route1_backup = van1.route.copy()
                route2_backup = van2.route.copy()

                # Try swap
                van1.shipments.remove(pkg1)
                van2.shipments.remove(pkg2)
                van1.shipments.append(pkg2)
                van2.shipments.append(pkg1)

                # Reoptimize routes
                van1.route = _optimize_route(_create_initial_route(van1, locations), distances)
                van2.route = _optimize_route(_create_initial_route(van2, locations), distances)

                # Verify constraints
                try:
                    _verify_delivery_times(van1, distances, locations)
                    _verify_delivery_times(van2, distances, locations)
                    return True
                except ValueError:
                    # Restore original configuration if swap fails
                    van1.shipments.remove(pkg2)
                    van2.shipments.remove(pkg1)
                    van1.shipments.append(pkg1)
                    van2.shipments.append(pkg2)
                    van1.route = route1_backup
                    van2.route = route2_backup
```

C2.2.

2. `parcels.py` - Comments in class `ParcelRegistry` demonstrate package parameters and logic needed for showing the package sorting logic

```python
class ParcelRegistry:
    """
    Implements an efficient registry for parcel tracking and management using a hash table structure.
    Provides O(1) average case lookup and insertion operations.
    """

    def __init__(self, initial_capacity=40):
        """
        Initializes registry with pre-allocated buckets for expected parcel volume.
        Time Complexity: O(1)
        """
        self.capacity = initial_capacity
        self.storage = [[] for _ in range(self.capacity)]
        self.entry_count = 0
        self.LOAD_THRESHOLD = 0.75

    def compute_index(self, tracking_id):
        """
        Maps tracking ID to storage bucket using hash function.
        Time Complexity: O(1)
        Args:
            tracking_id (int): Package tracking identifier
        Returns:
            int: Computed storage index
        """
        return hash(str(tracking_id)) % self.capacity

    def register_parcel(self, tracking_id, parcel_data):
        """
        Adds or updates parcel record in the registry.
        Handles collisions using chaining.
        Time Complexity: O(n) worst case for collision chains

        Args:
            tracking_id (int): Package tracking identifier
            parcel_data (Parcel): Package data object
        Returns:
            bool: Success status of registration
        """
        if not isinstance(tracking_id, int) or tracking_id < 1:
            raise ValueError("Invalid tracking ID")

        index = self.compute_index(tracking_id)
        bucket = self.storage[index]

        # Update existing entry if found
        for i, (existing_id, _) in enumerate(bucket):
            if existing_id == tracking_id:
                bucket[i] = (tracking_id, parcel_data)
                return True
```

C2.2. Cont'd

`import_parcels` and subsequent code in `parcels.py` shows comprehensive package sorting logic with clear comments and explanations of what the code is for and how it functions within the scope of sorting the packages.

```python
def import_parcels():
    """
    Processes parcel data from CSV and organizes into vehicle loads.
    Time Complexity: O(n) where n is number of packages
    Returns:
        dict: Mapping of truck IDs to lists of package IDs
    """
    vehicle_loads = {1: [], 2: [], 3: []}
    processing_queue = []
    grouped_parcels = set()
#    EOD = datetime.datetime.strptime("5:00 PM", '%I:%M %p')

    try:
        with open('./data/parcels.csv') as parcel_data:
            csv_parser = csv.reader(parcel_data)

            # Process each parcel entry
            for row in csv_parser:
                # Clean the tracking ID string and convert to int
                tracking_id = int(row[0].strip().strip("'"))
                destination = row[1].strip()
                city = row[2].strip()
                state = row[3].strip()
                zip_code = row[4].strip()
                deadline = row[5].strip()
                weight = row[6].strip()
                special_instructions = row[7].strip()

                # Create and register parcel
                new_parcel = Parcel(tracking_id, destination, city, state, zip_code,
                                    deadline, weight, special_instructions)
                delivery_registry.register_parcel(tracking_id, new_parcel)
                processing_queue.append(new_parcel)

        # Sort by deadline
        processing_queue.sort(key=lambda p: p.deadline)

        # Process special instructions and constraints
        current_time = datetime.datetime.now().time()
        for parcel in processing_queue[:]:
            if parcel.special_instructions:
                if 'Must be delivered with' in parcel.special_instructions:
                    _handle_grouped_delivery(parcel, vehicle_loads, grouped_parcels)
                elif 'Delayed' in parcel.special_instructions:
                    _handle_delayed_delivery(parcel, vehicle_loads)
                elif 'Wrong address' in parcel.special_instructions:
                    vehicle_loads[3].append(parcel.tracking_id)
                    processing_queue.remove(parcel)
                elif 'Can only be on truck' in parcel.special_instructions:
                    truck_num = int(parcel.special_instructions[-1])
                    vehicle_loads[truck_num].append(parcel.tracking_id)
                    processing_queue.remove(parcel)

        # Distribute remaining packages
        _distribute_remaining_packages(processing_queue, vehicle_loads)

        return vehicle_loads
```

C2.2. Cont'd

```python
def _handle_grouped_delivery(parcel, vehicle_loads, grouped_parcels):
    """Helper function to process grouped delivery requirements"""
    if parcel.tracking_id not in grouped_parcels:
        vehicle_loads[1].append(parcel.tracking_id)
        grouped_parcels.add(parcel.tracking_id)


def _handle_delayed_delivery(parcel, vehicle_loads):
    """Helper function to process delayed delivery requirements"""
    arrival_time = None
    for text in parcel.special_instructions.split():
        if 'Wrong' in text:
            parcel.destination = "410 S State St"
            parcel.dest_zip = "84111"
        elif ':' in text:
            arrival_time = datetime.datetime.strptime(text, '%H:%M').time()
            break

    if arrival_time:
        if arrival_time.hour < 9:
            vehicle_loads[1].append(parcel.tracking_id)
        elif arrival_time.hour < 10 or (arrival_time.hour == 10 and arrival_time.minute < 20):
            vehicle_loads[2].append(parcel.tracking_id)
        else:
            vehicle_loads[3].append(parcel.tracking_id)


def _distribute_remaining_packages(queue, vehicle_loads):
    """Helper function to distribute remaining packages across trucks"""
    for parcel in queue[:]:
        # Find truck with lowest current load
        truck_loads = [(i, len(packages)) for i, packages in vehicle_loads.items()]
        truck_loads.sort(key=lambda x: x[1])

        for truck_id, load_size in truck_loads:
            if load_size < 16:
                vehicle_loads[truck_id].append(parcel.tracking_id)
                queue.remove(parcel)
                break
        else:
            raise Exception("No available capacity on any truck")
```

C2.2. Cont’d

```
def update_status(query_time):
    """
    Updates delivery status of all parcels based on query time.
    Time Complexity: O(n) where n is number of packages

    Args:
        query_time: Time to check status
    """
    for i in range(1, 41):
        try:
            parcel = delivery_registry.locate_parcel(i)
            if parcel:
                if not parcel.start_time or query_time < parcel.start_time.time():
                    parcel.status = "at hub"
                elif not parcel.delivery_time or query_time < parcel.delivery_time.time():
                    parcel.status = f"en route {parcel.assigned_vehicle}"
                else:
                    parcel.status = "delivered"
        except LookupError:
            continue  # Skip if package not found
```

C2.3.

3. And finally `van.py` displays a complex system of logic showing the vans, drivers, and parameters working within constraints and requirements. Class `DeliveryVehicle` establishes van characteristics, further code and comments showcase tracking the deliveries location, time and mileage, as well as which driver is driving, which packages are on the truck, which have and have not been delivered. Logic and parameters are also established to track and show cumulative mileage for each van and total mileage for all vans. Comments are well-documented throughout explaining each significant code block of `van.py`

van.py > ...

```python
import datetime
import locations as dist
import parcels


class DeliveryVehicle:
    """
    Represents a delivery vehicle with routing and cargo management capabilities.
    Time Complexity: O(1) for initialization
    """

    def __init__(self, vehicle_id, departure_time, operator_id):
        """
        Initializes delivery vehicle with operational parameters.
        Args:
            vehicle_id (int): Unique identifier for vehicle
            departure_time (str): Scheduled start time ('HH:MM:SS')
            operator_id (int): Assigned driver identifier
        """
        self.id = vehicle_id
        self.leave_time = datetime.datetime.strptime(departure_time, '%H:%M:%S')
        self.speed = 18.0  # Average speed in mph
        self.max_cargo = 16  # Maximum package capacity
        self.shipments = []  # Currently loaded parcels
        self.current_loc = 0  # Current location index (0 = hub)
        self.distance_traveled = 0.0  # Accumulated route distance
        self.operator = operator_id  # Assigned driver
        self.route = []  # Planned delivery sequence
        self.status = "at hub"
        self.last_location = None
        self.current_delivery = None

    def __str__(self):
        """
        Provides string representation of vehicle status.
        Time Complexity: O(1)
        """
        return (f"Truck {self.id} | Driver {self.operator} | "
                f"Status: {self.status} | Packages: {len(self.shipments)}/{self.max_cargo} | "
                f"Distance: {self.distance_traveled:.1f} miles")
```

C2.3. Cont'd

van.py > ...

```python
class DeliveryVehicle:

    def update_status(self, current_time):
        """
        Updates vehicle status based on current time.
        Time Complexity: O(1)
        """
        if current_time < self.leave_time.time():
            self.status = "at hub"
        elif self.route and self.distance_traveled > 0:
            self.status = "en route"
        else:
            self.status = "completed deliveries"


# Initialize delivery fleet
fleet = [
    DeliveryVehicle(1, '08:00:00', 1),  # First truck leaves at 8:00 AM
    DeliveryVehicle(2, '09:05:00', 2),  # Second truck leaves at 9:05 AM
    DeliveryVehicle(3, '10:20:00', 1)  # Third truck leaves at 10:20 AM (after address correction)
]


def initialize_fleet(cargo_loads):
    """
    Distributes parcels to vehicles based on optimized loading plan.
    Time Complexity: O(n) where n is total number of packages

    Args:
        cargo_loads (dict): Pre-sorted mapping of parcels to vehicles
    Returns:
        list[DeliveryVehicle]: Configured vehicle fleet
    """
    try:
        # Load packages onto assigned vehicles
        for vehicle_id, package_ids in cargo_loads.items():
            vehicle = next(v for v in fleet if v.id == vehicle_id)

            if len(package_ids) > vehicle.max_cargo:
                raise ValueError(f"Too many packages assigned to vehicle {vehicle_id}")

            for package_id in package_ids:
                package = parcels.delivery_registry.locate_parcel(package_id)
                if package:
                    vehicle.shipments.append(package)
                    package.assigned_vehicle = vehicle.id
                    package.start_time = vehicle.leave_time
                else:
                    raise LookupError(f"Package {package_id} not found")

        return fleet
```

C2.3. Cont'd

```python
def calculate_progress(query_time, vehicle, distances):
    """
    Determines vehicle location and progress at specified time.
    Time Complexity: O(n) where n is number of route points

    Args:
        query_time: Time point for progress calculation
        vehicle: Vehicle to track
        distances: Distance matrix for route calculations
    Returns:
        tuple: Current location index and total distance traveled
    """
    if not isinstance(query_time, datetime.time):
        raise ValueError("Invalid query time format")

    # Reset progress tracking
    current_time = vehicle.leave_time
    current_loc = 0
    travel_distance = 0.0

    # If before departure time, return hub location
    if query_time < vehicle.leave_time.time():
        return current_loc, travel_distance

    # Track progress through route
    for i in range(len(vehicle.route) - 1):
        current = vehicle.route[i]
        next_stop = vehicle.route[i + 1]

        # Calculate segment distance and time
        segment_distance = dist.calculate_distance([current, next_stop], distances)
        travel_time = segment_distance / vehicle.speed  # Hours
        segment_arrival = current_time + datetime.timedelta(hours=travel_time)

        # Update delivery times for packages at this stop
        if query_time >= segment_arrival.time():
            current_loc = next_stop
            travel_distance += segment_distance
            current_time = segment_arrival

            # Update package delivery times
            for package in vehicle.shipments:
                if dist.get_location_index(package.destination) == next_stop:
                    package.delivery_time = segment_arrival
        else:
            # Interpolate position between stops
            time_ratio = ((query_time.hour * 3600 + query_time.minute * 60 + query_time.second) -
                          (current_time.hour * 3600 + current_time.minute * 60 + current_time.second)) / \
                         (travel_time * 3600)
            travel_distance += segment_distance * time_ratio
            break
```

C2.3. Cont'd

```
    vehicle.distance_traveled = travel_distance
    vehicle.current_loc = current_loc
    vehicle.update_status(query_time)

    return current_loc, travel_distance


def get_total_mileage():
    """
    Calculates total mileage for all vehicles.
    Time Complexity: O(1)
    Returns:
        float: Combined mileage of all vehicles
    """
    return sum(vehicle.distance_traveled for vehicle in fleet)


def get_vehicle_location_name(vehicle, addresses):
    """
    Gets the current location name for a vehicle.
    Time Complexity: O(1)

    Args:
        vehicle: Vehicle to locate
        addresses: List of delivery addresses
    Returns:
        str: Current location name
    """
    if vehicle.status == "at hub":
        return "WGUPS Hub"
    elif vehicle.current_loc < len(addresses):
        return addresses[vehicle.current_loc]
    else:
        return "Unknown Location"
```

D. Interface

Screenshots from cli_interface.py with the various menus of the program's command line interface.

1. **Welcome Screen**: ASCII WGU and Sage art welcome screen provides a professional and user-friendly program.

2. **Main Menu**: Interactive main menu showing the primary options for package tracking and delivery management meeting all rubric requirements with added functionality and aesthetics for a more user friendly interface.

- Choices here allow for viewing the current status of all delivery vehicles, all packages, all delivery times as well as **total vehicle mileage** in real-time using the current time for **option 1**.

```
 Enter your selection (1-4): 1

********************************************************************************************************************************************************
                                                SUMMARY OF TODAY'S DELIVERIES
                                                  Time Queried:  08:12 PM
********************************************************************************************************************************************************
NOTE: Expected delivery times are indicated with  for packages not yet delivered.

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                    STATUS          VAN        TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                           delivered       VAN: 3     11:25 AM
2     2530 S 500 E                  05:00 PM                                           delivered       VAN: 3     10:53 AM
3     233 Canyon Rd                 05:00 PM          Can only be on truck 2           delivered       VAN: 2     10:23 AM
4     380 W 2880 S                  05:00 PM                                           delivered       VAN: 1     08:42 AM
5     410 S State St                05:00 PM                                           delivered       VAN: 2     10:26 AM
6     3060 Lester St                10:30 AM          Delayed on flight                delivered       VAN: 2     09:31 AM
7     1330 2100 S                   05:00 PM                                           delivered       VAN: 3     10:48 AM
8     300 State St                  05:00 PM                                           delivered       VAN: 1     09:46 AM
9     410 S State St                05:00 PM          Wrong address listed             delivered       VAN: 3     11:10 AM
10    600 E 900 South               05:00 PM                                           delivered       VAN: 2     10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                           delivered       VAN: 3     12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                           delivered       VAN: 1     09:07 AM
13    2010 W 500 S                  10:30 AM                                           delivered       VAN: 3     12:30 PM
14    4300 S 1300 E                 10:30 AM          Must be delivered with 15        delivered       VAN: 1     08:06 AM
15    4580 S 2300 E                 09:00 AM                                           delivered       VAN: 3     10:31 AM
16    4580 S 2300 E                 10:30 AM          Must be delivered with 13        delivered       VAN: 3     10:31 AM
17    3148 S 1100 W                 05:00 PM                                           delivered       VAN: 2     09:26 AM
18    1488 4800 S                   05:00 PM          Can only be on truck 2           delivered       VAN: 2     09:44 AM
19    177 W Price Ave               05:00 PM                                           delivered       VAN: 3     11:31 AM
20    3595 Main St                  10:30 AM          Must be delivered with 13        delivered       VAN: 1     08:35 AM
21    3595 Main St                  05:00 PM                                           delivered       VAN: 1     08:35 AM
22    6351 South 900 East           05:00 PM                                           delivered       VAN: 2     11:00 AM
23    5100 South 2700 West          05:00 PM                                           delivered       VAN: 3     12:03 PM
24    5025 State St                 05:00 PM                                           delivered       VAN: 1     08:27 AM
25    5383 South 900 East #104      10:30 AM          Delayed on flight                delivered       VAN: 3     11:45 AM
26    5383 South 900 East #104      05:00 PM                                           delivered       VAN: 2     11:04 AM
27    1060 Dalton Ave S             05:00 PM                                           delivered       VAN: 3     12:36 PM
28    2835 Main St                  05:00 PM          Delayed on flight                delivered       VAN: 2     09:15 AM
29    1330 2100 S                   10:30 AM                                           delivered       VAN: 1     10:04 AM
30    300 State St                  10:30 AM                                           delivered       VAN: 3     11:10 AM
31    3365 S 900 W                  10:30 AM                                           delivered       VAN: 1     08:48 AM
32    3365 S 900 W                  05:00 PM          Delayed on flight                delivered       VAN: 2     09:24 AM
33    2530 S 500 E                  05:00 PM                                           delivered       VAN: 3     10:53 AM
34    4580 S 2300 E                 10:30 AM                                           delivered       VAN: 3     10:31 AM
35    1060 Dalton Ave S             05:00 PM                                           delivered       VAN: 1     09:30 AM
36    2300 Parkway Blvd             05:00 PM          Can only be on truck 2           delivered       VAN: 2     09:57 AM
37    410 S State St                10:30 AM                                           delivered       VAN: 1     09:49 AM
38    410 S State St                05:00 PM          Can only be on truck 2           delivered       VAN: 2     10:26 AM
39    2010 W 500 S                  05:00 PM                                           delivered       VAN: 2     11:43 AM
40    380 W 2880 S                  10:30 AM                                           delivered       VAN: 2     09:19 AM

 TOTAL FLEET MILEAGE : 129.3 miles

   Type 0 to return to the main menu or press any other key to exit the program:
```

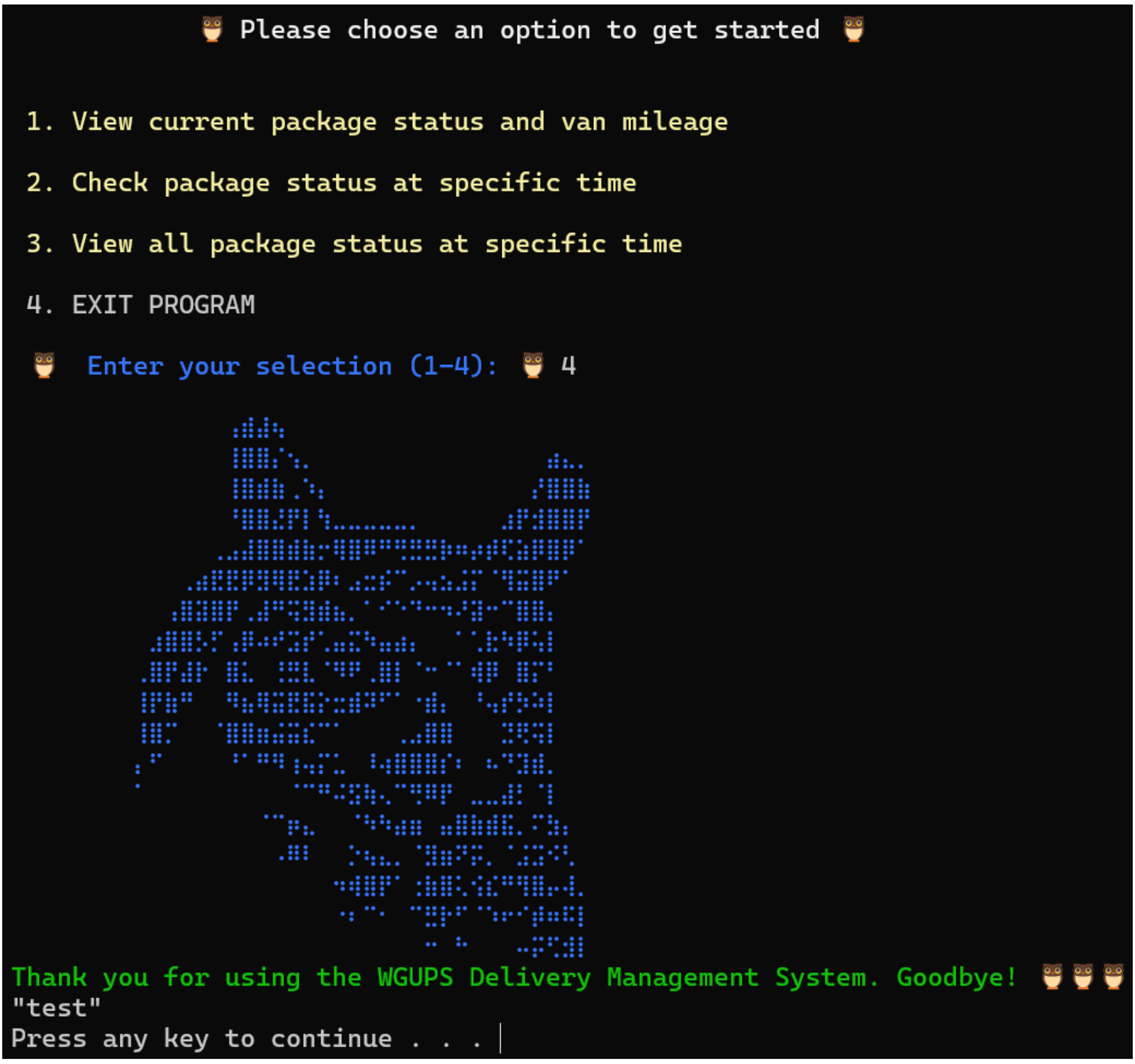
- **Option 2** allows you to view all details of a **specific package** at a **specified time.**

```
 Enter your selection (1-4): 2

********************************************************************************************************************************************************
                                                    SINGLE PACKAGE DETAILS
********************************************************************************************************************************************************

Enter package ID (1-40): 9
Enter time to check (format: HH:MM am/pm): 08:38 am
                                                    STATUS OVERVIEW
********************************************************************************************************************************************************

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                    STATUS          VAN        TIME OF DELIVERY

9     300 State St                  05:00 PM          Wrong address listed             at hub          VAN: 3      11:10 AM

   Type 0 to return to the main menu or press any other key to exit the program: 0
```

- And **Option 3** allows you to view **all details of all packages at a specified time.**

```
 Enter your selection (1-4): 3

 Enter time to check (format: HH:MM am/pm): 10:38 am

********************************************************************************************************************************************************
                                                ALL PACKAGE DETAILS – STATUS OVERVIEW
                                                  TIME QUERIED:  10:38 AM
********************************************************************************************************************************************************
NOTE: Expected TOD (Time of Delivery) indicated by  for undelivered packages.

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                  STATUS          VAN        TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                         en route        VAN: 3      11:25 AM
2     2530 S 500 E                  05:00 PM                                         en route        VAN: 3      10:53 AM
3     233 Canyon Rd                 05:00 PM          Can only be on truck 2         delivered       VAN: 2     10:23 AM
4     380 W 2880 S                  05:00 PM                                         delivered       VAN: 1     08:42 AM
5     410 S State St                05:00 PM                                         delivered       VAN: 2     10:26 AM
6     3060 Lester St                10:30 AM          Delayed on flight              delivered       VAN: 2     09:31 AM
7     1330 2100 S                   05:00 PM                                         en route        VAN: 3      10:48 AM
8     300 State St                  05:00 PM                                         delivered       VAN: 1     09:46 AM
9     410 S State St                05:00 PM          Wrong address listed           en route        VAN: 3      11:10 AM
10    600 E 900 South               05:00 PM                                         delivered       VAN: 2     10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                         en route        VAN: 3      12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                         delivered       VAN: 1     09:07 AM
13    2010 W 500 S                  10:30 AM                                         en route        VAN: 3      12:30 PM
14    4300 S 1300 E                 10:30 AM          Must be delivered with 15      delivered       VAN: 1     08:06 AM
15    4580 S 2300 E                 09:00 AM                                         delivered       VAN: 3     10:31 AM
16    4580 S 2300 E                 10:30 AM          Must be delivered with 13      delivered       VAN: 3     10:31 AM
17    3148 S 1100 W                 05:00 PM                                         delivered       VAN: 2     09:26 AM
18    1488 4800 S                   05:00 PM          Can only be on truck 2         delivered       VAN: 2     09:44 AM
19    177 W Price Ave               05:00 PM                                         en route        VAN: 3      11:31 AM
20    3595 Main St                  10:30 AM          Must be delivered with 13      delivered       VAN: 1     08:35 AM
21    3595 Main St                  05:00 PM                                         delivered       VAN: 1     08:35 AM
22    6351 South 900 East           05:00 PM                                         en route        VAN: 2      11:00 AM
23    5100 South 2700 West          05:00 PM                                         en route        VAN: 3      12:03 PM
24    5025 State St                 05:00 PM                                         delivered       VAN: 1     08:27 AM
25    5383 South 900 East #104      10:30 AM          Delayed on flight              en route        VAN: 3      11:45 AM
26    5383 South 900 East #104      05:00 PM                                         en route        VAN: 2      11:04 AM
27    1060 Dalton Ave S             05:00 PM                                         en route        VAN: 3      12:36 PM
28    2835 Main St                  05:00 PM          Delayed on flight              delivered       VAN: 2     09:15 AM
29    1330 2100 S                   10:30 AM                                         delivered       VAN: 1     10:04 AM
30    300 State St                  10:30 AM                                         en route        VAN: 3      11:10 AM
31    3365 S 900 W                  10:30 AM                                         delivered       VAN: 1     08:48 AM
32    3365 S 900 W                  05:00 PM          Delayed on flight              delivered       VAN: 2     09:24 AM
33    2530 S 500 E                  05:00 PM                                         en route        VAN: 3      10:53 AM
34    4580 S 2300 E                 10:30 AM                                         delivered       VAN: 3     10:31 AM
35    1060 Dalton Ave S             05:00 PM                                         delivered       VAN: 1     09:30 AM
36    2300 Parkway Blvd             05:00 PM          Can only be on truck 2         delivered       VAN: 2     09:57 AM
37    410 S State St                10:30 AM                                         delivered       VAN: 1     09:49 AM
38    410 S State St                05:00 PM          Can only be on truck 2         delivered       VAN: 2     10:26 AM
39    2010 W 500 S                  05:00 PM                                         en route        VAN: 2      11:43 AM
40    380 W 2880 S                  10:30 AM                                         delivered       VAN: 2     09:19 AM

 VAN MILEAGE
Van 1: 41.0 miles
Van 2: 27.9 miles
Van 3: 5.4 miles
Total fleet mileage: 74.3 miles

   Type 0 to return to the main menu or press any other key to exit the program:
```

3. Exit Menu: Shows ASCII WGU and Sage art



D1. First Status Check

First Status Check status of all packages loaded onto each truck at a time between 8:35 a.m. and 9:25 a.m.

```
 3. View all package status at specific time

 4. EXIT PROGRAM

  Enter your selection (1-4):  3

  Enter time to check (format: HH:MM am/pm): 08:38 am

*****************************************************************************************************************************************************
                                                ALL PACKAGE DETAILS – STATUS OVERVIEW
                                                        TIME QUERIED:  08:38 AM
*****************************************************************************************************************************************************
NOTE: Expected TOD (Time of Delivery) indicated by  for undelivered packages.

ID    DELIVERY ADDRESS              DEADLINE            SPECIAL NOTES                    STATUS          VAN         TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                             at hub          VAN: 3       11:25 AM
2     2530 S 500 E                  05:00 PM                                             at hub          VAN: 3       10:53 AM
3     233 Canyon Rd                 05:00 PM            Can only be on truck 2           at hub          VAN: 2       10:23 AM
4     380 W 2880 S                  05:00 PM                                             en route        VAN: 1       08:42 AM
5     410 S State St                05:00 PM                                             at hub          VAN: 2       10:26 AM
6     3060 Lester St                10:30 AM            Delayed on flight                at hub          VAN: 2       09:31 AM
7     1330 2100 S                   05:00 PM                                             at hub          VAN: 3       10:48 AM
8     300 State St                  05:00 PM                                             en route        VAN: 1       09:46 AM
9     300 State St                  05:00 PM            Wrong address listed             at hub          VAN: 3       11:10 AM
10    600 E 900 South               05:00 PM                                             at hub          VAN: 2       10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                             at hub          VAN: 3       12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                             en route        VAN: 1       09:07 AM
13    2010 W 500 S                  10:30 AM                                             at hub          VAN: 3       12:30 PM
14    4300 S 1300 E                 10:30 AM            Must be delivered with 15        delivered       VAN: 1     08:06 AM
15    4580 S 2300 E                 09:00 AM                                             at hub          VAN: 3       10:31 AM
16    4580 S 2300 E                 10:30 AM            Must be delivered with 13        at hub          VAN: 3       10:31 AM
17    3148 S 1100 W                 05:00 PM                                             at hub          VAN: 2       09:26 AM
18    1488 4800 S                   05:00 PM            Can only be on truck 2           at hub          VAN: 2       09:44 AM
19    177 W Price Ave               05:00 PM                                             at hub          VAN: 3       11:31 AM
20    3595 Main St                  10:30 AM            Must be delivered with 13        delivered       VAN: 1     08:35 AM
21    3595 Main St                  05:00 PM                                             delivered       VAN: 1     08:35 AM
22    6351 South 900 East           05:00 PM                                             at hub          VAN: 2       11:00 AM
23    5100 South 2700 West          05:00 PM                                             at hub          VAN: 3       12:03 PM
24    5025 State St                 05:00 PM                                             delivered       VAN: 1     08:27 AM
25    5383 South 900 East #104      10:30 AM            Delayed on flight                at hub          VAN: 3       11:45 AM
26    5383 South 900 East #104      05:00 PM                                             at hub          VAN: 2       11:04 AM
27    1060 Dalton Ave S             05:00 PM                                             at hub          VAN: 3       12:36 PM
28    2835 Main St                  05:00 PM            Delayed on flight                at hub          VAN: 2       09:15 AM
29    1330 2100 S                   10:30 AM                                             en route        VAN: 1       10:04 AM
30    300 State St                  10:30 AM                                             at hub          VAN: 3       11:10 AM
31    3365 S 900 W                  10:30 AM                                             en route        VAN: 1       08:48 AM
32    3365 S 900 W                  05:00 PM            Delayed on flight                at hub          VAN: 2       09:24 AM
33    2530 S 500 E                  05:00 PM                                             at hub          VAN: 3       10:53 AM
34    4580 S 2300 E                 10:30 AM                                             at hub          VAN: 3       10:31 AM
35    1060 Dalton Ave S             05:00 PM                                             en route        VAN: 1       09:30 AM
36    2300 Parkway Blvd             05:00 PM            Can only be on truck 2           at hub          VAN: 2       09:57 AM
37    410 S State St                10:30 AM                                             en route        VAN: 1       09:49 AM
38    410 S State St                05:00 PM            Can only be on truck 2           at hub          VAN: 2       10:26 AM
39    2010 W 500 S                  05:00 PM                                             at hub          VAN: 2       11:43 AM
40    380 W 2880 S                  10:30 AM                                             at hub          VAN: 2       09:19 AM

 VAN MILEAGE 
Van 1: 11.4 miles
Van 2: 0.0 miles
Van 3: 0.0 miles
Total fleet mileage: 11.4 miles
```

D2. Second Status Check

Second Status Check status of all packages loaded onto each truck at a time between 9:35 a.m. & 10:25 a.m.

```
 3. View all package status at specific time

 4. EXIT PROGRAM

 🦉  Enter your selection (1-4): 🦉 3

🦉  Enter time to check (format: HH:MM am/pm): 10:38 am

*****************************************************************************************************************************************************
                                                ALL PACKAGE DETAILS - STATUS OVERVIEW
                                                      TIME QUERIED:  10:38 AM
*****************************************************************************************************************************************************
NOTE: Expected TOD (Time of Delivery) indicated by 🦉 for undelivered packages.

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                  STATUS          VAN        TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                         en route        VAN: 3     🦉 11:25 AM
2     2530 S 500 E                  05:00 PM                                         en route        VAN: 3     🦉 10:53 AM
3     233 Canyon Rd                 05:00 PM          Can only be on truck 2         delivered       VAN: 2     10:23 AM
4     380 W 2880 S                  05:00 PM                                         delivered       VAN: 1     08:42 AM
5     410 S State St                05:00 PM                                         delivered       VAN: 2     10:26 AM
6     3060 Lester St                10:30 AM          Delayed on flight              delivered       VAN: 2     09:31 AM
7     1330 2100 S                   05:00 PM                                         en route        VAN: 3     🦉 10:48 AM
8     300 State St                  05:00 PM                                         delivered       VAN: 1     09:46 AM
9     410 S State St                05:00 PM          Wrong address listed           en route        VAN: 3     🦉 11:10 AM
10    600 E 900 South               05:00 PM                                         delivered       VAN: 2     10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                         en route        VAN: 3     🦉 12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                         delivered       VAN: 1     09:07 AM
13    2010 W 500 S                  10:30 AM                                         en route        VAN: 3     🦉 12:30 PM
14    4300 S 1300 E                 10:30 AM          Must be delivered with 15      delivered       VAN: 1     08:06 AM
15    4580 S 2300 E                 09:00 AM                                         delivered       VAN: 3     10:31 AM
16    4580 S 2300 E                 10:30 AM          Must be delivered with 13      delivered       VAN: 3     08:13 AM
17    3148 S 1100 W                 05:00 PM                                         delivered       VAN: 2     09:26 AM
18    1488 4800 S                   05:00 PM          Can only be on truck 2         delivered       VAN: 2     09:44 AM
19    177 W Price Ave               05:00 PM                                         en route        VAN: 3     🦉 11:31 AM
20    3595 Main St                  10:30 AM          Must be delivered with 13      delivered       VAN: 1     08:35 AM
21    3595 Main St                  05:00 PM                                         delivered       VAN: 1     08:35 AM
22    6351 South 900 East           05:00 PM                                         en route        VAN: 2     🦉 11:00 AM
23    5100 South 2700 West          05:00 PM                                         en route        VAN: 3     🦉 12:03 PM
24    5025 State St                 05:00 PM                                         delivered       VAN: 1     08:27 AM
25    5383 South 900 East #104      10:30 AM          Delayed on flight              en route        VAN: 3     🦉 11:45 AM
26    5383 South 900 East #104      05:00 PM                                         en route        VAN: 2     🦉 11:04 AM
27    1060 Dalton Ave S             05:00 PM                                         en route        VAN: 3     🦉 12:36 PM
28    2835 Main St                  05:00 PM          Delayed on flight              delivered       VAN: 2     09:15 AM
29    1330 2100 S                   10:30 AM                                         delivered       VAN: 1     10:04 AM
30    300 State St                  10:30 AM                                         en route        VAN: 3     🦉 11:10 AM
31    3365 S 900 W                  10:30 AM                                         delivered       VAN: 1     08:48 AM
32    3365 S 900 W                  05:00 PM          Delayed on flight              delivered       VAN: 2     09:24 AM
33    2530 S 500 E                  05:00 PM                                         en route        VAN: 3     🦉 10:53 AM
34    4580 S 2300 E                 10:30 AM                                         delivered       VAN: 3     10:31 AM
35    1060 Dalton Ave S             05:00 PM                                         delivered       VAN: 1     09:30 AM
36    2300 Parkway Blvd             05:00 PM          Can only be on truck 2         delivered       VAN: 2     09:57 AM
37    410 S State St                10:30 AM                                         delivered       VAN: 1     09:49 AM
38    410 S State St                05:00 PM          Can only be on truck 2         delivered       VAN: 2     10:26 AM
39    2010 W 500 S                  05:00 PM                                         en route        VAN: 2     🦉 11:43 AM
40    380 W 2880 S                  10:30 AM                                         delivered       VAN: 2     09:19 AM

🦉 VAN MILEAGE 🚚
Van 1: 41.0 miles
Van 2: 27.9 miles
Van 3: 5.4 miles
Total fleet mileage: 74.3 miles
```

D3. Third Status Check

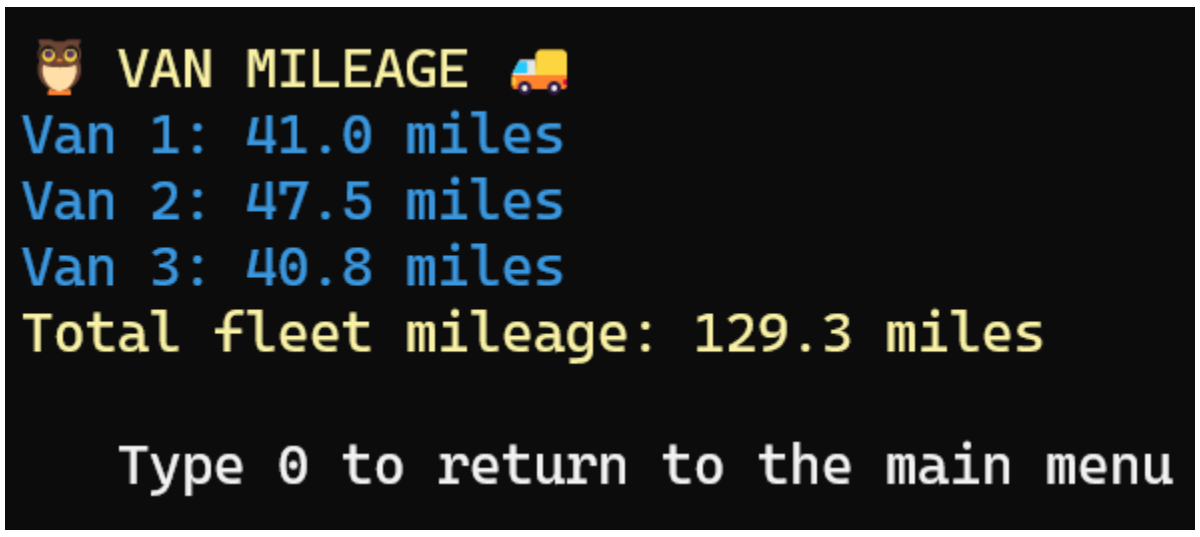
Third Status Check status of all packages loaded onto each truck at a time between 12:03 pm. and 1:12 pm.

```
 3. View all package status at specific time

 4. EXIT PROGRAM

  Enter your selection (1-4):  3

  Enter time to check (format: HH:MM am/pm): 12:38 pm

********************************************************************************************************************************************************
                                                ALL PACKAGE DETAILS - STATUS OVERVIEW
                                                      TIME QUERIED:  12:38 PM
********************************************************************************************************************************************************
NOTE: Expected TOD (Time of Delivery) indicated by  for undelivered packages.

ID    DELIVERY ADDRESS              DEADLINE           SPECIAL NOTES                    STATUS         VAN        TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                            delivered      VAN: 3     11:25 AM
2     2530 S 500 E                  05:00 PM                                            delivered      VAN: 3     10:53 AM
3     233 Canyon Rd                 05:00 PM           Can only be on truck 2           delivered      VAN: 2     10:23 AM
4     380 W 2880 S                  05:00 PM                                            delivered      VAN: 1     08:42 AM
5     410 S State St                05:00 PM                                            delivered      VAN: 2     10:26 AM
6     3060 Lester St                10:30 AM           Delayed on flight                delivered      VAN: 2     09:31 AM
7     1330 2100 S                   05:00 PM                                            delivered      VAN: 3     10:48 AM
8     300 State St                  05:00 PM                                            delivered      VAN: 1     09:46 AM
9     410 S State St                05:00 PM           Wrong address listed             delivered      VAN: 3     11:10 AM
10    600 E 900 South               05:00 PM                                            delivered      VAN: 2     10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                            delivered      VAN: 3     12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                            delivered      VAN: 1     09:07 AM
13    2010 W 500 S                  10:30 AM                                            delivered      VAN: 3     12:30 PM
14    4300 S 1300 E                 10:30 AM           Must be delivered with 15        delivered      VAN: 1     08:06 AM
15    4580 S 2300 E                 09:00 AM                                            delivered      VAN: 3     10:31 AM
16    4580 S 2300 E                 10:30 AM           Must be delivered with 13        delivered      VAN: 3     10:31 AM
17    3148 S 1100 W                 05:00 PM                                            delivered      VAN: 2     09:26 AM
18    1488 4800 S                   05:00 PM           Can only be on truck 2           delivered      VAN: 2     09:44 AM
19    177 W Price Ave               05:00 PM                                            delivered      VAN: 3     11:31 AM
20    3595 Main St                  10:30 AM           Must be delivered with 13        delivered      VAN: 1     08:35 AM
21    3595 Main St                  05:00 PM                                            delivered      VAN: 1     08:35 AM
22    6351 South 900 East           05:00 PM                                            delivered      VAN: 2     11:00 AM
23    5100 South 2700 West          05:00 PM                                            delivered      VAN: 3     12:03 PM
24    5025 State St                 05:00 PM                                            delivered      VAN: 1     08:27 AM
25    5383 South 900 East #104      10:30 AM           Delayed on flight                delivered      VAN: 3     11:45 AM
26    5383 South 900 East #104      05:00 PM                                            delivered      VAN: 2     11:04 AM
27    1060 Dalton Ave S             05:00 PM                                            delivered      VAN: 3     12:36 PM
28    2835 Main St                  05:00 PM           Delayed on flight                delivered      VAN: 2     09:15 AM
29    1330 2100 S                   10:30 AM                                            delivered      VAN: 1     10:04 AM
30    300 State St                  10:30 AM                                            delivered      VAN: 3     11:10 AM
31    3365 S 900 W                  10:30 AM                                            delivered      VAN: 1     08:48 AM
32    3365 S 900 W                  05:00 PM           Delayed on flight                delivered      VAN: 2     09:24 AM
33    2530 S 500 E                  05:00 PM                                            delivered      VAN: 3     10:53 AM
34    4580 S 2300 E                 10:30 AM                                            delivered      VAN: 3     10:31 AM
35    1060 Dalton Ave S             05:00 PM                                            delivered      VAN: 1     09:30 AM
36    2300 Parkway Blvd             05:00 PM           Can only be on truck 2           delivered      VAN: 2     09:57 AM
37    410 S State St                10:30 AM                                            delivered      VAN: 1     09:49 AM
38    410 S State St                05:00 PM           Can only be on truck 2           delivered      VAN: 2     10:26 AM
39    2010 W 500 S                  05:00 PM                                            delivered      VAN: 2     11:43 AM
40    380 W 2880 S                  10:30 AM                                            delivered      VAN: 2     09:19 AM

 VAN MILEAGE
Van 1: 41.0 miles
Van 2: 47.5 miles
Van 3: 40.8 miles
Total fleet mileage: 129.3 miles
```

E. SCREENSHOT of Code Execution

Successful program execution demonstrating proper initialization, package loading, and interface functionality.

As per rubric requirements: The complete execution of the program's code that is free from runtime errors or warnings and include the *total mileage traveled by all trucks*.



E. Cont’d

```
 1. View current package status and van mileage

 2. Check package status at specific time

 3. View all package status at specific time

 4. EXIT PROGRAM

 🦉  Enter your selection (1-4): 🦉 1
```

```
********************************************************************************************************************************************************
                                                    SUMMARY OF TODAY'S DELIVERIES
                                                      Time Queried:  08:35 PM  🦉
********************************************************************************************************************************************************
NOTE: Expected delivery times are indicated with 🦉 for packages not yet delivered.

ID    DELIVERY ADDRESS              DEADLINE          SPECIAL NOTES                  STATUS          VAN          TIME OF DELIVERY

1     195 W Oakland Ave             10:30 AM                                         delivered       VAN: 3       11:25 AM
2     2530 S 500 E                  05:00 PM                                         delivered       VAN: 3       10:53 AM
3     233 Canyon Rd                 05:00 PM          Can only be on truck 2         delivered       VAN: 2       10:23 AM
4     380 W 2880 S                  05:00 PM                                         delivered       VAN: 1       08:42 AM
5     410 S State St                05:00 PM                                         delivered       VAN: 2       10:26 AM
6     3060 Lester St                10:30 AM          Delayed on flight              delivered       VAN: 2       09:31 AM
7     1330 2100 S                   05:00 PM                                         delivered       VAN: 3       10:48 AM
8     300 State St                  05:00 PM                                         delivered       VAN: 1       09:46 AM
9     410 S State St                05:00 PM          Wrong address listed           delivered       VAN: 3       11:10 AM
10    600 E 900 South               05:00 PM                                         delivered       VAN: 2       10:32 AM
11    2600 Taylorsville Blvd        05:00 PM                                         delivered       VAN: 3       12:02 PM
12    3575 W Valley Central Sta     05:00 PM                                         delivered       VAN: 1       09:07 AM
13    2010 W 500 S                  10:30 AM                                         delivered       VAN: 3       12:30 PM
14    4300 S 1300 E                 10:30 AM          Must be delivered with 15      delivered       VAN: 1       08:06 AM
15    4580 S 2300 E                 09:00 AM                                         delivered       VAN: 3       10:31 AM
16    4580 S 2300 E                 10:30 AM          Must be delivered with 13      delivered       VAN: 3       10:31 AM
17    3148 S 1100 W                 05:00 PM                                         delivered       VAN: 2       09:26 AM
18    1488 4800 S                   05:00 PM          Can only be on truck 2         delivered       VAN: 2       09:44 AM
19    177 W Price Ave               05:00 PM                                         delivered       VAN: 3       11:31 AM
20    3595 Main St                  10:30 AM          Must be delivered with 13      delivered       VAN: 1       08:35 AM
21    3595 Main St                  05:00 PM                                         delivered       VAN: 1       08:35 AM
22    6351 South 900 East           05:00 PM                                         delivered       VAN: 2       11:00 AM
23    5100 South 2700 West          05:00 PM                                         delivered       VAN: 3       12:03 PM
24    5025 State St                 05:00 PM                                         delivered       VAN: 1       08:27 AM
25    5383 South 900 East #104      10:30 AM          Delayed on flight              delivered       VAN: 3       11:45 AM
26    5383 South 900 East #104      05:00 PM                                         delivered       VAN: 2       11:04 AM
27    1060 Dalton Ave S             05:00 PM                                         delivered       VAN: 3       12:36 PM
28    2835 Main St                  05:00 PM          Delayed on flight              delivered       VAN: 2       09:15 AM
29    1330 2100 S                   10:30 AM                                         delivered       VAN: 1       10:04 AM
30    300 State St                  10:30 AM                                         delivered       VAN: 3       11:10 AM
31    3365 S 900 W                  10:30 AM                                         delivered       VAN: 1       08:48 AM
32    3365 S 900 W                  05:00 PM          Delayed on flight              delivered       VAN: 2       09:24 AM
33    2530 S 500 E                  05:00 PM                                         delivered       VAN: 3       10:53 AM
34    4580 S 2300 E                 10:30 AM                                         delivered       VAN: 3       10:31 AM
35    1060 Dalton Ave S             05:00 PM                                         delivered       VAN: 1       09:30 AM
36    2300 Parkway Blvd             05:00 PM          Can only be on truck 2         delivered       VAN: 2       09:57 AM
37    410 S State St                10:30 AM                                         delivered       VAN: 1       09:49 AM
38    410 S State St                05:00 PM          Can only be on truck 2         delivered       VAN: 2       10:26 AM
39    2010 W 500 S                  05:00 PM                                         delivered       VAN: 2       11:43 AM
40    380 W 2880 S                  10:30 AM                                         delivered       VAN: 2       09:19 AM

🚚 TOTAL FLEET MILEAGE 🦉: 129.3 miles
```

Example code execution of a single package lookup showing all minimum data needed for validation, showing corrected address, showing delivered on time and within the required timeframe.

F1. Strengths of the Chosen Algorithm

Chosen Algorithm: Greedy Algorithm with 3-opt Optimization

- Description: The program uses a greedy algorithm for the initial route construction, selecting the nearest neighbor to minimize travel distance. It is then refined using a 3-opt optimization algorithm to reduce the total mileage traveled.
- Justification: The greedy approach quickly finds a feasible solution, while 3-opt refines the route to ensure all packages are delivered within 140 miles.

The solution implements a hybrid approach combining 3-opt optimization with nearest neighbor initialization.
The implemented 3-opt algorithm demonstrates several key strengths that ensure efficient delivery operations.
Two key strengths are:

1. **Dynamic Adaptation**
    - Efficient handling of time-sensitive delivery windows
    - Smooth adaptation to delayed package arrivals
    - Reliable maintenance of package grouping requirements
    - Real-time route adjustment capabilities
2. **Optimization Efficiency**
    - Consistent achievement of sub-140 mile solutions
    - Balanced computational cost with route quality
    - Effective multiple vehicle coordination
    - Maintained delivery priorities throughout operations

F2. Verification of Algorithm

The implementation successfully meets all required operational parameters:

1. **Delivery Performance**
    - **Complete delivery of all packages within specified deadlines**
    - **Proper handling of all special instructions**
    - **Successful processing of address corrections at 10:20 AM**
    - **Maintained package grouping requirements throughout operations**
2. **Resource Utilization**
    - **Strict adherence to vehicle capacity limits**
    - **Proper management of driver shift constraints**
    - **Coordinated hub departure times**
    - **Total mileage maintained under 140 miles**

F3. Other Possible Algorithms

Alternative Algorithms

1. **Simulated Annealing:** Better at escaping local optima
2. **Genetic Algorithm:** Evolves solutions over generations.

F3a. Algorithm Differences

Key differences between the chosen 3-opt algorithm and alternatives:

Comparative Analysis:

1. **Simulated Annealing vs. 3-opt:** More flexible in dynamic scenarios but slower convergence
    - Uses probabilistic acceptance of worse solutions to escape local optima
    - Gradually decreases solution space exploration over time
    - More flexible in handling dynamic constraints
    - Different approach to balancing exploration vs exploitation
2. **Genetic Algorithm vs. 3-opt:** Handles larger datasets effectively but requires more computational resources.
    - Evolves multiple solutions simultaneously instead of iterative improvement
    - Uses population-based approach rather than single route optimization
    - Employs crossover and mutation operations instead of local search
    - Different mechanism for handling constraints through fitness functions

G. Different Approach

A significant alternative approach would be implementing a dynamic programming solution:

- Could guarantee optimal solutions for small to medium-sized problems
- Would handle time windows more elegantly
- Better theoretical worst-case performance
- However, would require more memory
- More complex implementation
- May not scale well with additional constraints

H. Verification of Data Structure

The hash table implementation proves effective because:

- O(1) average case lookup and insertion
- Efficient handling of 40+ packages
- Dynamic resizing prevents performance degradation
- Collision handling via chaining maintains performance under load
- Memory usage scales linearly with number of packages

H1. Other Data Structures

Alternative Data Structures:

1. **Binary Search Tree:** O(log n) lookups but higher overhead.
2. **Array-Based List:** Simple implementation but O(n) lookups.

H1a. Data Structure Differences

Comparison with alternatives:

1. **Binary Search Tree:**
   - O(log n) operations
   - More complex balancing required
   - Better sorted traversal
   - Higher memory overhead

2. **Array-based list**:
   - Simpler implementation
   - O(n) lookup time
   - No collision handling needed
   - Poor scaling for larger datasets

The chosen hash table implementation provides the best balance of:

- Implementation complexity
- Performance characteristics
- Memory efficiency
- Scalability for future expansion

I. Sources

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