PROJECT TITLE HERE

EMÜ 405 System Analyses and Design I

FINAL REPORT

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ABSTRACT

Abstract:
Write 100–250 words here.

Key Words: [keyword1; keyword2; keyword3; ...]

Contents

List of Figures

List of Tables

ABBREVIATIONS

- VRP: Vehicle Routing Problem
- VRPSPD: Capacitated Vehicle Routing Problem with Simultaneous Pickup and Delivery
- MILP: Mixed-Integer Linear Programming
- MTZ: Miller–Tucker–Zemlin
- UNSDG: United Nations Sustainable Development Goals

1 INTRODUCTION

Background, motivation, context, and brief report roadmap.

2 LITERATURE REVIEW

Summarize relevant studies; add citations with IEEE style if you use BibTeX later or manual numbering.

3 SCOPE OF THE PROJECT

3.1 Problem Definition

Define the problem clearly.

3.1.1 UNSDG Consideration for Problem Definition

Which UNSDG(s) are relevant and why.

3.2 Objectives of the Study

- Objective 1: ...
- Objective 2: ...
- Objective 3: ...

3.2.1 Real Life Constraints of the Study

- Constraint 1 (e.g., capacity, time window, shift, stop count): ...
- Constraint 2: ...

3.2.2 Ethical Considerations

Fairness, data privacy, workload balance, etc.

3.3 Multidisciplinary Approaches and Interactions

How IE interacts with CS, logistics, operations, etc.

4 METHODOLOGIES

4.1 Problem Formulation / Mathematical Model (MILP)

Insert MILP here.

5 Problem Class

The project addresses a: *Capacitated Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD)* with route-length, stop-count, vehicle-capacity, route-duration (shift) and neighborhood-adjacency constraints.

This classification follows directly from:

- simultaneous pickup and delivery at customer stops,
- dynamically changing vehicle load,
- capacity constraints,
- routes starting and ending at a single depot,
- no binding fleet size constraint (fleet chosen sufficiently large),
- operational constraints imposed by UPS (shift duration, stop limits, spatial compactness).

6 Sets and Indices

- $N = \{0, 1, \ldots, n\}$: set of nodes; node 0 is the depot (Istanbul Anadolu Aktarma Merkezi coordinates: (40.920153, 29.348245)), and nodes $1, \ldots, n$ are customer stops.
- $C = N \setminus \{0\}$: set of customer nodes.
- K: set of vehicles identified by unique IDs (vehicle dataset). Each $k \in K$ is a unique vehicle.

- L: set of neighborhoods (districts).
- V: set of vehicle types (stored as an attribute of each vehicle in the dataset).
- R: set of shipment types (e.g., $R = \{\text{Normal}, \text{Urgent}\}$).
- Indices: $i, j \in N$ (nodes), $i, j \in C$ (customers), $k \in K$ (vehicles), $r \in R$ (shipment type).

7 Parameters

- d_{ij}: distance between node i and node j.
- t_{ij}: travel time between node i and node j.
- s_i: service time at node i ($s_0 = 0$).
- Q: vehicle capacity (350 packages).
- $S_{\min}$: minimum stops per route (80).
- $S_{\max}$: maximum stops per route (110).
- $T_{\min}$: minimum route duration (420 minutes, 7 hours).
- $T_{\max}$: maximum route duration (510 minutes, 8.5 hours).
- $h_i \in L$: neighborhood of node i.
- $A_{lm} \in \{0, 1\}$: 1 if neighborhoods l and m are adjacent, 0 otherwise.
- $\text{type}_k \in V$: type attribute of vehicle k (from the vehicle dataset).
- F_k: fixed cost of activating vehicle k.
- c_k^{dist}: distance cost coefficient for vehicle k.
- c_k^{time}: time cost coefficient for vehicle k.
- c^{stop}: per-stop cost (each visited customer stop).
- P_{ir}: pickup demand quantity at customer i of shipment type r.
- D_{ir}: delivery demand quantity at customer i of shipment type r.
- P_r^p: backlog penalty coefficient for pickup of type r.
- P_r^d: backlog penalty coefficient for delivery of type r.
- M: sufficiently large constant.

8 Decision Variables

- $x_{kij} \in \{0, 1\}$: 1 if vehicle k travels from node i to node j.
- $y_{ki} \in \{0, 1\}$: 1 if customer node i is visited/served by vehicle k.
- $z_k \in \{0, 1\}$: 1 if vehicle k is used (activated).
- $q_{ki} \geq 0$: load of vehicle k after visiting node i.
- $a_{ki} \geq 0$: arrival time of vehicle k at node i.
- $T_k \geq 0$: total route duration of vehicle k (used for shift constraints, not in the objective).
- $\pi_{kir} \geq 0$: pickup amount of type r collected by vehicle k at customer i.
- $\delta_{kir} \geq 0$: delivery amount of type r delivered by vehicle k at customer i.
- $B^p_{ir} \geq 0$: pickup backlog amount for customer i and type r.
- $B^d_{ir} \geq 0$: delivery backlog amount for customer i and type r.
- $u_{ki} \geq 0$: MTZ ordering variable for subtour elimination.

9 Objective Function

Objective: Minimize total cost including distance/time costs (vehicle-dependent), fixed vehicle activation cost, per-stop cost, and type-based backlog penalties.

$$\min Z = \sum_{k\in K}\sum_{i\in N}\sum_{\substack{j\in N\\ j\neq i}} \left(c_k^{dist}\, d_{ij} + c_k^{time}\, t_{ij}\right) x_{kij} + \sum_{k\in K} F_k\, z_k + c^{stop}\sum_{k\in K}\sum_{i\in C} y_{ki} + \sum_{i\in C}\sum_{r\in R}\left(P_r^p\, B_{ir}^p + P_r^d\, B_{ir}^d\right) \tag{1}$$

EN: Total cost includes distance/time costs (vehicle-dependent), fixed vehicle usage cost, per-stop cost, and type-based backlog penalties (Urgent has higher penalty).
TR: Toplam maliyet; mesafe/süre maliyetleri (araç bazlı), araç kullanım sabit maliyeti, durak başı maliyet ve tür bazlı backlog cezasını içerir (Acil türün cezası daha yüksektir).

10 Constraints

10.1 1) Customer Assignment

Each customer is served exactly once:

$$\sum_{k\in K} y_{ki} = 1 \qquad \forall i \in C \tag{2}$$

10.2 2) Vehicle Activation

A vehicle is active if it serves at least one customer:

$$\sum_{i\in C} y_{ki} \le M\, z_k \qquad \forall k \in K \tag{3}$$

10.3 3) Flow Conservation (Linking x and y)

For each customer node, if it is served by vehicle k, it must have exactly one incoming and one outgoing arc:

$$\sum_{\substack{j\in N\\ j\neq i}} x_{kij} = y_{ki} \qquad \forall i \in C,\ \forall k \in K \tag{4}$$

$$\sum_{\substack{j\in N\\ j\neq i}} x_{kji} = y_{ki} \qquad \forall i \in C,\ \forall k \in K \tag{5}$$

10.4 4) Depot Constraints

Each active vehicle starts and ends at the depot:

$$\sum_{j\in C} x_{k0j} = z_k \qquad \forall k \in K \tag{6}$$

$$\sum_{i\in C} x_{ki0} = z_k \qquad \forall k \in K \tag{7}$$

10.5 5) Stop Count Constraints

$$S_{\min}\, z_k \le \sum_{i\in C} y_{ki} \le S_{\max}\, z_k \qquad \forall k \in K \tag{8}$$

10.6 6) Neighborhood-Adjacency (Spatial Compactness)

Vehicles cannot directly travel between non-adjacent neighborhoods:

$$x_{kij} \le A_{h_i h_j} \qquad \forall i \in C,\ \forall j \in C,\ i \ne j,\ \forall k \in K \tag{9}$$

10.7 7) Backlog Definition (Single-Day)

Unserved pickup/delivery demand becomes backlog (type-based):

$$\sum_{k \in K} \pi_{kir} + B^{p}_{ir} = P_{ir} \qquad \forall i \in C,\ \forall r \in R \tag{10}$$

$$\sum_{k \in K} \delta_{kir} + B^{d}_{ir} = D_{ir} \qquad \forall i \in C,\ \forall r \in R \tag{11}$$

Tie served quantities to whether customer is visited by vehicle k:

$$0 \le \pi_{kir} \le P_{ir}\, y_{ki} \qquad \forall i \in C,\ \forall k \in K,\ \forall r \in R \tag{12}$$

$$0 \le \delta_{kir} \le D_{ir}\, y_{ki} \qquad \forall i \in C,\ \forall k \in K,\ \forall r \in R \tag{13}$$

10.8 8) Dynamic Capacity Constraints (Simultaneous Pickup & Delivery)

Initial load at depot equals total deliveries assigned to the vehicle:

$$q_{k0} = \sum_{i \in C} \sum_{r \in R} \delta_{kir} \qquad \forall k \in K \tag{14}$$

Load propagation along arcs (two-sided Big-M to enforce equality when $x_{kij} = 1$):

$$q_{kj} \ge q_{ki} - \sum_{r \in R} \delta_{kjr} + \sum_{r \in R} \pi_{kjr} - M(1 - x_{kij}) \qquad \forall i \in N,\ \forall j \in C,\ i \ne j,\ \forall k \in K \tag{15}$$

$$q_{kj} \le q_{ki} - \sum_{r \in R} \delta_{kjr} + \sum_{r \in R} \pi_{kjr} + M(1 - x_{kij}) \qquad \forall i \in N,\ \forall j \in C,\ i \ne j,\ \forall k \in K \tag{16}$$

Capacity bounds:

$$0 \le q_{ki} \le Q \qquad \forall i \in N,\ \forall k \in K \tag{17}$$

10.9 9) Route Duration (Shift) Constraints

Time propagation:

$$a_{kj} \geq a_{ki} + s_i + t_{ij} - M(1 - x_{kij}) \qquad \forall i \in N,\ \forall j \in N,\ i \neq j,\ \forall k \in K \tag{18}$$

Fix start time at depot:

$$a_{k0} = 0 \qquad \forall k \in K \tag{19}$$

Route duration variable (arrival back to depot):

$$T_k \geq a_{ki} + s_i + t_{i0} - M(1 - x_{ki0}) \qquad \forall i \in C,\ \forall k \in K \tag{20}$$

Shift bounds:

$$T_{\min}\, z_k \leq T_k \leq T_{\max}\, z_k \qquad \forall k \in K \tag{21}$$

10.10 10) Subtour Elimination (MTZ)

MTZ constraints per vehicle:

$$u_{ki} - u_{kj} + |C|\, x_{kij} \leq |C| - 1 \qquad \forall i \in C,\ \forall j \in C,\ i \neq j,\ \forall k \in K \tag{22}$$

Link ordering to visits:

$$y_{ki} \leq u_{ki} \leq |C|\, y_{ki} \qquad \forall i \in C,\ \forall k \in K \tag{23}$$

10.11 11) Variable Domains

$$x_{kij},\ y_{ki},\ z_k \in \{0, 1\} \tag{24}$$

$$q_{ki} \geq 0, \quad a_{ki} \geq 0, \quad T_k \geq 0, \quad \pi_{kir} \geq 0, \quad \delta_{kir} \geq 0, \quad B^p_{ir} \geq 0, \quad B^d_{ir} \geq 0, \quad u_{ki} \geq 0 \tag{25}$$

10.12 Solution Approach

- Solver and version: ...
- Hardware/compute environment: ...
- Time limit / optimality gap: ...

10.13 Experimental Design (Scenarios)

- Scenario 1: ...
- Scenario 2: ...
- Scenario 3: ...

11 ANALYSIS AND RESULTS

11.1 Analysis

Explain methodology of analysis: KPIs, scenario setup, data pipeline, validation checks, etc.

11.2 Results

Table 1: Example KPI Summary (replace with your results)

KPI	Scenario 1	Scenario 2	Scenario 3
Total cost			
Urgent backlog (end)			
Normal backlog (end)			
Vehicles used			

12 DISCUSSIONS

12.1 Study limitations

Limitations: modeling assumptions, data limits, scalability, etc.

12.2 Applicability of the project under real life situations

How/when it can be applied; deployment notes. [?]

12.3 Health and Safety Issues

Operational safety, driver workload, road safety, etc.

12.4 Legal Issues

Data protection, compliance, regulations.

12.5 Economical Issues and Constraints

Costs, budget, ROI, constraints.

12.6 Sustainability

Emissions, efficiency, UN SDGs, etc.

12.7 Producibility-Manufacturability

If relevant; otherwise justify N/A.

12.8 Social and Political Issues

Equity, social impacts, etc.

12.9 Environmental Issues

Environmental impacts, waste, emissions.

12.10 Multidisciplinary Collaboration

Team coordination, cross-discipline contributions.

13 CONCLUSIONS

Conclude with key findings and what they mean.

14 PROJECT PLAN AND FUTURE STUDIES

Remaining tasks, future improvements, and updated Gantt chart.

15 REFERENCES

References

[1] Author, “Title,” Journal/Conference, year.

[2] Author, *Book Title*. Publisher, year.

16 APPENDIX

Appendix A: Additional Tables / Figures

Extra material here.

17 references