Methodology, Modelling and Consulting Skills (MMCS)

Project: Optimisation Models for a Future Edinburgh Cycle Scheme

1. Introduction

Students will act as technical consultants engaged by a consortium formed of Edinburgh City Council and local employers to design operational research models for a proposed future cycle hire / micromobility scheme that replaces the previous cycle scheme in Edinburgh. The task is to analyse the provided spatial and usage data, propose and implement models that identify optimal operational and funding strategies and present results in a technical report and an executive presentation.

2. Project brief

Edinburgh is considering a new, employer-supported micro mobility scheme after the previous version, with its locations demonstrated in Figure 1 failed. Businesses (large employers, business parks and smaller employers spread across the region) are prepared to subsidise part of the scheme in return for discounted access for their employees. Employees can use the scheme for commutes and short local journeys. Demand and supply vary by home location, business location, time of day and day of week.

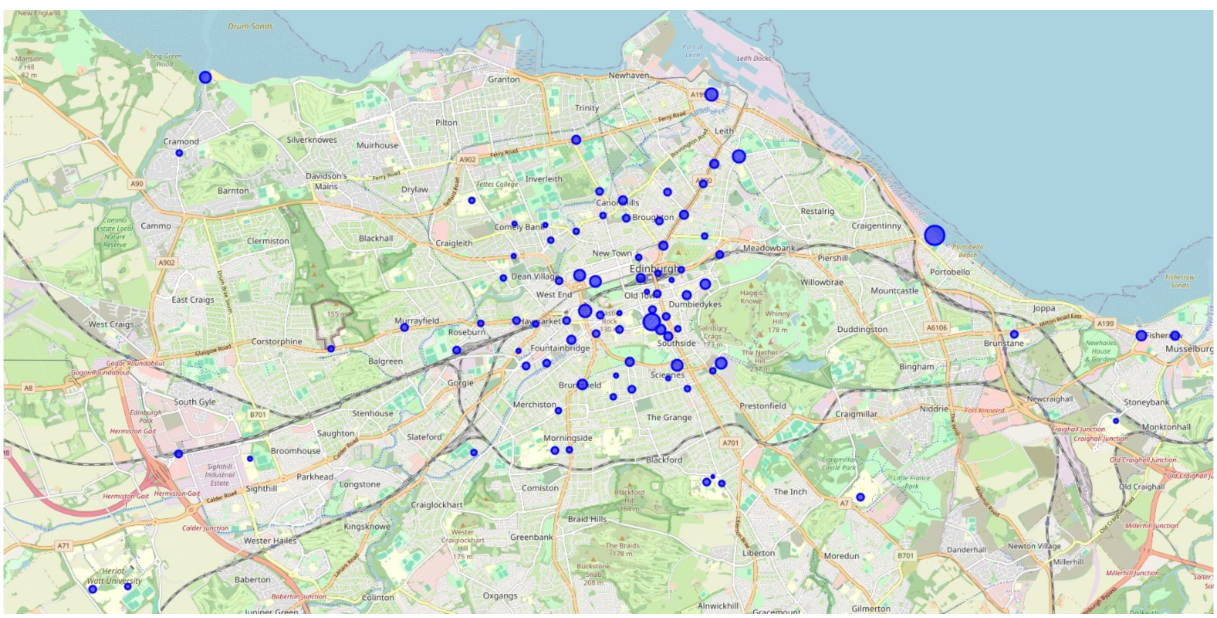

Figure 1- An illustration of the old bicycle locations.

Students are asked to:

1. Analyse the provided geography and usage data from the old cycle scheme (map and spreadsheet).
2. Build operational research models to determine station locations (and rebalancing strategies), pricing and subsidy mixes that meet policy goals (e.g. maximise ridership, minimise public cost, meet equity targets, maximise employer satisfaction), subject to operational constraints.
3. Quantify stochasticity in demand and test robustness of solutions under uncertain demand scenarios.
4. Produce a technical report, code repository and a concise management presentation with policy recommendations.

Initial Data

We have provided you with four primary data sets:

- station_data.csv – This file contains all of the locations of the previous bicycle sharing system together with some attributes of the stations such as their capacity

- edinburgh_pois.csv – This contains the coordinates of several points of interest around Edinburgh. This includes residential properties, schools, university buildings and other commercial buildings.

- cyclehire-data – This folder contains data of every trip that was completed from October 2018 until September 2021. This includes the time that the trip started, the origin and destination and the time then trip ended.

- counts-data – This folder contains the number of completed trips from origin destination pair in the cycle-data folder in a month for each hour of the day.

3. Key facts about the data

The dataset replicates features of the former cycle scheme. Missing values and realistic inconsistencies should be identified and handled.

Suggested data features (students may not need to use all):

- **Stations / potential docking points**: location (lat/lon), capacity (docks), historical pick-up and drop-off counts by time-of-day and day-of-week, nearby land use type (business park, residential, retail), distance to nearest public transport stop (see for example The Stop-and-Go City: Buses in Edinburgh | Blog).

- **Trip logs / aggregated flows**: origin station, destination station, start time bucket, trip duration, user type (member/casual), weekday/weekend indicator.

- **Residential demand proxy**: home-location density grid or aggregated postcode sectors with population and commuting flow estimates.

- **Employer locations**: business park points and other employers; size in employees; willingness to subsidise (binary or continuous proxy); offered subsidy per trip or monthly deduction option.

- **Cost components**:
    - Council capital and operating subsidy options (per station install cost, per-dock cost, running cost per bike per day).
    - Employer contribution (per-ride subsidy, bulk purchase of passes or percentage of user fee).
    - User payments (pay-as-you-go fares, capped daily/weekly passes).
- **Operational constraints**: fleet size, vehicle capacity and cost, maximum installation budget, station capacity limits.

- **Temporal demand patterns**: morning/evening peaks (commute), lunchtime, weekend leisure; behavioural differences for employees incentivised by employers.

Note: Business parks often show higher densities of pickups/drop-offs (i.e. concentrated employer demand clusters), whereas outlying employers or remote homes produce sparser demand with different cost-to-serve characteristics.

4. Modelling challenges and scope

Students are expected to combine demand modelling, location allocation, fleet sizing, rebalancing and pricing/subsidy optimisation using appropriate deterministic and stochastic OR techniques. Specific challenges include:

- Incorporating employer subsidies that alter user price elasticity and modal choice.
- Variable demand density (high-density business parks vs sparse suburbs) and its impact on station siting and fleet allocation.
- Multi-source funding optimisation: find combinations of council investment, employer contributions and user payments that meet policy/financial objectives.
- Operational rebalancing under uncertain trip patterns and limited resources.
- Accessibility for under-served residential areas vs cost-efficiency in dense areas.

5. Stochastic modelling and uncertainty

Demand is uncertain. Students should model randomness in:

- Trip counts (time-of-day and day-to-day variation).
- Employer participation levels.
- User price sensitivity / elasticity.

Recommended approaches: scenario-based stochastic programming, robust optimisation (e.g. budgeted uncertainty sets), simulation (e.g. Monte Carlo) for operational performance and sensitivity analyses for funding mixes. Students should justify the chosen uncertainty model and show how solutions perform across plausible scenarios.

6. Key objectives and constraints (examples)

Each team should propose objective(s) that reflect stakeholder priorities (choose at least one primary objective and justify). Examples:

- **Maximise ridership** subject to a budget cap for Council capital and operating subsidy.
- **Minimise public expenditure** while achieving a target ridership or access coverage.
- **Maximise social welfare**: ridership weighted by user benefit minus total costs (Council + employers + users), potentially include equity penalty for underserved areas.
- **Maximise employer satisfaction** subject to wage-bill constraints (optimise subsidy allocations that yield highest uptake among employees).

Constraints to consider:

- Capital budget for station installation / docks.
- Fleet (number of cycles) and maximum daily rebalancing resource.
- Minimum service levels for defined residential or business areas.
- Operational constraints (dock capacity, vehicle routing for rebalancing with limited crew).

7. Suggested mathematical models and methods

Students are encouraged to combine methods. Possible model components:

1. **Location allocation**: Mixed-integer programming to decide which stations to open and how many docks to allocate or continuous facility-location relaxations.
2. **Fleet sizing and inventory**: linear or integer programming for fleet and dock capacity decisions.
3. **Demand assignment**: gravity models or regression to estimate mode choice and capture employer subsidy effects on uptake.
4. **Pricing/subsidy optimisation**: perhaps MIP with price-elastic demand functions to find optimal subsidy mixes (employer vs council vs user).

5. **Rebalancing**: vehicle routing problem variants for daily rebalancing with time windows and capacity constraints; or heuristics for operational plans.
6. **Stochastic programming / simulation**: scenario-based models (investment first stage; operational second stage), Monte Carlo simulation to estimate expected performance and variance.
7. **Robustness & sensitivity analysis**: evaluate performance under worst-case/alternative scenarios; provide confidence intervals for key KPIs.

Example modelling pipeline:
demand estimation -> siting -> fleet & rebalancing -> pricing
(or an integrated model, if feasible)

8. Exploratory questions (examples for analysis part)

1. Which combination of council capital, council operating subsidy, employer contributions and user payments minimises public cost while keeping expected ridership above a target?
2. How does employer subsidy concentration (a few large employers vs many small employers) affect service design and equity?
3. Under what scenarios does an employer-targeted pass produce measurable modal shift from car to bike among employees? Bonus points: discuss CO_2 savings and congestion effects.
4. How many vehicles and crews are required to keep outage rates (empty/full station events) below a given threshold during peak hours? What is the trade-off between more docks vs more rebalancing cost?
5. Provide alternative network designs optimised for (a) cost-efficiency and (b) geographic equity. Compare their performance under stochastic demand.