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DATA-DRIVEN STRATEGIC OPTIMIZATION FOR SUSTAINABLE ELECTRIC LAST-MILE DELIVERY

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Context-Motivation

Running Industrial PhD:

“Strategic Decision-Making and Optimization: Empowering SMEs with Data-Driven Systems for Resilience and Digital Competitiveness”

How can we design and implement decision-support systems that improve SMEs by making them more resilient, competitive, and flexible in a changing market with limited resources?

Background: Telecommunications – Scotland (Fintech & e-learning) – Data Science

Data Optimization & Innovation Engineer in CLIQPOD, S.L.

Why SMEs?

My family has a long history of entrepreneurship

When Facing Storms – Resilience → Learning + Knowledge + Opportunities



Significance

99% of European businesses are SMEs according to the European Commission

2025 OECD Survey:

SME's AI Adoption: 26% (2024) → 39% (2025)

Top Use - GenAI: 18% (2024) → 26% (2025)

But only 50% digitally mature (\geq competent)

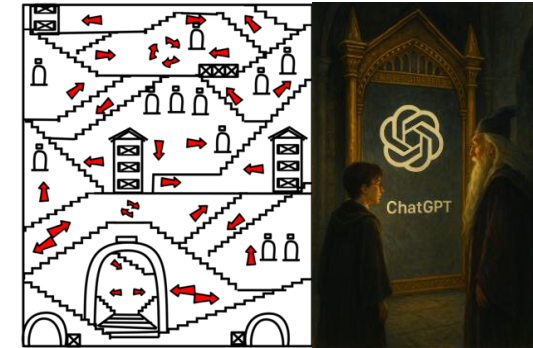
Adoption Main Barriers:

40% Maintenance Costs

39% Lack of time for Training

32% Hardware Costs

Context



Hard Competition

- Rapid evolution of digital technologies (globalization intensifies competition)
- Overwhelming amount of information.
- Uncertainty in market changes

Chaos

- No clear guidance, data policies or path to follow for successful data initiatives.
- PoC and pilot projects fail to deliver value – Fit specific needs and constraints of SMEs

AI Adoption

- Sensationalist news or skepticism about AI
- Lack of resources and knowledge to Adopt AI
- New tools & New way to do things
- Gap between Business application and technical implementation.

Are you 110% sure?

Bias

- Cognitive Biases (intuition over analytical reasoning).
- Underdeveloped an iterative feedback-driven strategic decision-making

Resources

- Long-term planning difficulties
- Return of investment on a data/AI workforce & infrastructure

No Data Culture

- Lack of a data-driven mindset, using/defining KPIs and Data Quality tests.
- No clear understanding to apply the most appropriate data methodology.
- Different approaches may produce different results and conclusions.



Industrial PhD Main Objectives Challenges & Opportunities

Ingestion & Infrastructure

- Simple process for SMEs to process large amounts of data to feed systems.
- Minimal infrastructure to ensure viability.

Generalization

- How to consider unique contexts and constraints in a general framework.

Integration

- Analytics Ecosystem Integration aligned with strategic goals and operational realities.

Evidence

- Quantification and evidence of system effects on strategic decisions.

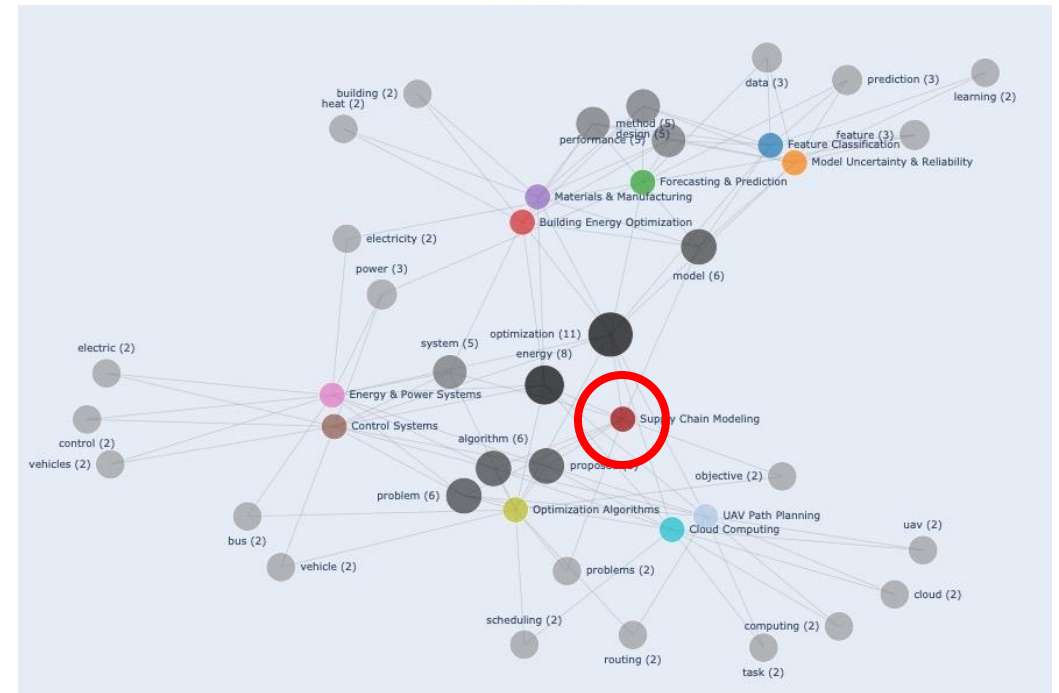
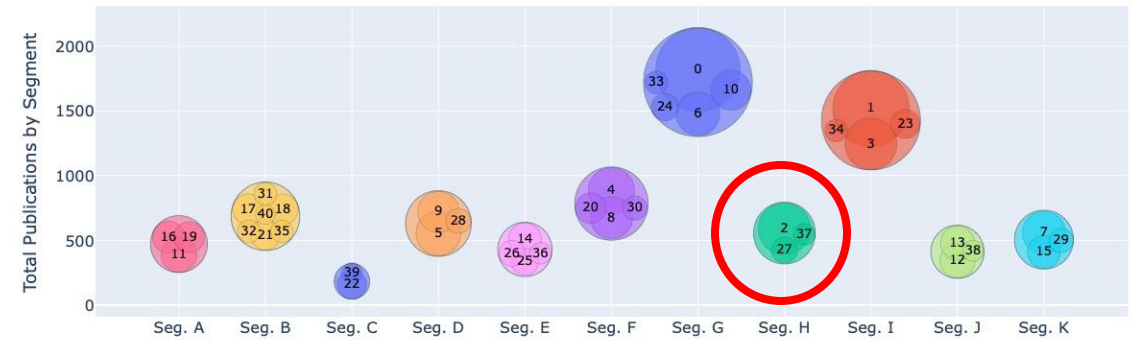
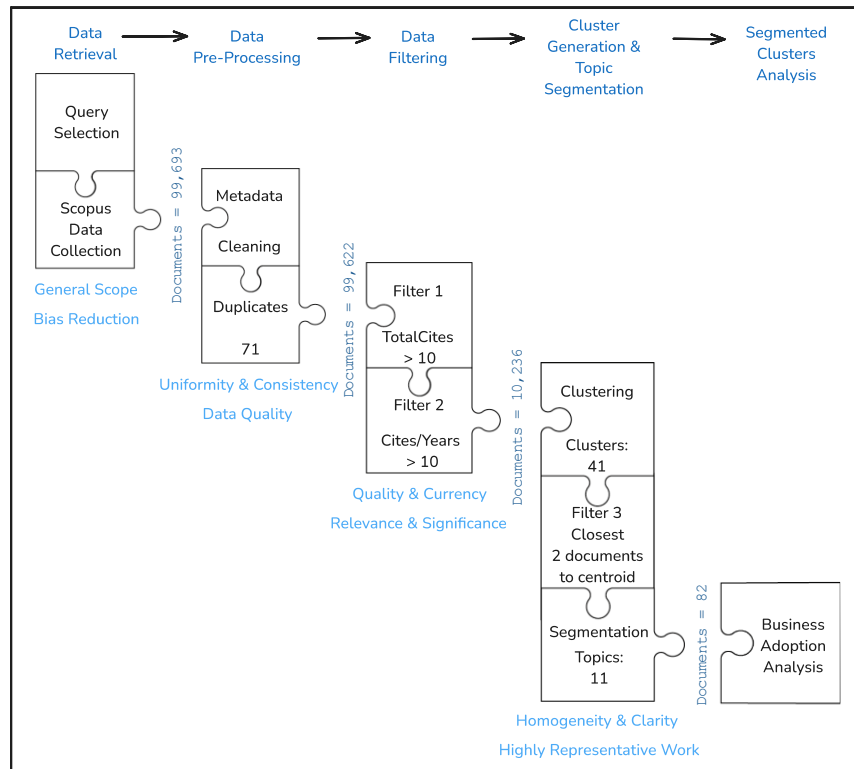
Adaptability

- Adapting models to be iteratively integrated.
- Close the feedback loop between model outputs and regular strategy reviews.

Data Culture

- How to build and sustain a data culture, with trust on data?
- Evaluate different approaches or models based on ease of use, potential impact, etc.

Literature Review



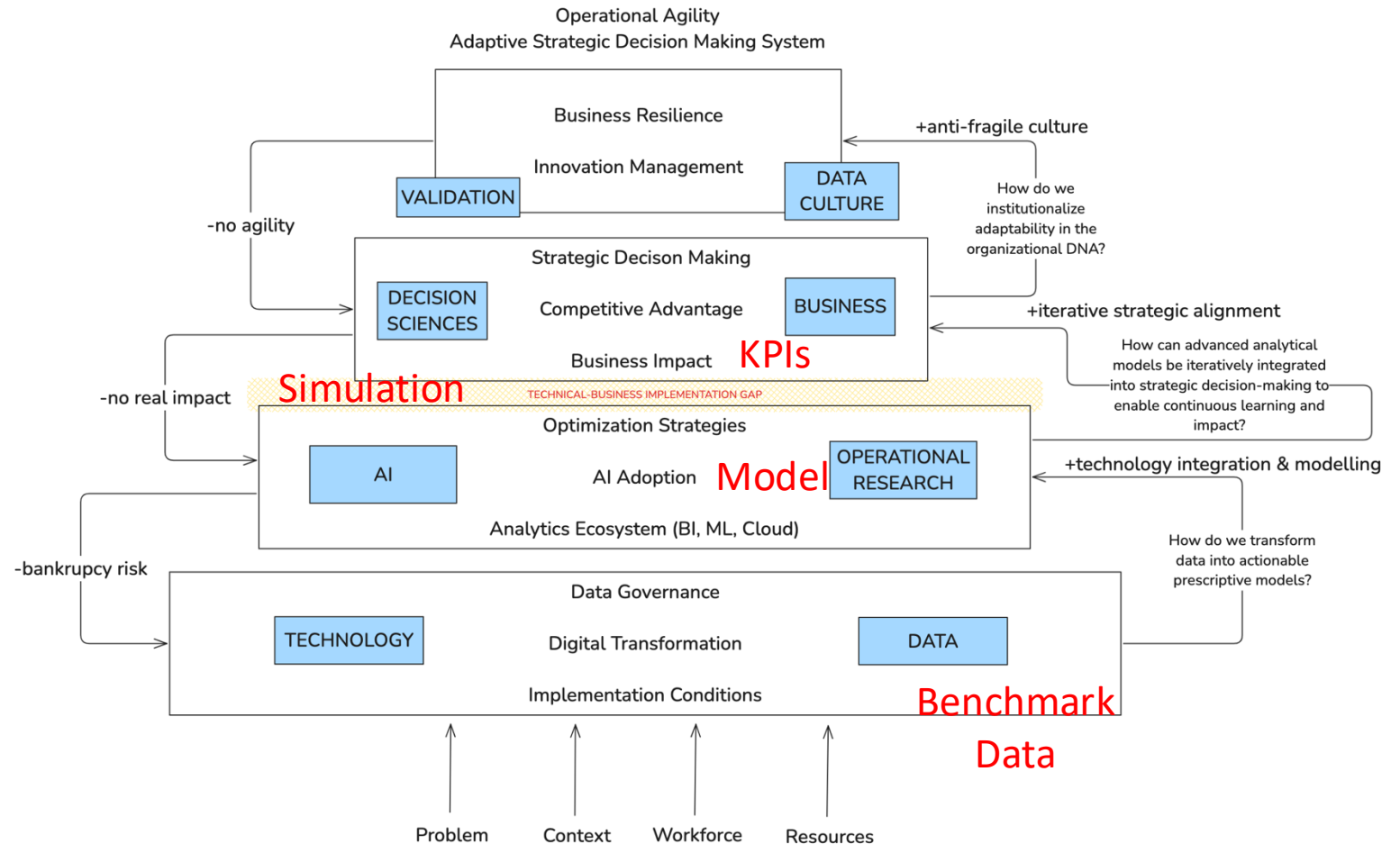
Methodology

Problem: Bi-objective Vehicle Routing Problem (VRP) for electric vehicles: minimize total distance and energy consumption, with dynamic replanning under uncertainty

Context: Urban last-mile delivery for SMEs adopting electric vehicles, facing operational and sustainability challenges, with limited computational and financial resources.

Workforce: Fleet of delivery drivers (4 vehicles as in E-n22-k4 instance), each assigned to a route; no explicit driver scheduling, but each route simulates a vehicle and its operator.

Resources: Fleet of electric vehicles. 4 units, each with 6-ton capacity and 250 kWh battery



Use case – Model

Objectives:

- Minimize total distance travelled
- Minimize total energy consumed

Main Constraints:

- Each customer is served exactly once
- All routes start and end at the depot
- Vehicle capacity and battery limits are respected
- Battery recharged at charging stations as needed
- Flow conservation: vehicles follow continuous, valid routes

Energy Model:

- Energy use depends on distance and vehicle efficiency

• Bi-Objective function:

$$\text{Minimize } Z = \alpha \sum_{k \in K} \sum_{i \in VUC} \sum_{\substack{j \in VUC \\ j \neq i}} d_{ij} x_{ijk} + \beta \sum_{k \in K} \sum_{i \in VUC} \sum_{\substack{j \in VUC \\ j \neq i}} e_{ij} x_{ijk}$$

Where:

- d_{ij} is the energy consumption modeled as:
 - o $e_{ij} = \beta \cdot \eta_{ij} \cdot d_{ij}^2$

• Constraints:

- o Flow Conservation:

$$\sum_{\substack{j \in VUC \\ j \neq i}} x_{ijk} = \sum_{\substack{j \in VUC \\ j \neq i}} x_{jik} = y_{ik}, \quad \forall i \in V \cup C, \forall k \in K$$

- o Customer Service Requirement:

$$\sum_{k \in K} y_{ik} = 1, \quad \forall i \in V \setminus \{0\}$$

- o Vehicle depot Constraints:

$$\sum_{\substack{j \in VUC \\ j \neq 0}} x_{0jk} = \sum_{\substack{i \in VUC \\ i \neq 0}} x_{i0k} = 1, \quad \forall k \in K$$

- o Capacity Constraints:

$$\sum_{i \in V \setminus \{0\}} d_i y_{ik} \leq Q, \quad \forall k \in K$$

- o Battery Dynamics:

$$b_{jk} \leq b_{ik} - e_{ij} x_{ijk} + B(1 - x_{ijk}), \quad \forall (i, j) \in E, \forall k \in K$$

$$b_{ik} + c_{ck} \leq B, \quad \forall c \in C, \forall k \in K$$

$$b_{0k} = B, \quad \forall k \in K$$

$$b_{ik} \geq 0, \quad \forall i \in V \cup C, \forall k \in K$$

- o Charging Constraints:

$$c_{ck} \leq r_c y_{ck}, \quad \forall c \in C, \forall k \in K$$

Use case – Proposed Changes

Start Simulation: Launch simulation for each planned route.

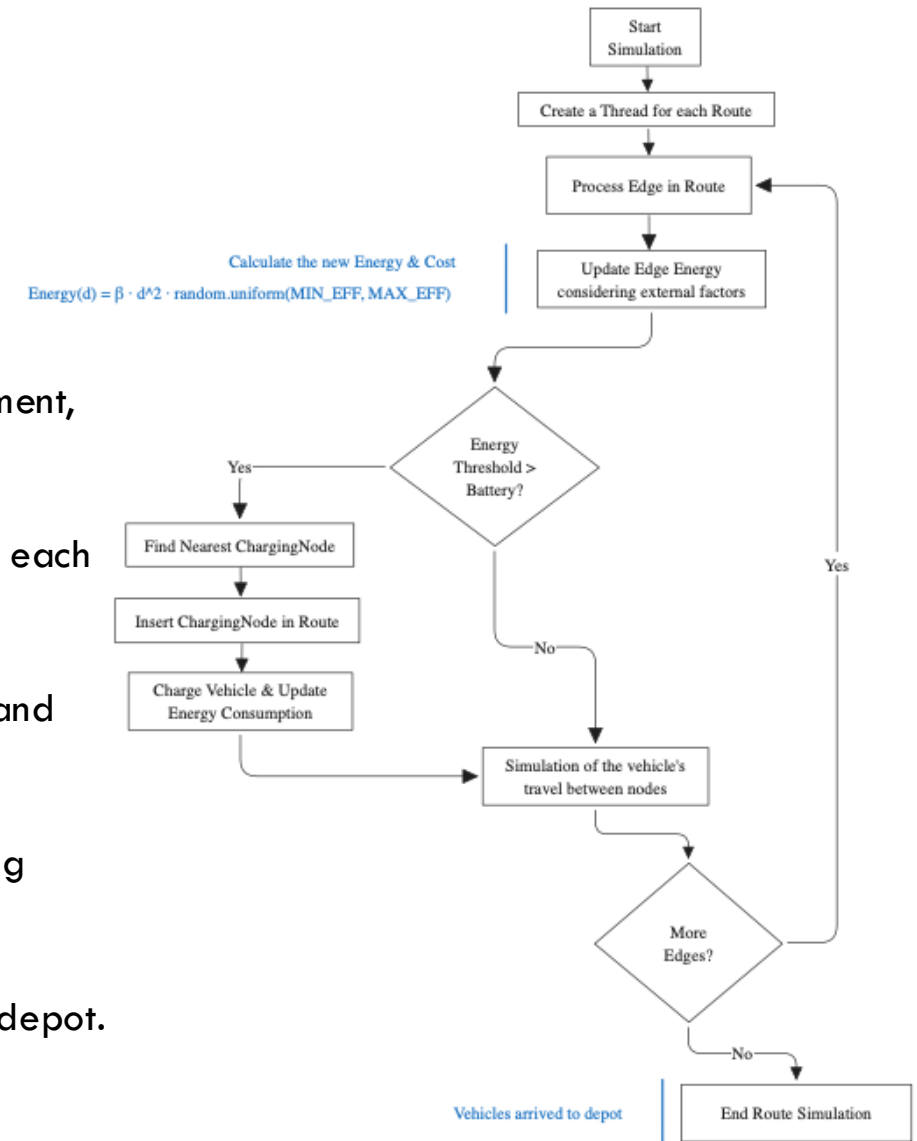
Dynamic Energy Calculation: Update energy cost for each route segment, considering external factors and randomness.

Battery Monitoring: Check if vehicle battery is below threshold before each segment.

Smart Charging: If needed, find nearest charging station, insert stop, and recharge vehicle.

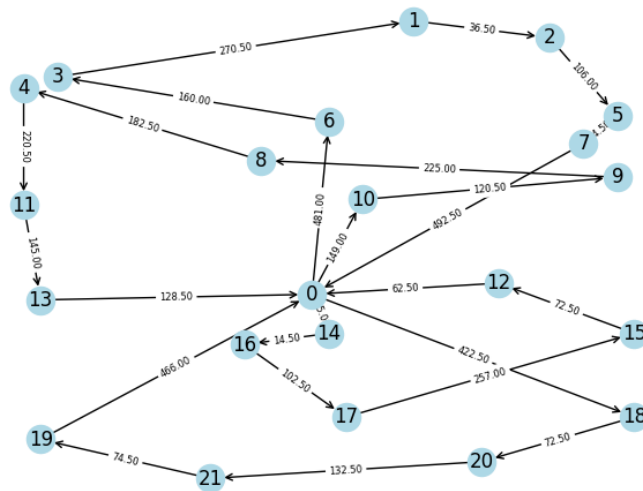
Travel Simulation: Simulate vehicle movement between nodes, updating energy and route status.

Iterate Until Complete: Repeat for all segments until vehicles return to depot.

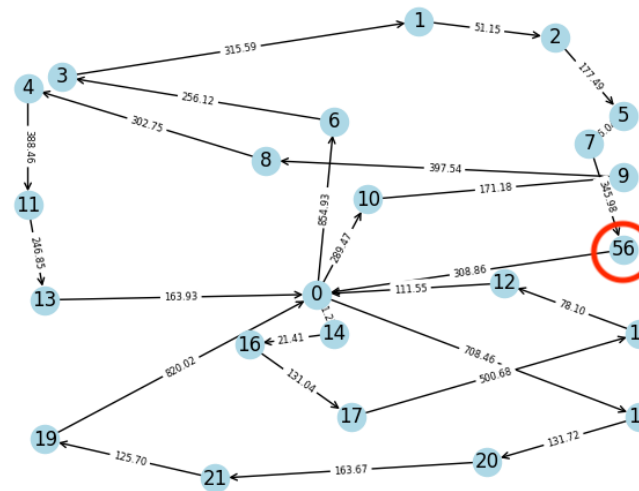


Use case – Example

CWS Standard Solution



Simulation (random MIN_EFF & MAX_EFF per edge)



--- Vehicle 2 Segment 1: Node 0 -> Node 14 ---
 Updated parameters: Edge Distance = 7.07, Edge Energy = 41.20, Route Energy = 550.21
 Previous Edge Energy: 25.00
 Previous Route Energy: 534.00
 Energy Threshold (worst case scenario): 559.00
 Battery Limit: 2,500.00
 Vehicle can continue its journey

--- Vehicle 0 Segment 7: Node 7 -> Node 0 ---
 Energy limited - Passes through recharge node 56

--- Vehicle 0 Segment 7: Node 7 -> Node 56 ---
 Updated parameters: Edge Distance = 19.10, Route Energy = 345.98

--- Vehicle 0 Segment 8: Node 56 -> Node 0 ---
 Updated parameters: Edge Distance = 19.70, Route Energy = 356.89

--- Node 0 has been reached from Vehicle 0.
 Vehicle 0 has arrived at the depot.

Our experimental results confirm 100% solution feasibility across scenarios, showing that modest distance increases (435.7 ± 3.71 km vs. 431.99 km) can accommodate charging requirements while maintaining route feasibility.



Conclusions & Future Research

Industrial PhD: From Specific Application to Generalizable Decision Support –
e.g: Benchmarking using Operations Research Question Answering (ORQA) dataset

Simulation & Learning Under Uncertainty: Simulates real-world uncertainty to test and adapt decision-making.

Path to Real SME Integration: Designed for future integration into daily SME operations through pilot projects



Thank you!

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