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An Optimisation Model for Multi-period, Multi-project Logistics Problem with Capitated Storage and Heterogenous Fleet

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HONORING 60 YEARS OF PROJECT MANAGEMENT:

LEADING THE WAY INTO THE FUTURE

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Introduction

- In today's competitive world, organisations undertake various projects to achieve their goals and drive growth.
- Logistics plays an important role in the execution of projects.
- In multi-project environments, a group of independent projects are managed simultaneously. They share at least some common pool of limited resources (He et al., 2022).

Motivation

- Literature lacks a comprehensive study that considers vehicle allocation, routing, and inventory decisions in a multi-project and multi-period setting with a real-life case study.

Contribution

- A bi-objective optimisation framework.
- Integration of multiple interdependent decisions, such as heterogeneous vehicle allocation, routing, inventory management, and storage leasing.
- A real-life case study.

Literature review

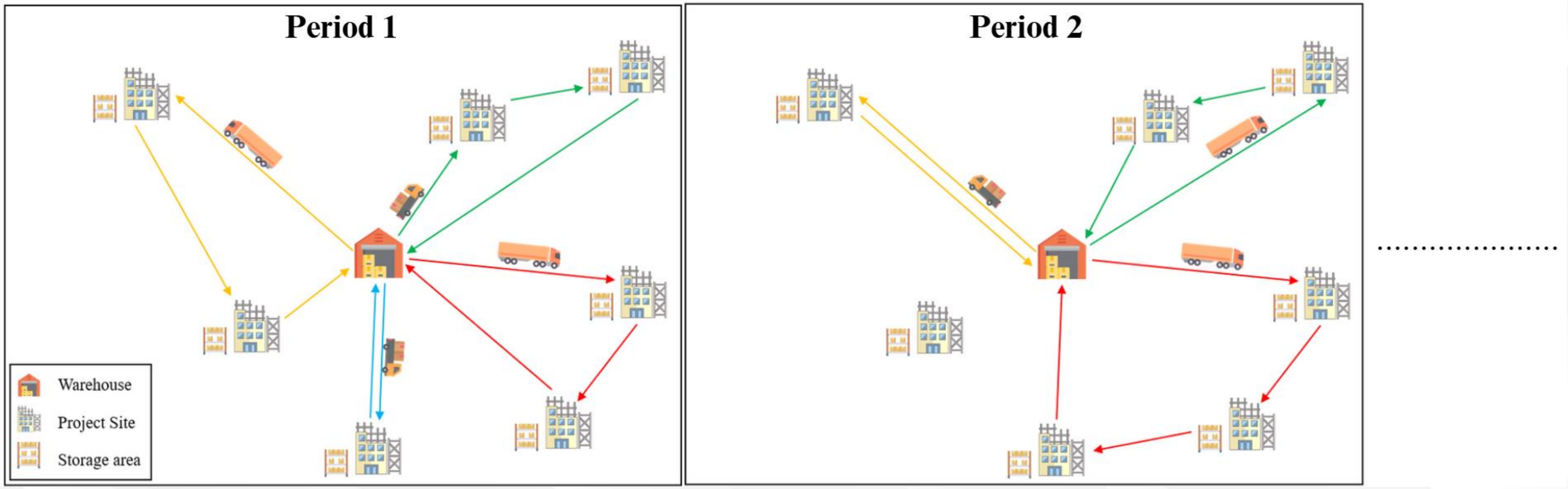
Reference	Year	Environment		Objective function		Objective function(s)	Decisions			Multi-period
		Single project	Multi-project	Single objective	Multi-objective		Vehicle allocation	Routing	Inventory	
Alinaghian and Zamani	2019				✓	Min. emissions, Min. fuel cost	✓	✓	✓	✓
RezaHoseini et al.	2021		✓		✓	Min. total costs, Min.	✓		✓	
Ferreira et al.	2021			✓		Min. emissions	✓	✓		
Abdzadeh et al.	2022		✓	✓		Min. total costs	✓	✓	✓	
Afra and Kheirkhah	2023		✓	✓		Min. total costs			✓	✓
Asadujjaman et al.	2024		✓	✓		Max. NPV			✓	✓
Wang et al.	2024		✓		✓	Min. total transportation time, Min. total costs	✓	✓		
Aliahmadi et al.	2024		✓		✓	Min. project delay, Min. total costs, Min. environmental impact			✓	✓
Darabad et al.	2024		✓		✓	Min. total costs, Min.	✓	✓		✓
This study	2025		✓		✓	Min. total costs, Min. emissions	✓	✓	✓	✓

Summary of Relevant Studies

Problem description

- This problem involves the transportation of resources from a central warehouse to multiple project sites.
- Each site has specific resource demands and time constraints.
- Delays in transportation will incur a backorder cost, representing the crashing cost required to compensate for lost time and to keep the project on track.
- Additionally, each site can rent storage to temporarily store the resources.

Problem description (contd.)



Structure of the distribution network in a multi-period setting

Math Model: Sets & Parameters

Sets:

A: Set of all nodes

N: Set of all demand nodes

V: Set of all vehicles

T: Set of periods

L: Set of storage levels

Parameters:

Node 1: Warehouse

Nodes 2 to $n+1$: Project sites

Node $n+2$: Warehouse (Duplicated node for the purpose of math modelling only)

n: Number of demand nodes

TC_{ijkt}: Travel cost from node *i* to node *j* in period *t* using vehicle *k*

FCV_{kt}: Fixed cost of operating vehicle *k* in period *t*

Math Model: Sets & Parameters

SC_{ilt}: Storage cost of level *l* at node *i* in period *t*

BC_{it}: Backorder cost per unit at node *i* in period *t*

D_{it}: Demand at node *i* in period *t*

C_k: Capacity of vehicle *k*

S_{il}: Capacity at node *i* for level *l*

τ_k^l: Resource loading time of vehicle *k*

τ_{ijk}^t: Travel time from node *i* to node *j* by vehicle *k*

$dist_{ij}$: Travel time from node *i* to node *j*

ER_k: CO_2 emissions per meter travelled by vehicle *k*

τ_{it}^s: Service time at node *i* in period *t*

TW_{it}^U: Upper limit of time window at node *i* in period *t*

TW_{it}^L: Lower limit of time window at node *i* in period *t*

Math Model: Decision variables

x_{ijkt}: equal to 1 if a vehicle *k* travels from node *i* to node *j* in period *t*

y_{ikt}: equal to 1 if node *i* is assigned to vehicle *k* in period *t*

v_{it}: equal to 1 if vehicle *k* is operated in period *t*

t^a_{ikt}: Arrival time of vehicle *k* at node *i* during period *t*

t^d_{ikt}: Departure time of vehicle *k* at node *i* during period *t*

γ_{ikt}: Load in vehicle *k* after servicing node *i* during period *t*

d_{ikt}: Number of units of resources delivered at node *i* in vehicle *k* during the period *t*

I_{it}: Ending inventory in node *i* during period *t*

B_{it}: Backorder quantity in node *i* during period *t*

H_{ilt}: Equal to 1 if storage level *l* is rented at node *i* in period *t*

Math Model: Objective function

The objective function, expressed in Eq. 1, minimises the total cost:

$$\min \sum_{i,j\epsilon A} \sum_{k\epsilon V} \sum_{t\epsilon T} \left(TC_{ijkt} \times x_{ijkt}\right) + \sum_{k\epsilon V} \sum_{t\epsilon T} \left(FCV_{kt} \times v_{kt}\right) + \sum_{i\epsilon A} \sum_{l\epsilon L} \sum_{t\epsilon T} \left(SC_{ilt} \times H_{ilt}\right) + \sum_{i\epsilon A} \sum_{t\epsilon T} \left(BC_{ilt} \times B_{it}\right). \quad (1)$$

The objective function, expressed in Eq. 2, minimises the total CO_2 emissions:

$$\min \sum_{i,j\epsilon A} \sum_{k\epsilon V} \sum_{t\epsilon T} \left(ER_k \times dist_{ijkt} \times x_{ijkt}\right), \quad (2)$$

Math Model: Routing Constraints

$$\sum_{k \epsilon V} y_{ikt} \leq 1, \forall\, i \,\epsilon\, N, \forall\, t \,\epsilon\, T \quad (3)$$

$$\sum_{j \epsilon A} \sum_{k \epsilon V} x_{ijkt} \leq 1, \forall\, i \,\epsilon\, N, \forall\, t \,\epsilon\, T \quad (4)$$

$$\sum_{j \epsilon A} \sum_{k \epsilon V} x_{jikt} \leq 1, \forall\, i \,\epsilon\, N, \forall\, t \,\epsilon\, T \quad (5)$$

$$\sum_{j \epsilon A} x_{ijkt} = y_{ikt}, \forall\, i \,\epsilon\, N, \forall\, k \,\epsilon\, V, \forall\, t \,\epsilon\, T \quad (6)$$

$$\sum_{j \epsilon A} x_{jikt} = y_{ikt}, \forall\, i \,\epsilon\, N, \forall\, k \,\epsilon\, V, \forall\, t \,\epsilon\, T \quad (7)$$

Math Model: Routing Constraints

$$x_{ijkt} + x_{jikt} \leq 1, \forall\, i, j \in N, \forall\, k \in V, \forall\, t \in T \quad (8)$$

$$x_{iikt} = 0, \forall\, i \in N, \forall\, k \in V, \forall\, t \in T \quad (9)$$

$$\sum_{j \in A} x_{1jkt} = \sum_{j \in A} x_{j(n+2)kt}, \forall\, k \in V, \forall\, t \in T \quad (10)$$

$$\sum_{j \in A} \sum_{k \in V} \sum_{t \in T} x_{j1kt} = 0 \quad (11)$$

$$\sum_{j \in A} \sum_{k \in V} \sum_{t \in T} x_{(n+2)jkt} = 0 \quad (12)$$

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Math Model: Routing Constraints

$$y_{ikt} - y_{jkt} \leq 1 - x_{ijkt}, \forall\, i, j \in A, \forall\, k \in V, \forall\, t \in T \qquad (13)$$

$$y_{ikt} \leq y_{1kt}, \forall\, i \in N, \forall\, k \in V, \forall\, t \in T \qquad (14)$$

$$y_{1kt} \leq \sum_{j \in N} x_{1jkt}, \forall\, k \in V, \forall\, t \in T \qquad (15)$$

$$\sum_{i \in A} y_{ikt} \leq (n+2) \times v_{kt}, \forall\, k \in V, \forall\, t \in T \qquad (16)$$

$$\sum_{j \in A} x_{ijkt} \leq v_{kt}, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \qquad (17)$$

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Math Model: Time Constraints

$$t^{a}_{1kt} = \tau^{l}_{k}, \forall\, k \in V, \forall\, t \in T \qquad (18)$$

$$t^{a}_{jkt} \geq t^{a}_{ikt} + \tau^{t}_{ijk} - M \times (1 - x_{ijkt}), \forall\, i, j \in A, \forall\, k \in V, \forall\, t \in T \qquad (19)$$

$$t^{d}_{ikt} \geq t^{a}_{ikt} + \tau^{s}_{it}, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \qquad (20)$$

$$t^{a}_{ikt} \geq TW^{L}_{it}, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \qquad (21)$$

$$t^{d}_{ikt} \leq TW^{U}_{it}, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \qquad (22)$$

Math Model: Load Constraints

$$d_{ikt} \leq M \times y_{ikt}, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \quad (23)$$

$$\gamma_{1kt} = \sum_{i \in A} d_{ikt}, \forall\, k \in V, \forall\, t \in T \quad (24)$$

$$\gamma_{ikt} \geq \gamma_{jkt} + d_{jkt} - M \times (1 - x_{ijkt}), \forall\, i, j \in A, \forall\, k \in V, \forall\, t \in T \quad (25)$$

$$\gamma_{ikt} \leq C_k, \forall\, i \in A, \forall\, k \in V, \forall\, t \in T \quad (26)$$

Math Model: Inventory Constraints

$$I_{it} \geq \sum_{t'=1}^{t} \sum_{k \epsilon V} d_{ikt'} - \sum_{t'=1}^{t} D_{it'}, \forall\, i \,\epsilon\, A, \forall\, t \,\epsilon\, T \tag{27}$$

$$B_{it} \geq \sum_{t'=1}^{t} D_{it'} - \sum_{t'=1}^{t} \sum_{k \epsilon V} d_{ikt'}, \forall\, i \,\epsilon\, A, \forall\, t \,\epsilon\, T \tag{28}$$

$$I_{it} \leq \sum_{l \epsilon L} (S_{il} \times H_{ilt}), \forall\, i \,\epsilon\, A, \forall\, t \,\epsilon\, T \tag{29}$$

$$\sum_{l \epsilon L} H_{ilt} \leq 1, \forall\, i \,\epsilon\, A, \forall\, t \,\epsilon\, T \tag{30}$$

$$\sum_{k \epsilon V} \sum_{t \epsilon T} d_{ikt} = \sum_{t \epsilon T} D_{it}, \forall\, i \,\epsilon\, N \tag{31}$$

ε-Constraint Method to address multiple objectives

$$\min f_1(x)$$

s.t.

$$f_2(x) \leq \Omega$$

$$x \in X$$

where $f_1(x)$ is the total cost and $f_2(x)$ is the total CO_2 emissions.

The Ω value for each iteration is computed as follows.

$$\varepsilon = \frac{f_2^{max}(x) - f_2^{min}(x)}{\alpha}$$

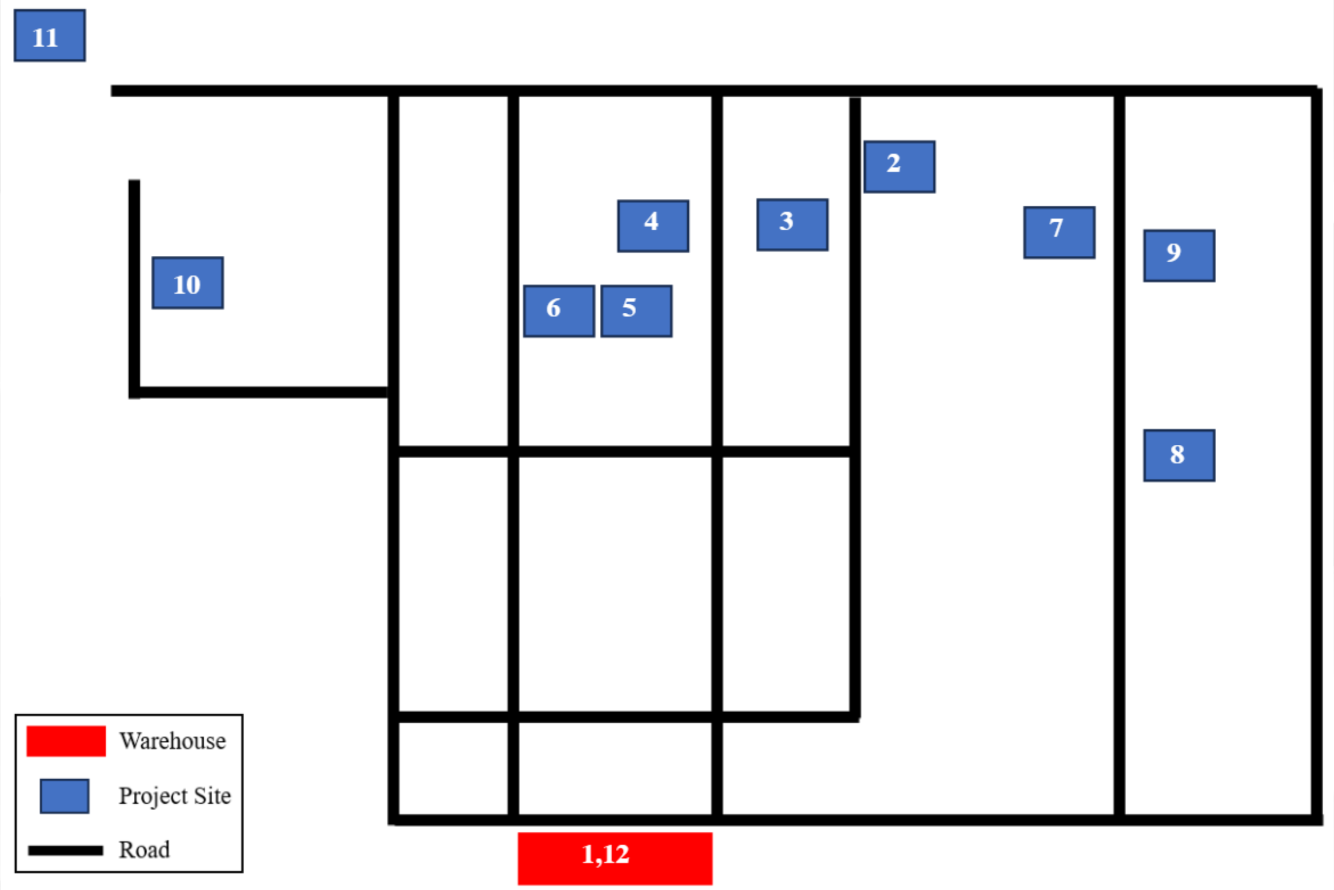
$$\Omega = f_2^{min}(x) + \varepsilon \times i, \qquad \forall\, i = 0, 1, \ldots, \alpha$$

Case study

- A real-world power plant construction project in India.
- On average, the material demand was 150 metric tonnes. The entire project spanned 20 months.
- Two types of vehicles were used for material transportation, while containers served as on-site storage units.
- Loading and unloading times were assumed to be constant, and all material handling activities were restricted to daylight hours due to the challenges of working at night.

Case study (contd.)

- For analysis, we consider 10 prominent sites over 3 periods.
- We only consider three periods as the demand was dynamic, and planning for longer periods is not viable.



Schematic diagram of the power plant project

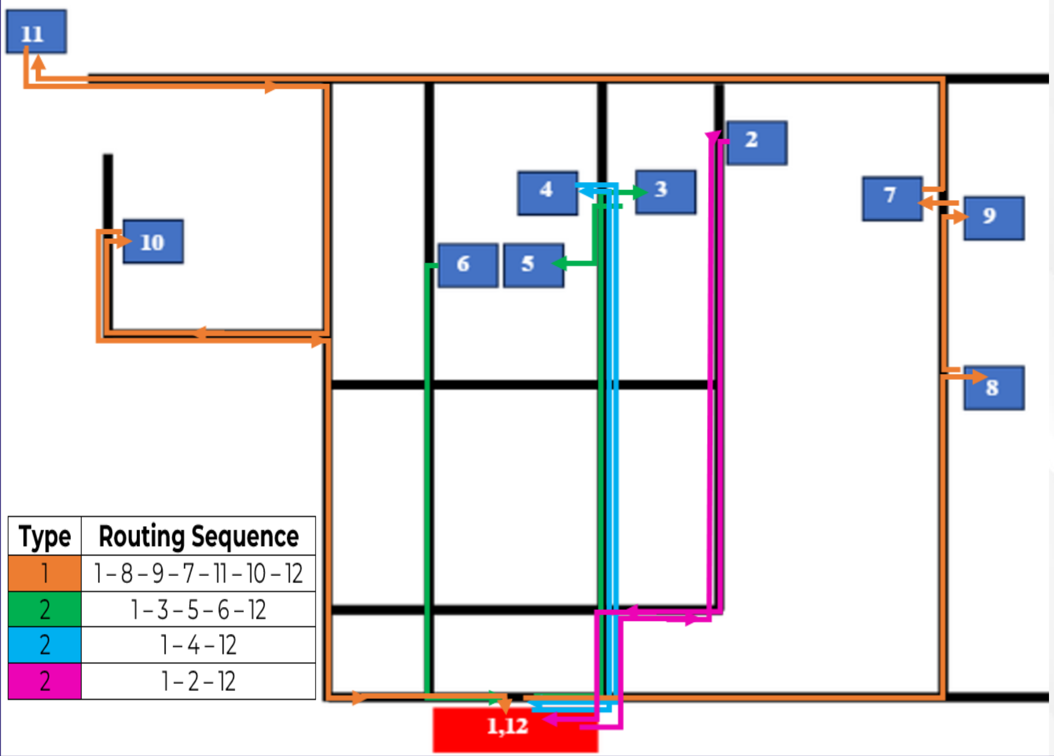
Results: Solving independently

- The model is run for 600 seconds solving for each objective independently.

	Minimizing costs	Minimizing CO_2 emissions
Primary objective function value	Rs. 10122.0825	4.7798 kg
Secondary objective function value	5.9174 kg	Rs. 17914.8768

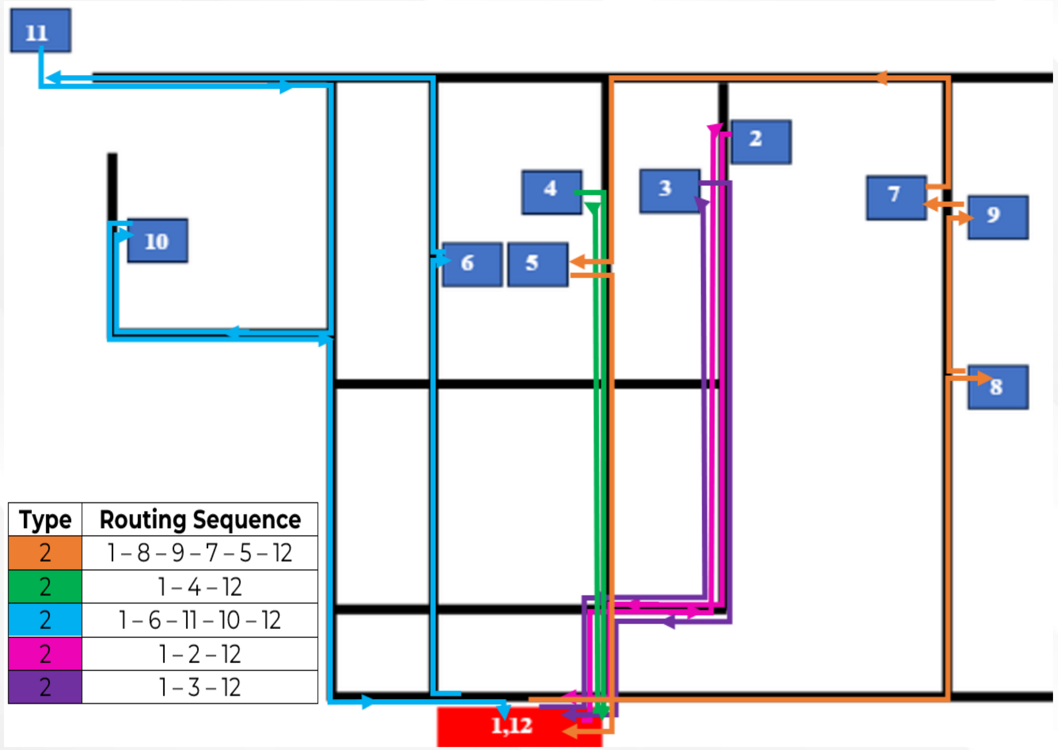
Results: Solving independently (contd.)

Minimizing costs



Type	Routing Sequence
1	1 – 8 – 9 – 7 – 11 – 10 – 12
2	1 – 3 – 5 – 6 – 12
2	1 – 4 – 12
2	1 – 2 – 12

Minimizing CO_2 emissions

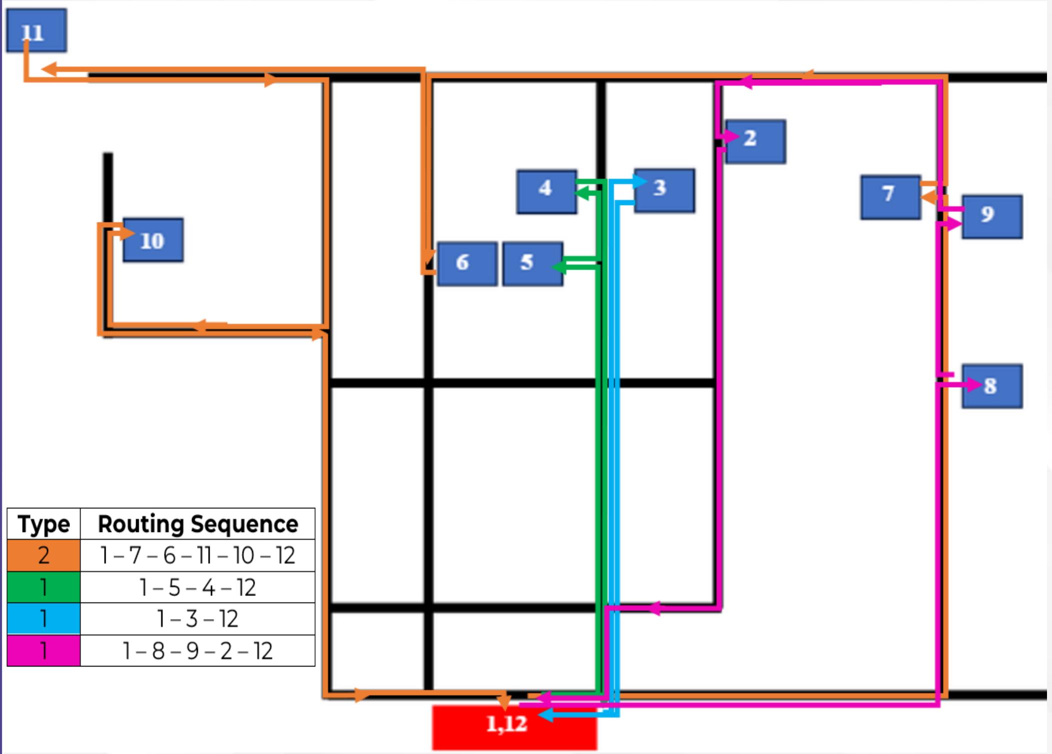


Type	Routing Sequence
2	1 – 8 – 9 – 7 – 5 – 12
2	1 – 4 – 12
2	1 – 6 – 11 – 10 – 12
2	1 – 2 – 12
2	1 – 3 – 12

Period 1 routing

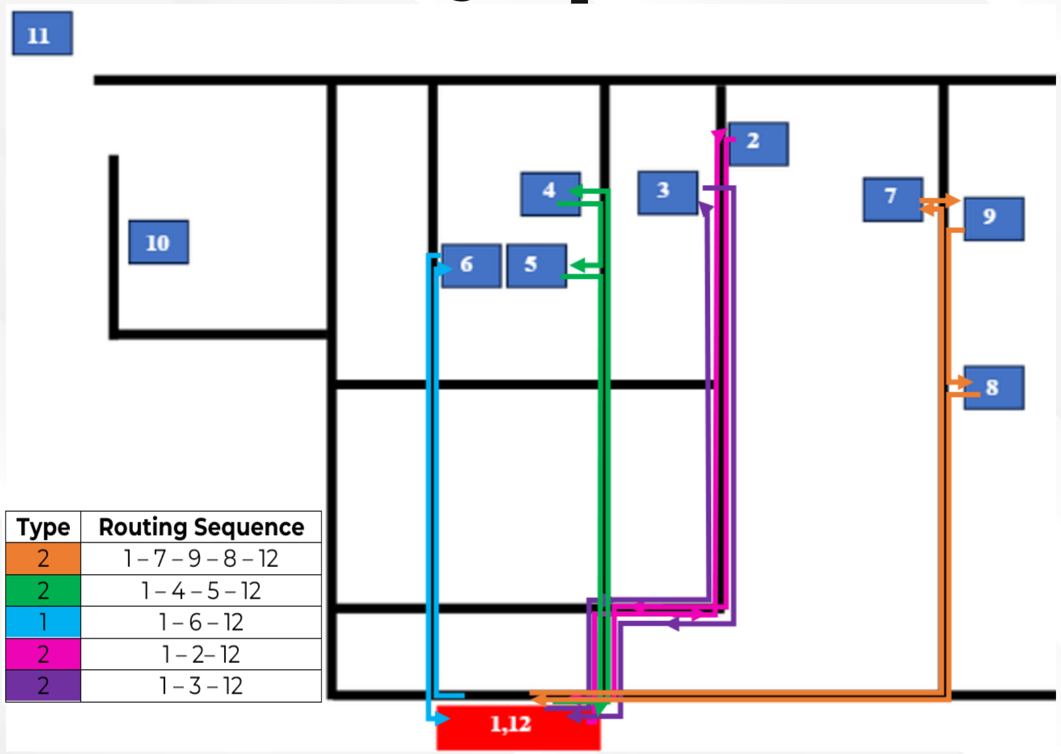
Results: Solving independently (contd.)

Minimizing costs



Type	Routing Sequence
2	1 – 7 – 6 – 11 – 10 – 12
1	1 – 5 – 4 – 12
1	1 – 3 – 12
1	1 – 8 – 9 – 2 – 12

Minimizing CO_2 emissions

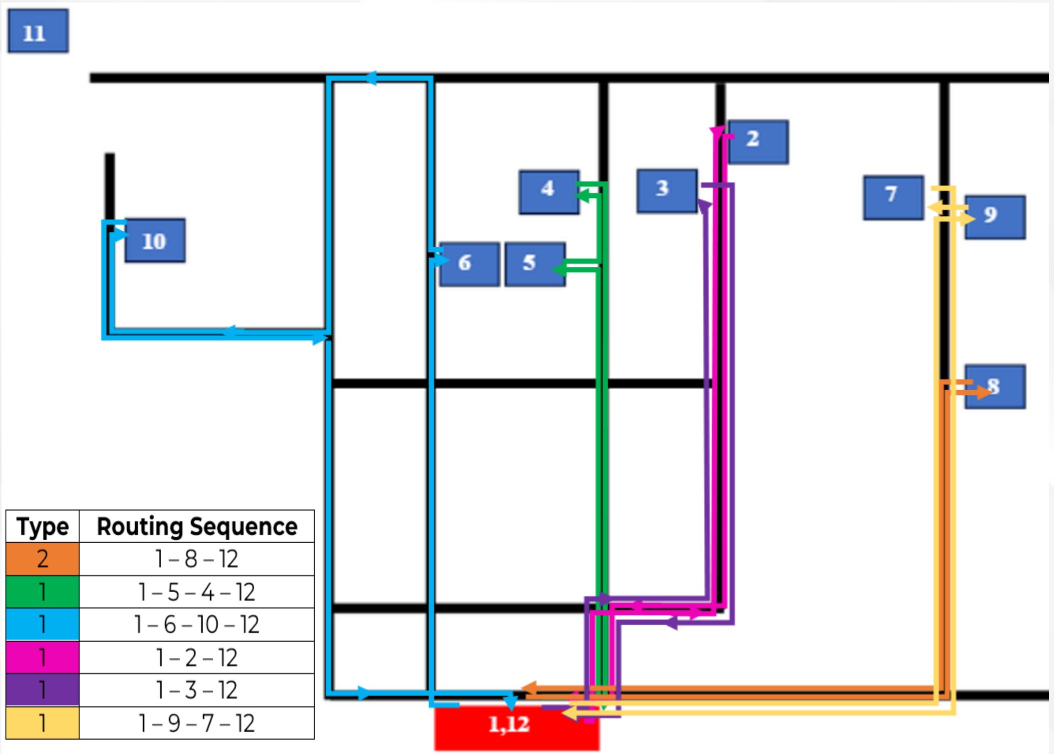


Type	Routing Sequence
2	1 – 7 – 9 – 8 – 12
2	1 – 4 – 5 – 12
1	1 – 6 – 12
2	1 – 2– 12
2	1 – 3 – 12

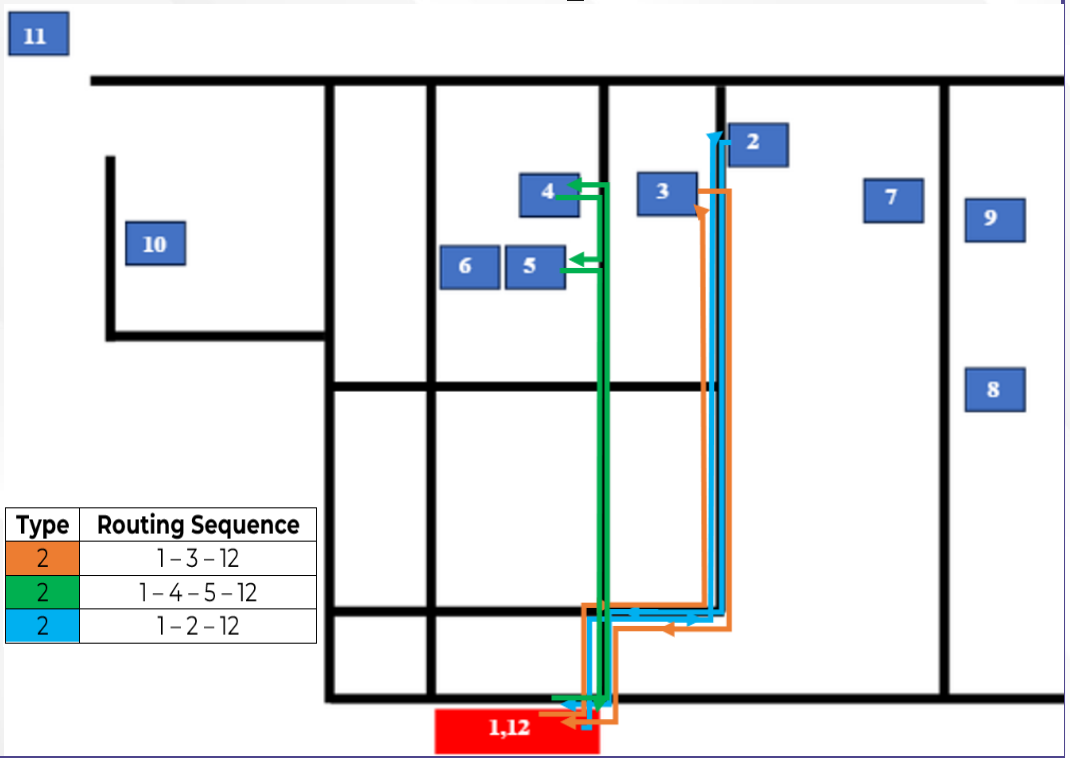
Period 2 routing

Results: Solving independently (contd.)

Minimizing costs

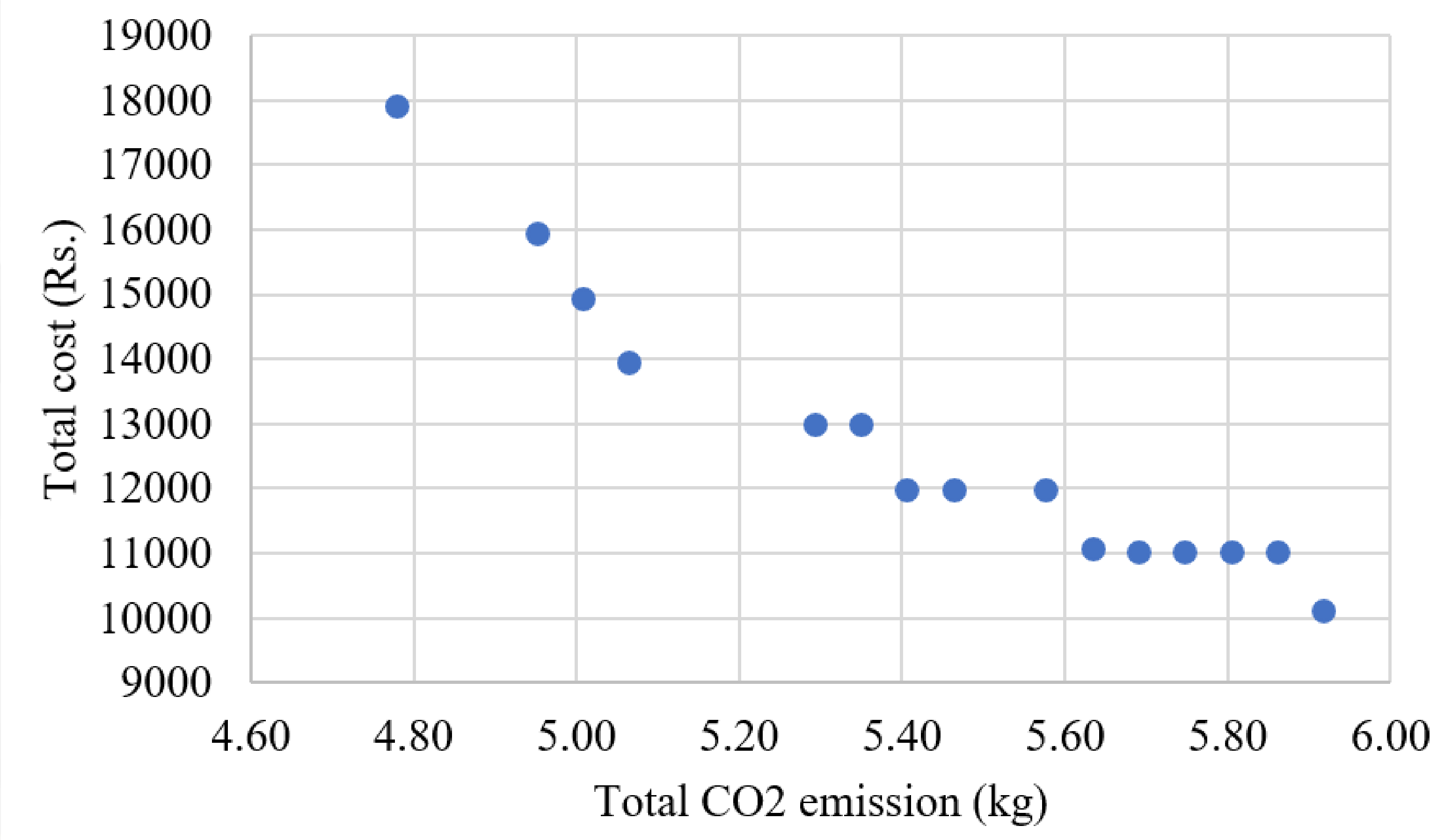


Minimizing CO_2 emissions



Period 3 routing

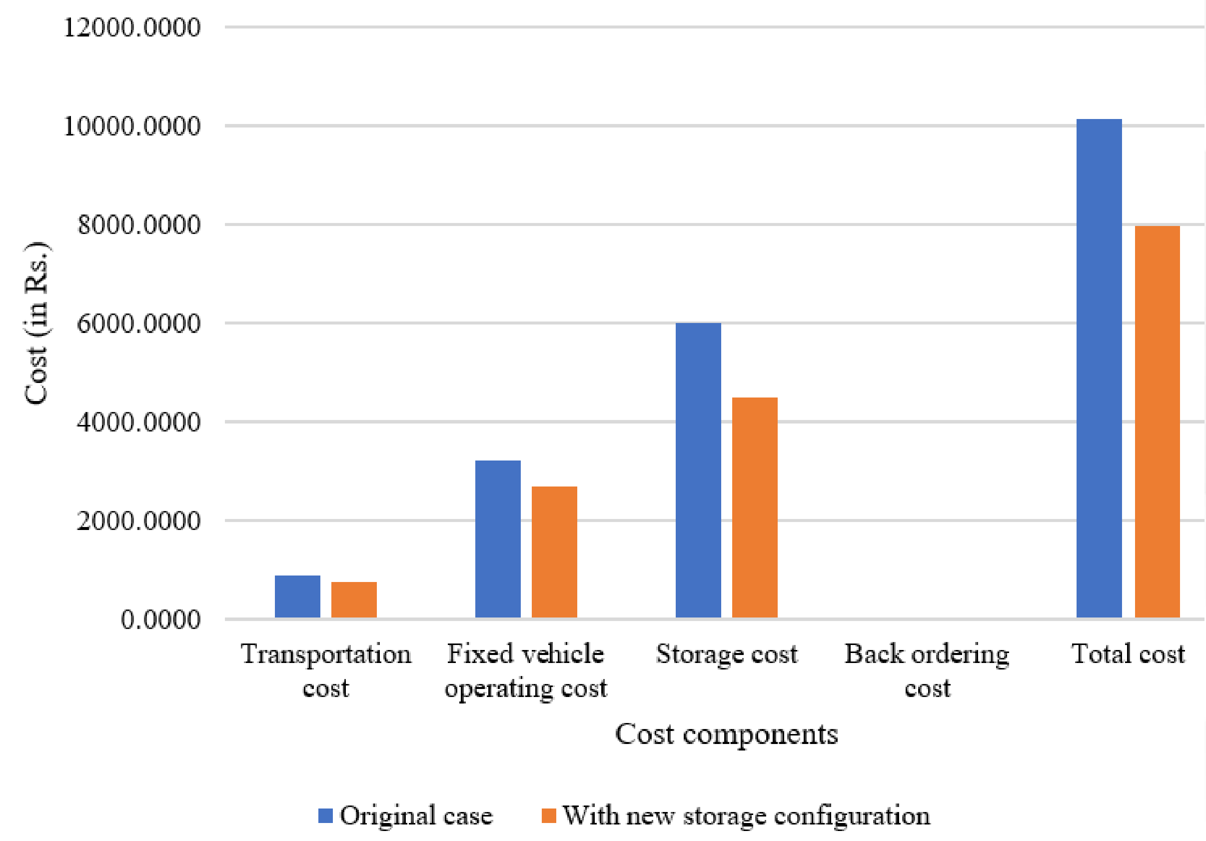
Results: Non-Dominated front



Results: Sensitivity analysis

A new storage option with a 10 MT capacity and a per-period cost of Rs. 500 was introduced, and the first objective function is minimized.

Best objective function value (Rs.)	
Without 10 MT storage option	With 10 MT storage option
10122.0825	7967.7750

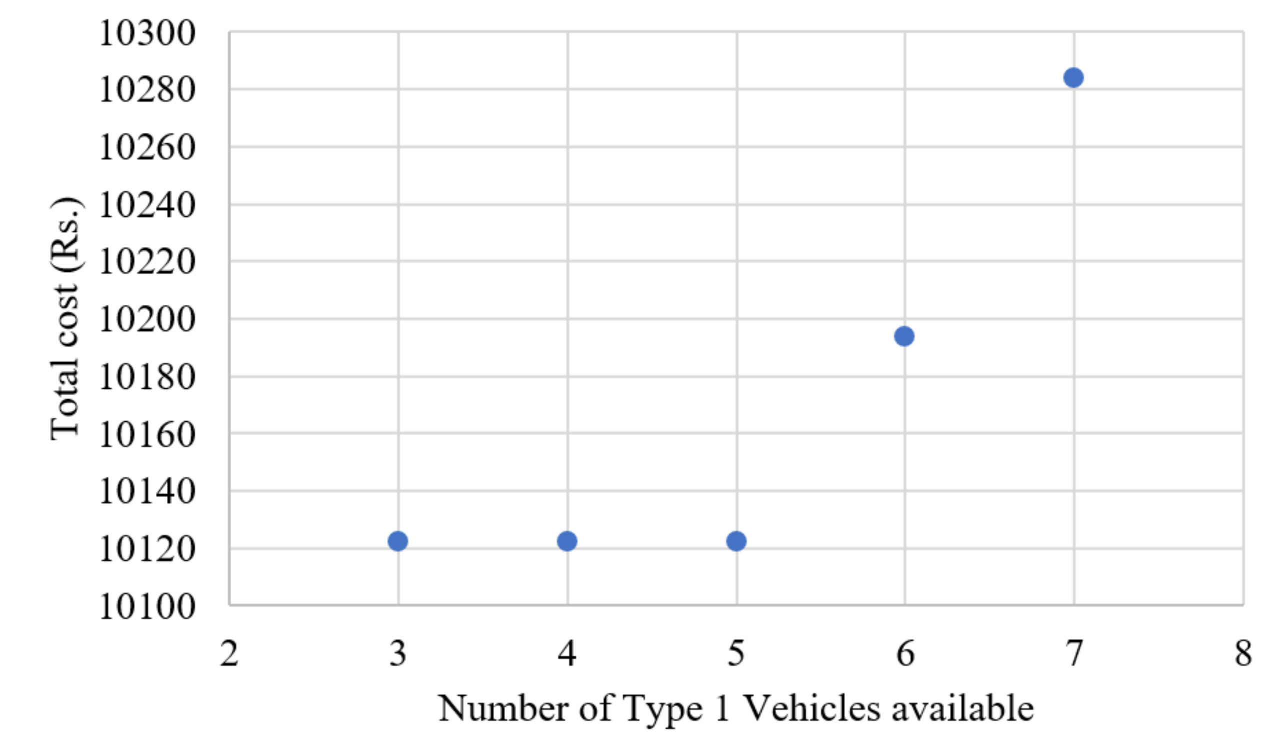


Cost Comparison Between Original and New Storage Configuration

Results: Sensitivity analysis (contd.)

We also have varied the number of Type 1 and Type 2 vehicles available and studied the impact on total cost.

Number of vehicles available		Total cost (in Rs.)
Type 1	Type 2	
3	7	10122.0825
4	6	10122.0825
5	5	10122.0825
6	4	10193.4925
7	3	10283.8773

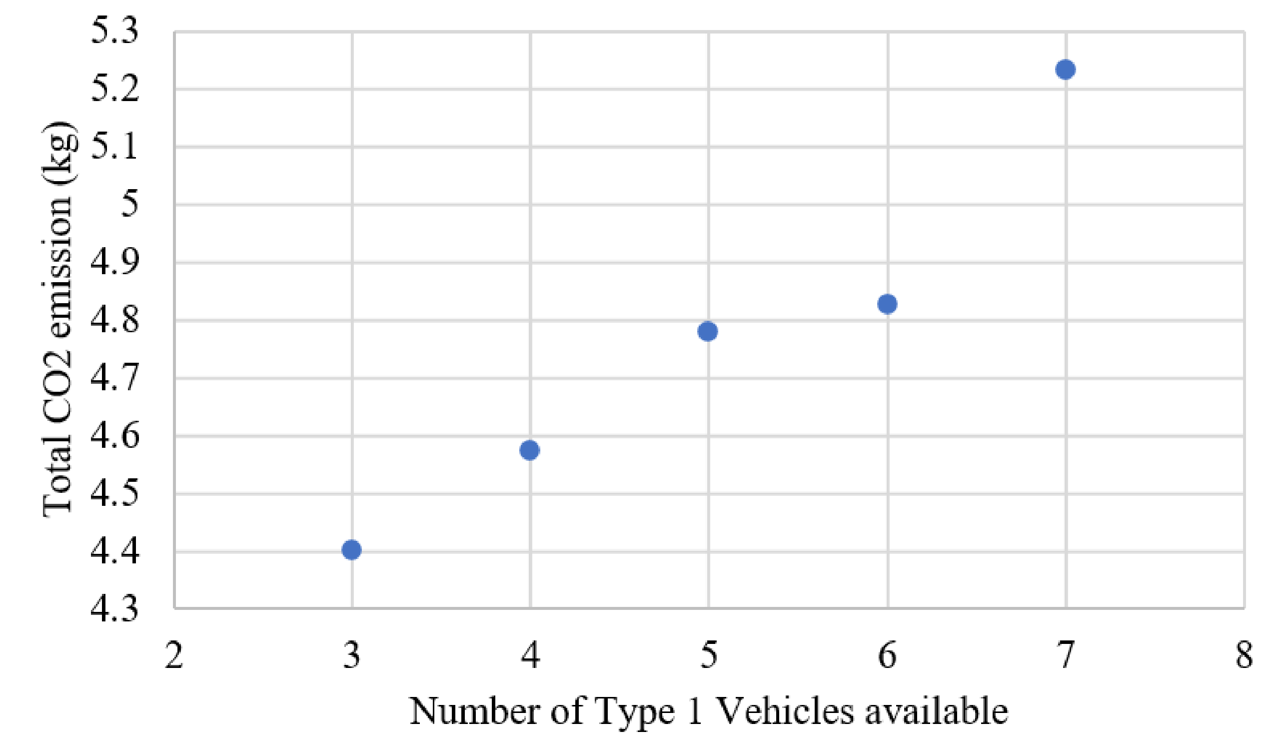


Number of Type 1 vehicles available vs. Total cost

Results: Sensitivity analysis (contd.)

We also have varied the number of Type 1 and Type 2 vehicles available and studied the impact on total CO_2 emissions.

Number of vehicles available		Total emission (in kg)
Type 1	Type 2	
3	7	4.4001
4	6	4.5736
5	5	4.7798
6	4	4.8254
7	3	5.2314



Number of Type 1 vehicles available vs. Total CO_2 emissions

Conclusions

- A bi-objective optimisation framework has been developed that minimises both costs and emissions and employs the ε-constraint method to generate a non-dominated front.
- This model is adaptable to various multi-project scenarios requiring the movement of resources using a wide range of vehicles, including drones.

Source: CIN Magazine (2024)

Source: Royal Aeronautical Society (2024)

Future research

- The model's scalability could be improved by incorporating heuristics to handle larger instances.
- In addition, incorporating material demand and travel time uncertainty could provide a more robust solution.
- Further exploring the application of this model in different project types and integrating other sustainability metrics could further enhance its practical utility.

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Thank you!

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Appendix

Distance Between Nodes (in metres)

Nodes	1	2	3	4	5	6	7	8	9	10	11	12
1	0	400	380	340	310	310	500	400	500	450	560	0
2	400	0	20	200	230	330	200	300	220	520	440	400
3	380	20	0	180	210	310	220	320	240	500	420	380
4	340	200	180	0	30	180	270	370	290	450	370	340
5	310	230	210	30	0	30	300	400	320	420	340	310
6	310	330	310	180	30	0	400	500	420	320	240	310
7	500	200	220	270	300	400	0	100	20	700	620	500
8	400	300	320	370	400	500	100	0	80	800	720	400
9	500	220	240	290	320	420	20	80	0	720	640	500
10	450	520	500	450	420	320	700	800	720	0	350	450
11	560	440	420	370	340	240	620	720	640	300	0	560
12	0	400	380	340	310	310	500	400	500	450	560	0

Material Demand at Sites During Different Time Periods

	Demand (in MT)	
	In both Period 1 and 2	**Period 3**
Sites 2 to 4	[8, 12]	[27, 32]
Sites 5 to 11	[1, 3]	[6, 8]

Storage Facility Parameters

Storage level	Capacity in MT	Cost per period (in Rs.)
1	20	1000
2	40	2000
3	60	3000

Appendix

Vehicle Parameters

Vehicle type	Capacity (in MT)	Fixed operating cost per period (in Rs.)	Speed (in kmph)	No. of vehicles available	CO_2 emissi rate (kg/kn
1	18	230	30	5	0.4483
2	10	150	30	5	0.3843

The carbon content in a litre of diesel is 0.734 kg (USEPA, 2005)*. The CO_2 emission per litre of diesel is 2.69 kg. The mileage of the vehicle is considered along with the CO_2 emission per litre to arrive at CO_2 emission per km travelled.

Backordering Costs

Site	Backordering cost per period (in Rs.)
2	15,000
3	15,000
4	7,000
5	6,000
6	6,000
7	6,000
8	6,000
9	6,000
10	6,000
11	6,000

* USEPA, 2005. Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel [WWW Document]. URL https://nepis.epa.gov/