Optimization of Truck and Driver Scheduling Using Simulated Annealing

N.A. Chami M. Keerthisinghe, H.M.N. Dilum Bandara, and N.A. Samarasekara

Dept. of Computer Science & Engineering,

University of Moratuwa, Sri Lanka

chami.16@cse.mrt.ac.lk

Research Contribution

- Automating truck and driver scheduling for goods delivery
- Reduce manipulations by the scheduling manager
  - Based on experience
  - Trial and error process
- Cater to high demand with available resources
- Maximize order coverage and minimize cost
- Ability to tolerate sudden changes; delays, breakdowns, unavailability of driver, etc.

Introduction

- Distribute heavy goods from plant to sites
- When an order is placed, assign a truck and a driver to deliver order while considering:
  - Order: Location, Delivery Time
  - Vehicle: Availability, Fuel Mileage
  - Driver: Availability, Hourly rate, Resting hours, Operating hours
  - External factors: Fuel price, Wear and tear, Traffic, Delays
- Need to optimize the scheduling process → Reduce costs, Increase customer satisfaction

Characteristics of Problem

Description	Characteristics
Housing of vehicles/ No of plants	Multiple
Size of Available Fleet	Multiple
Type of Available Fleet	Homogeneous
Capacity of Available Fleet	Same
Total No of Drivers	No of Drivers is higher than size of fleet
Nature of demand/ order	Deterministic / 1 Full Truck Load Predefined Delivery Time
Location of demand	Known / at nodes (Geographically dispersed)
Operations	Bulk Cement Deliveries (Drop offs to sites only)
Costs	Travel cost, Driver cost, Vehicle cost

Problem Statement

- Given set of Orders O, Trucks V and Drivers D;

How to automatically schedule trucks and drivers to serve as many orders as possible while reducing cost, maximizing customer and driver safety and satisfaction, and efficiency?

Constraints and Conditions

1. Truck Availability Constraint	$\forall v \in V; v^{t}_{status} ! \text{ON\_LEAVE} \rightarrow v$
2. Driver Availability Constraint	$\forall d \in D; d^{t}_{status} ! \text{ON\_LEAVE} \rightarrow d$
3. Feasibility Constraint for Trucks	If truck *v* is IDLE within time frame (t_1, t_2), truck is eligible to deliver order *o* only if: $o_{Early\_Start\_Time} < t_1 < o_{Late\_Start\_Time} \cap o^{v}_{Early\_End\_Time} < t_2 < o^{v}_{Late\_End\_Time}$
4. Feasibility Constraint for Drivers	If driver *d* is IDLE within time frame (t_1, t_2), driver is eligible to deliver order *o* only if: $o_{Early\_Start\_Time} < t_1 < o_{Late\_Start\_Time} \cap o^{d}_{Early\_End\_Time} < t_2 < o^{d}_{Late\_End\_Time}$

Constraints and Conditions (Cont.)

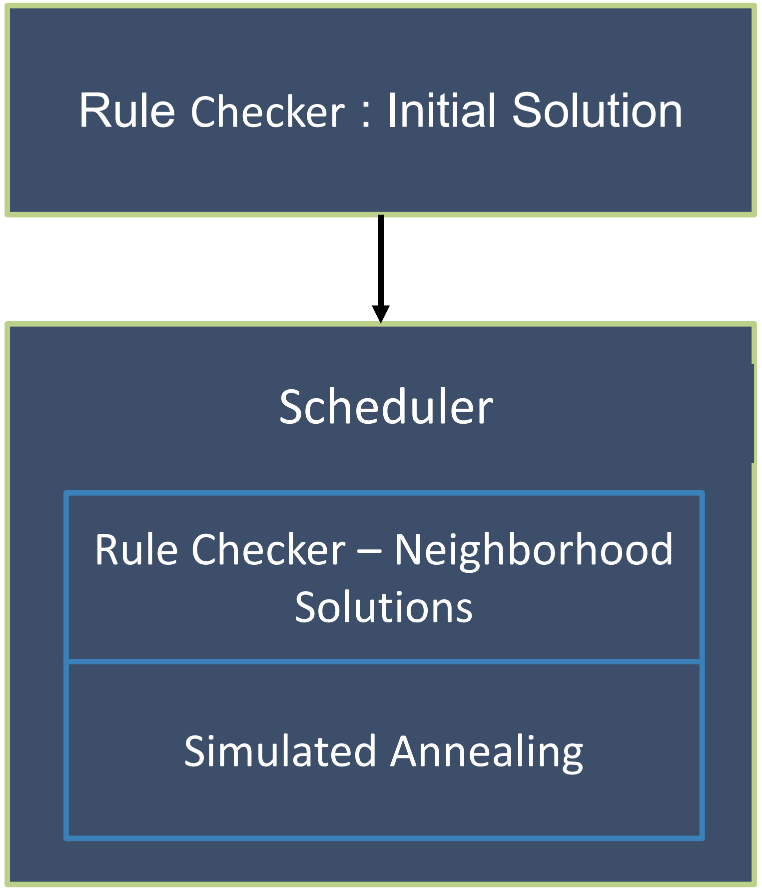
5. Working hour constraint	$d^{day}_{cum\_working\_time} < d^{day}_{max\_working\_time}$
6. Resting hour conditions	$\mathrm{rest}(i,j) = \begin{cases} 15\mathrm{mts}, & t(i,j) \leq 270\mathrm{mts} \\ (t(i,j) * 0.4872 - 101.544), & 270\mathrm{mts} < t(i,j) < 1440 \\ 600\mathrm{mts}, & t(i,j) \geq 1440\mathrm{mts} \end{cases}$

Objectives

- Primary Objective
  - Deliver as many orders as possible in right time with right quality
- Secondary Objective
  - $Min \sum_{\substack{o \in O, \\ v \in V}} (c_{v,d}^{o})$
  - Where;
    - $c_{v,d}^{o} = c_{travel} + c_{driver} + c_{vehicle}$
    - $c_{travel} = \left\{ \left(v_{ave_{mileage}}^{with_{load}} * dist(i,j) \right) + \left(v_{ave_{mileage}}^{no_{load}} * dist(i,j) \right) \right\} * fuel_{up}$
    - $c_{driver} = d_{hourly\_rate}^{t} * d_{travel\_time}$
    - $c_{vehicle} = x * dist(i,j)$

Solution

- ❑ Schedule orders day prior to delivery date
- ❑ 2 part solution
  1. Rule Checker
     - Enforce constraints
     - Filter out possible trucks and drivers
     - Initial solution generation
  2. Scheduler
     - Use Simulated Annealing (SA)
       - Optimized solution generation



Rule Checker

New order o

$$\forall d \in D;\ d^{t}_{status}!ON\_LEAVE \rightarrow d$$

$$\forall v \in V;\ v^{t}_{status}!ON\_LEAVE \rightarrow v$$

$$o_{earliest\_start\_time} = o_{DT} - t(plant, o_{DL}) - v_{load\_time} - o_{time\_buffer}$$

$$o_{latest\_start\_time} = o_{DT} - t(plant, o_{DL}) - v_{load\_time} + o_{time\_buffer}$$

$$o^{v}_{earliest\_end\_time} = o_{Early\_Start\_Time} + t(plant, o_{DL}) + v_{load\_time} + drest_{(plant, oDL)} + v_{unload\_time} + t(o_{DL}, plant)$$

$$o^{v}_{latest\_end\_time} = o_{latest\_Start\_Time} + t(plant, o_{DL}) + v_{load\_time} + drest_{(plant, oDL)} + v_{unload\_time} + t(o_{DL}, plant)$$

$$o^{d}_{earliest\_end\_time} = o_{Early\_Start\_Time} + t(plant, o_{DL}) + v_{load\_time} + drest_{(plant, oDL)} + v_{unload\_time} + t(o_{DL}, plant) + drest(o_{DL}, plant)$$

$$o^{d}_{latest\_end\_time} = o_{latest\_Start\_Time} + t(plant, o_{DL}) + v_{load\_time} + drest_{(plant, oDL)} + v_{unload\_time} + t(o_{DL}, plant) + drest(o_{DL}, plant)$$

$$o_{Early\_Start\_Time} < t_1 < o_{Late\_Start\_Time} \cap o^{d}_{Early_{End_{Time}}} < t_2 < o^{d}_{Late\_End\_Time} \rightarrow d$$

$$o_{Early\_Start\_Time} < t_1 < o_{Late\_Start\_Time} \cap o^{v}_{Early_{End_{Time}}} < t_2 < o^{v}_{Late\_End\_Time} \rightarrow v$$

$$d^{day}_{cum\_working\_time} < d^{day}_{max\_workingl\_time}$$

$$Min \sum_{\substack{o \in O, \\ v \in V}} c^{o}_{v,d}$$

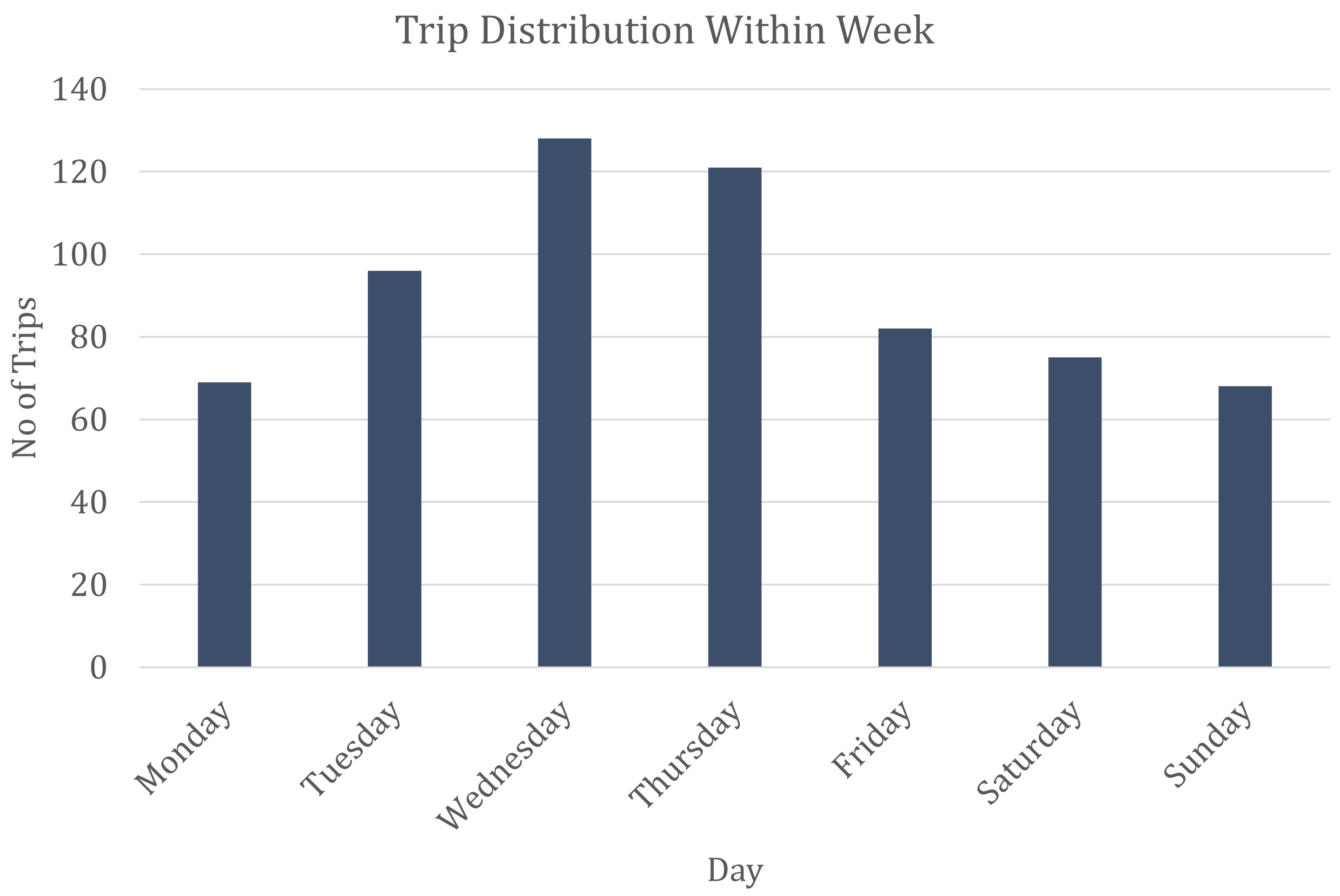
Simulated Annealing

- Probabilistic technique for approximating global optimum of given function
  - Powerful in solving complex combinatorial problem
  - Ability to customize algorithm
  - Not depend on model constraints
  - Very short computational time
- SA outperform algorithms Hill Climbing, K2, Look Ahead Hill Climbing, Repeated Hill Climbing, Tabu Search, and Genetic Algorithm
- Guidance: research on "Simultaneous vehicle and driver scheduling: Case study in a limousine rental company"

M. Maghrebi and S.T. Waller, "Exploring experts decisions in concrete delivery dispatching systems using Bayesian network learning techniques", In Proc. *Second Intl. Conf. on Artificial Intelligence, Modelling and Simulation*,2014 .
B. Laurent and J.-K. Hao, "Simultaneous vehicle and driver scheduling: Case study in a limousine rental company," Computers & Industrial Engineering, vol. 53, pp. 542–558, 2007.

Workload Creation

Trip Distribution



- Different workloads throughout the week

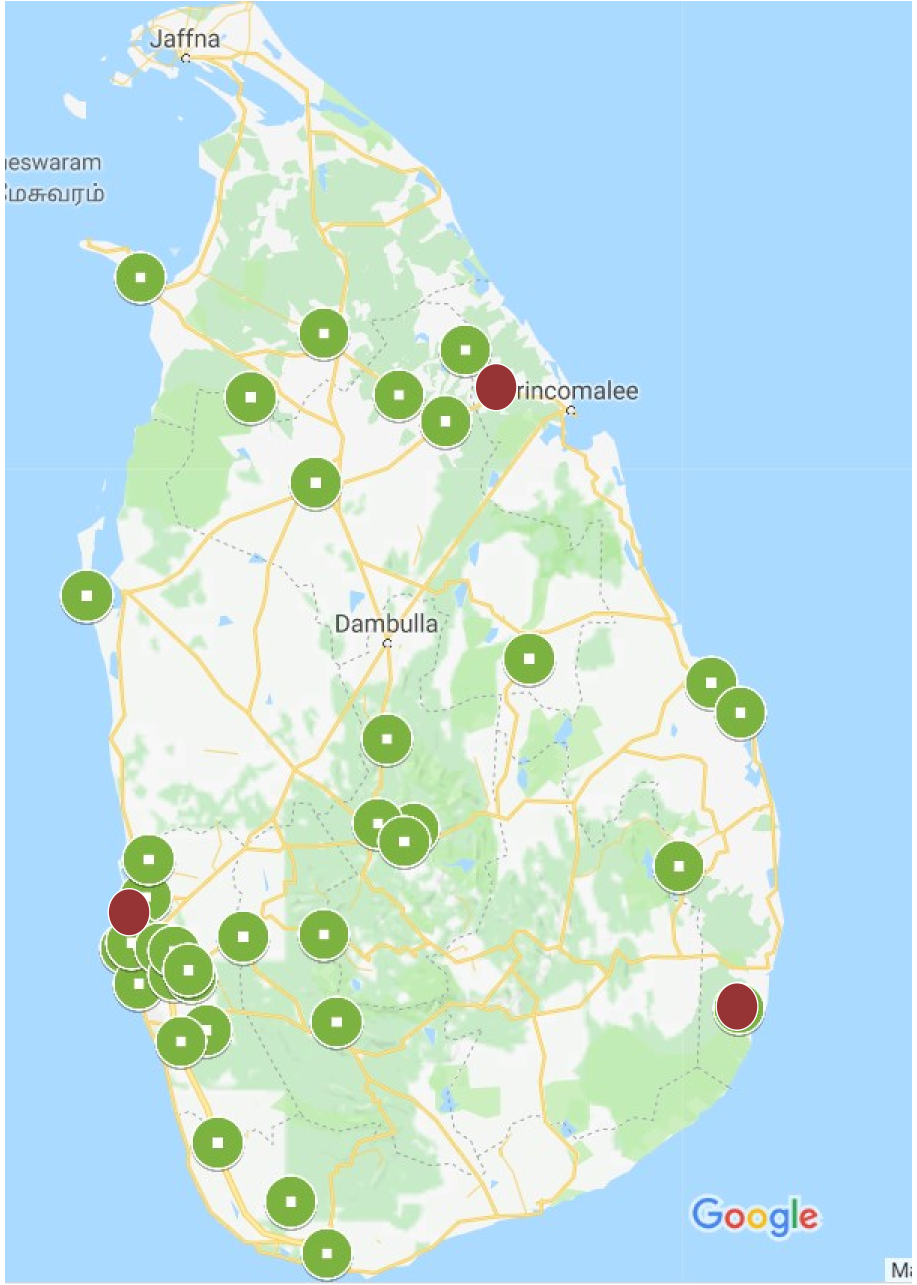
Key Aspects of Profiling Vehicle Performance

- Average no. of trips per day: 28
- No of days with total distance travelled less than average: 14 days
- Range of fuel mileage is between 0.5Km/L and 3Km/L
- Wednesday and Thursday have highest no of trips while Monday and Sunday have the lowest no of trips
- 19th June to 21st June are Holidays: Lower no of trips
- Average distance per truck per month: 5,392.90 Km
- Average travel time per truck is 207.5 hours (3 trucks are above average and 4 trucks are below average)

Dataset- Workload Creation

- ❑ Reference to the real BCD case study
- ❑ Order set for 7 days (week)

Day	No of Orders	No of Available Trucks	No of Available Drivers
Monday	38	14	33
Tuesday	52	19	33
Wednesday	70	22	34
Thursday	60	20	32
Friday	46	15	28
Saturday	43	15	27
Sunday	35	13	28



Initial Configuration

- Objective Function
  - Fuel Unit Price : 1
  - Day Hourly Rate :100
  - Night Hourly Rate: 25% addition to Day Hourly Rate

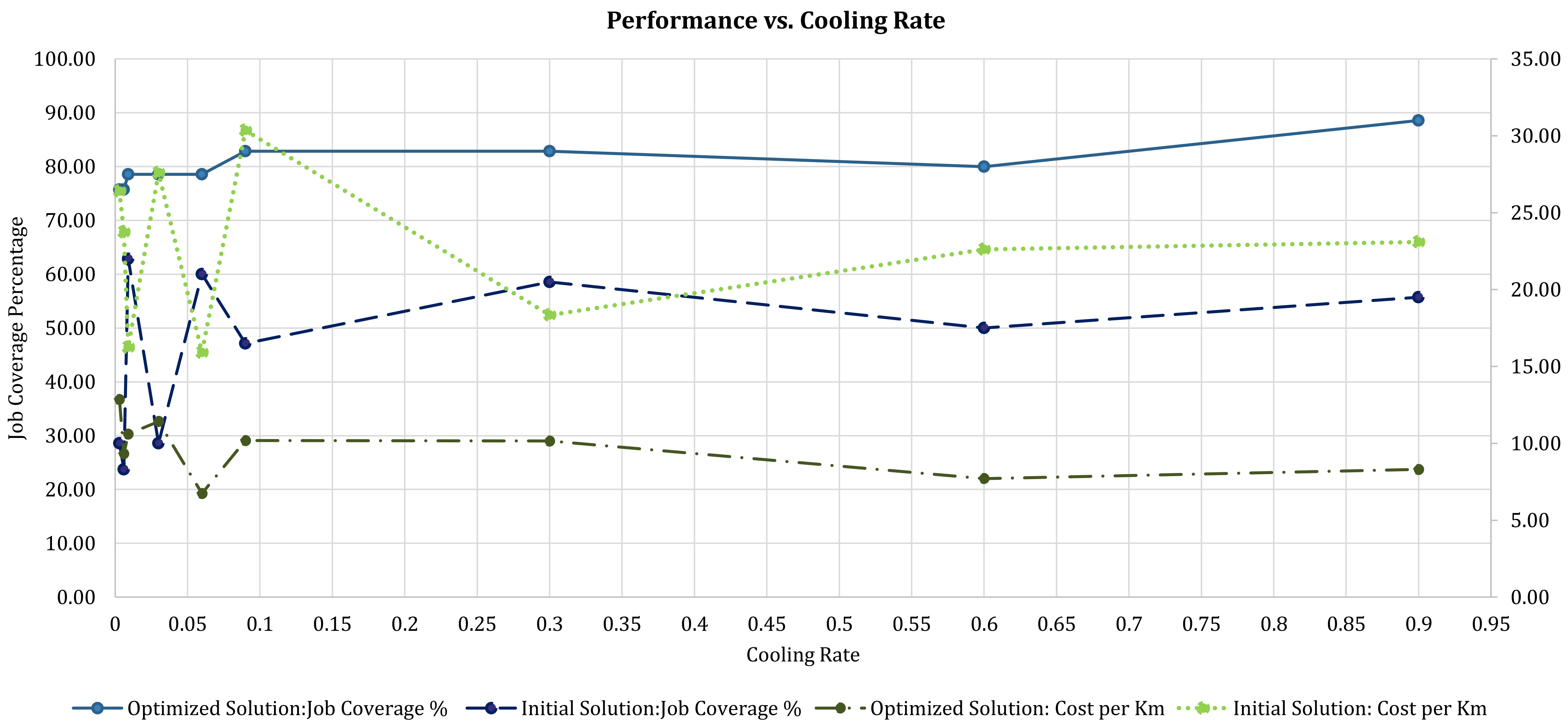
- Scheduler
  - Initial temperature :10000
  - Cooling rate:0.9
  - Terminating condition temperature <1
  - Time window: ±3H
  - Time window is the adjustment for delivery time by advancing or delaying a certain period of time

Solutions Considered

- Optimized Solution: After applying Scheduler and SA
- Initial solution
  - Enforce constraints and conditions
  - Randomly assign a truck and driver
- Genetic Algorithm based optimized solution

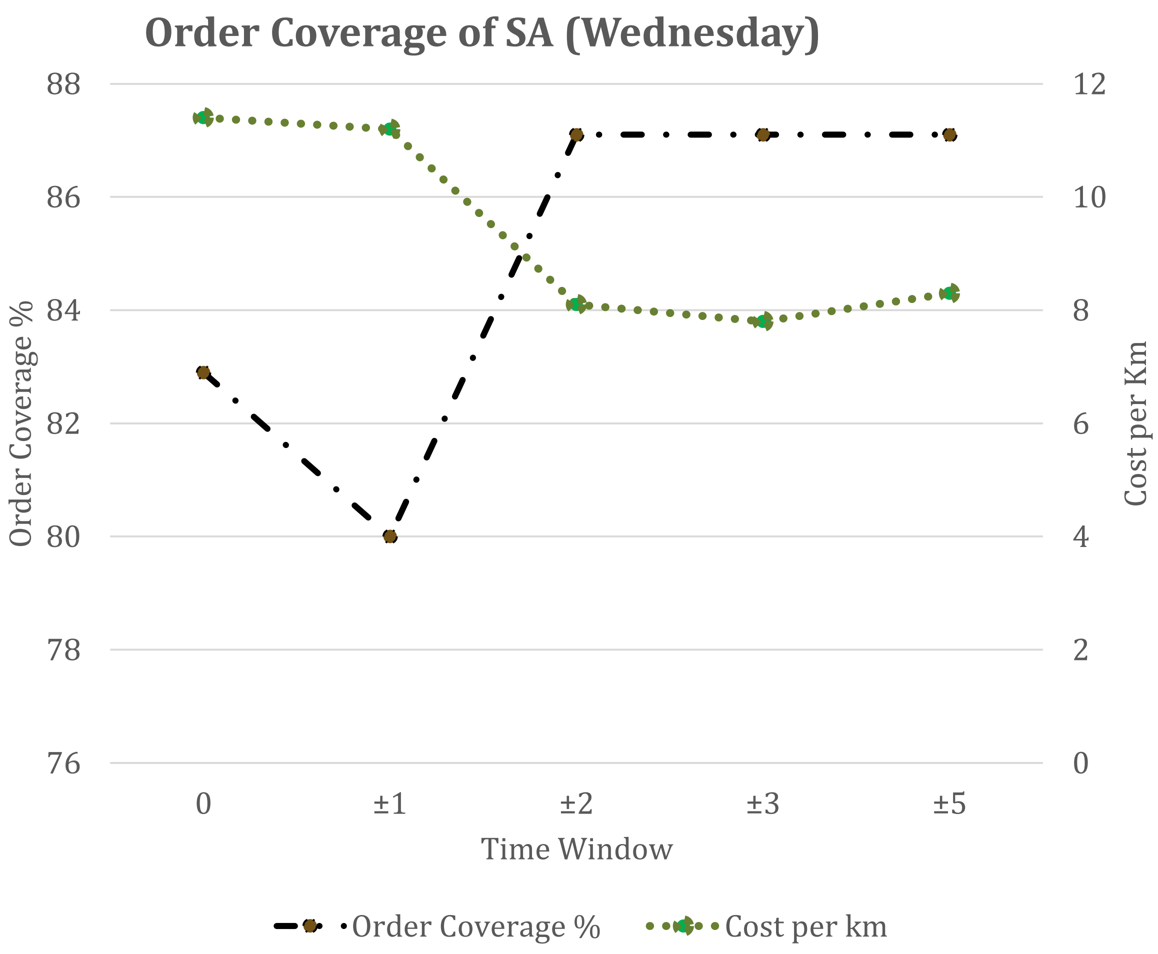
Performance Analysis

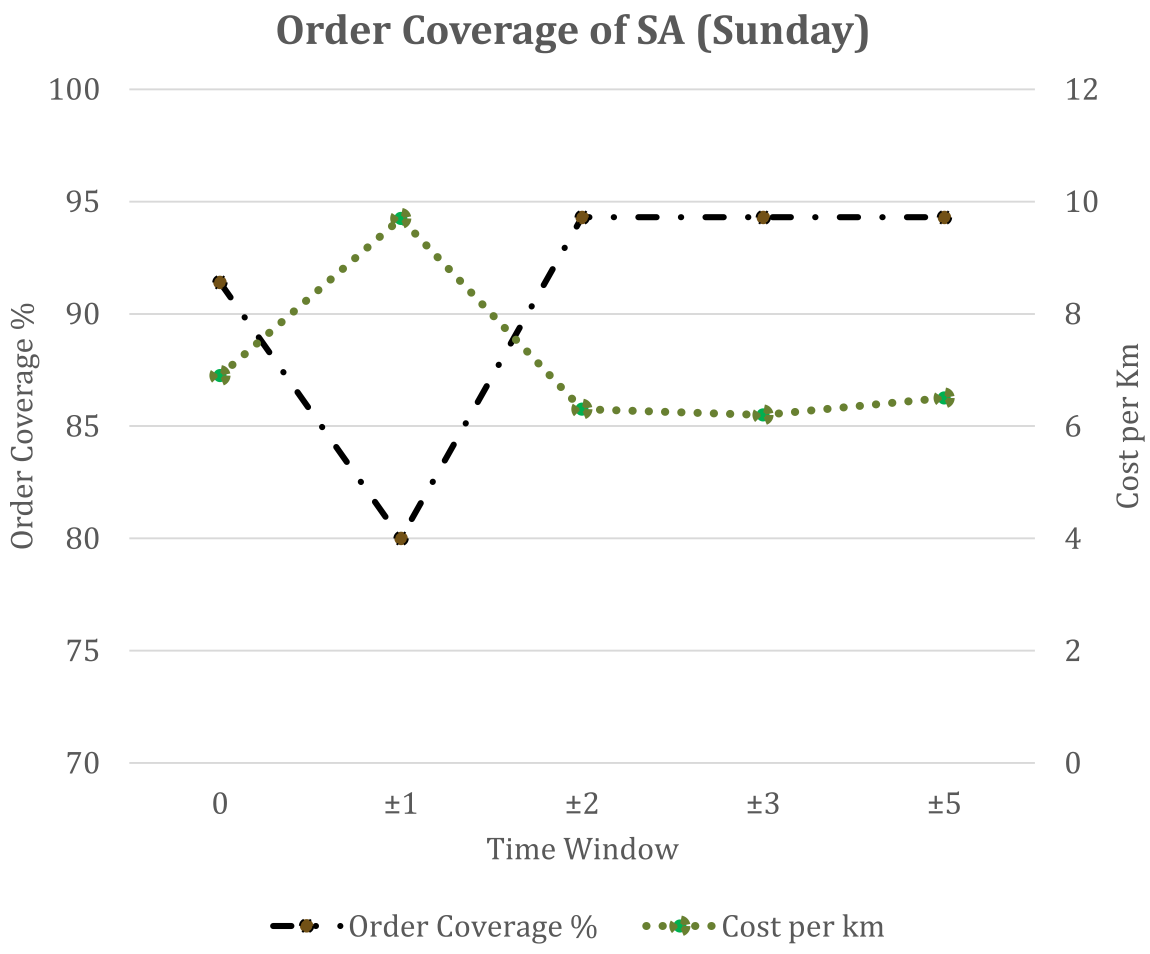
Performance vs. Cooling Rate



- Selected cooling rate : 0.9

Order Coverage with SA (Cooling Rate 0.9)



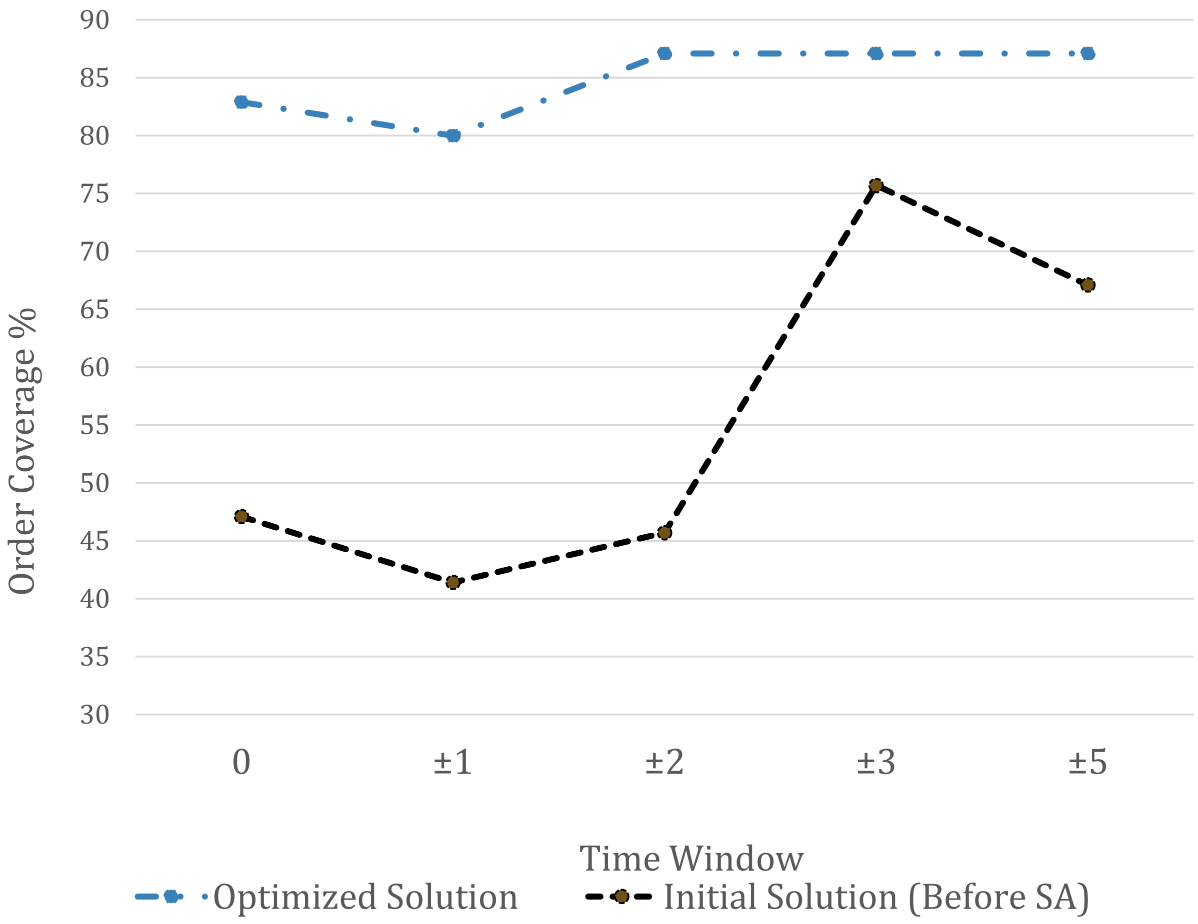


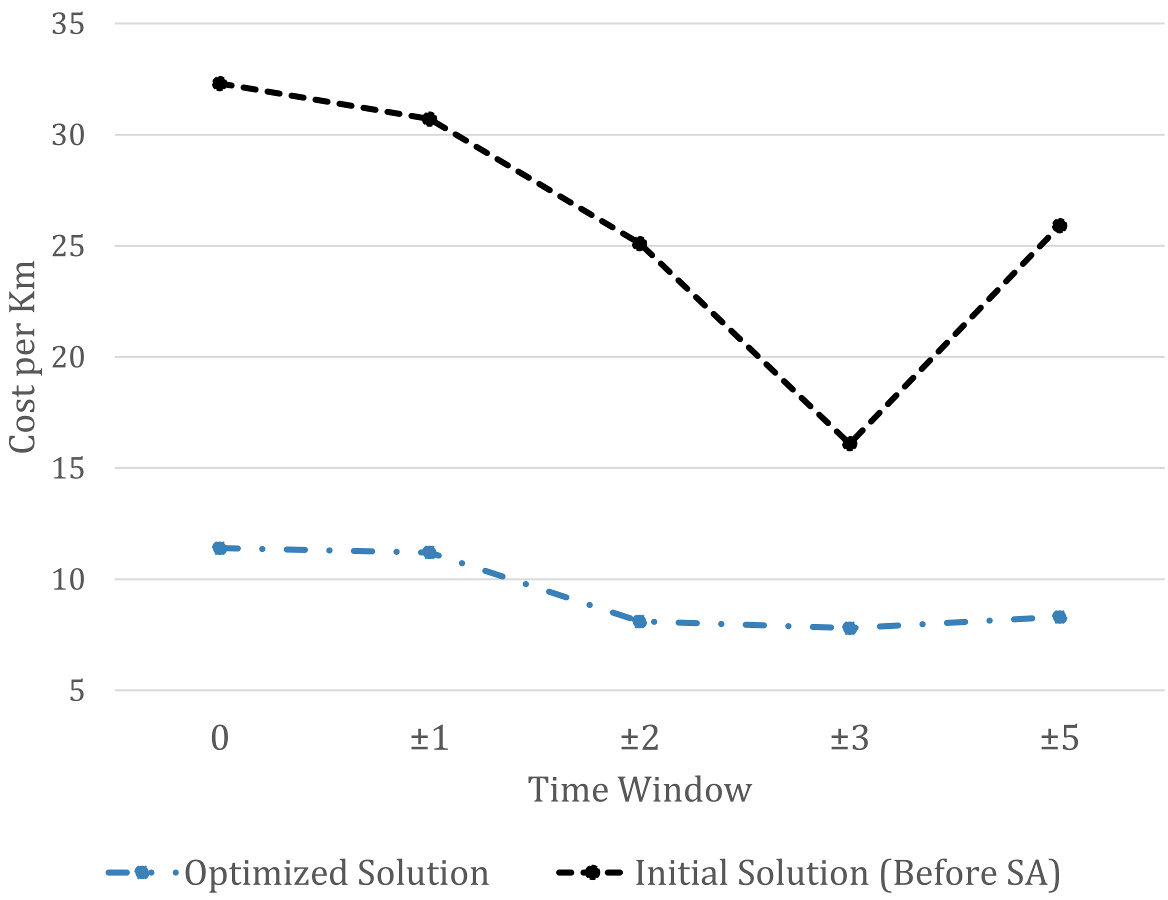
- Time window : +/- 3 with highest order coverage and lowest cost per Km

Performance on Selected Days

		Optimized Solution	Initial Solution
Wednesday	Order Coverage %	82.9	47.1
	Cost per Km	11.4	32.3
Sunday	Order Coverage %	91.4	51.4
	Cost per Km	6.9	18.2

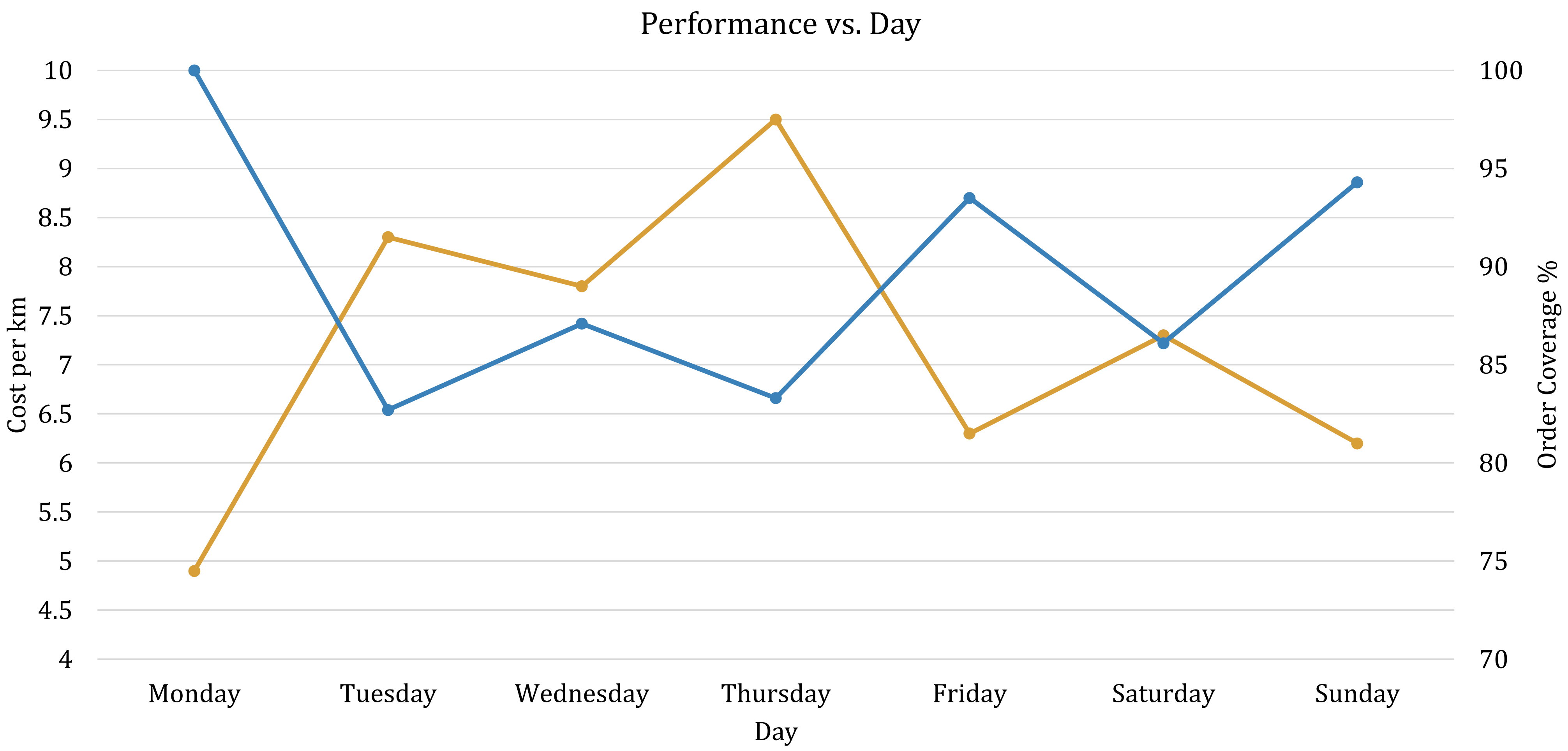
Order Coverage and Cost Comparison





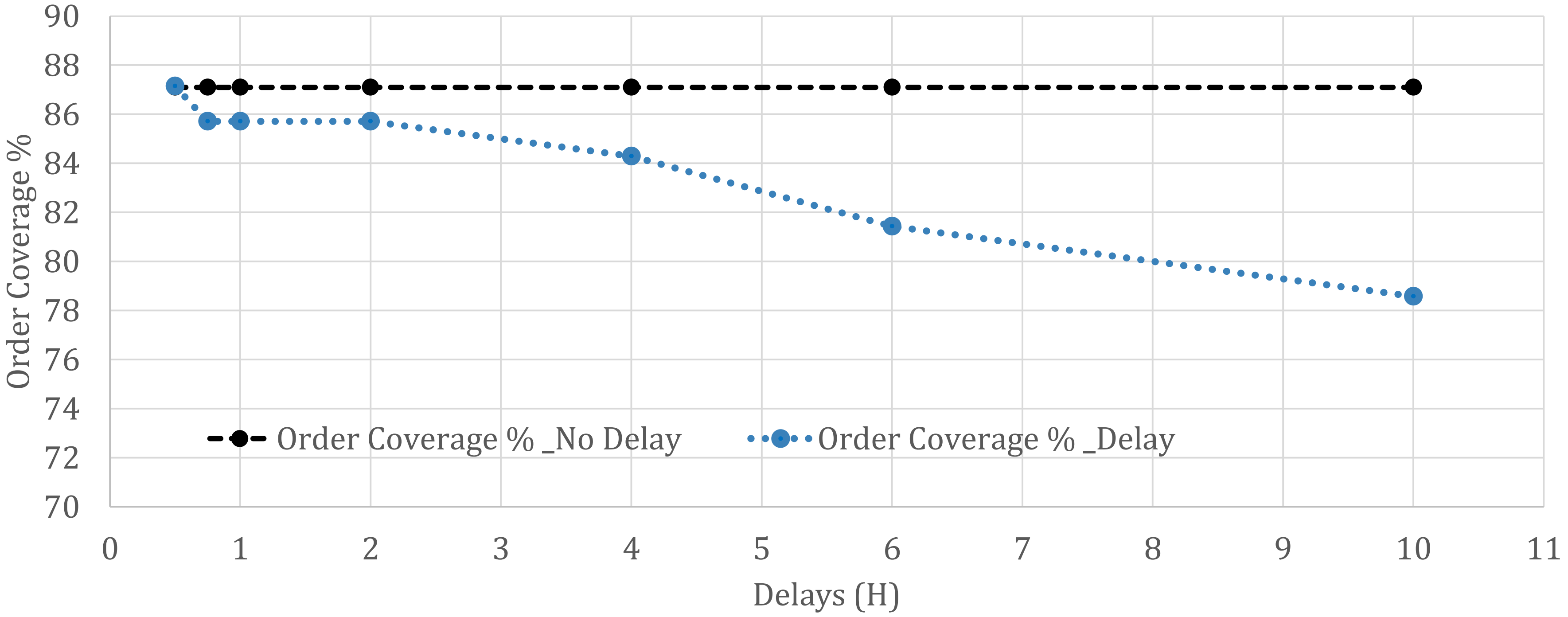
- ❑ Optimum solution: Highest Order Coverage and Lowest Cost at +/-3H

Order Coverage and Cost Throughout the Week



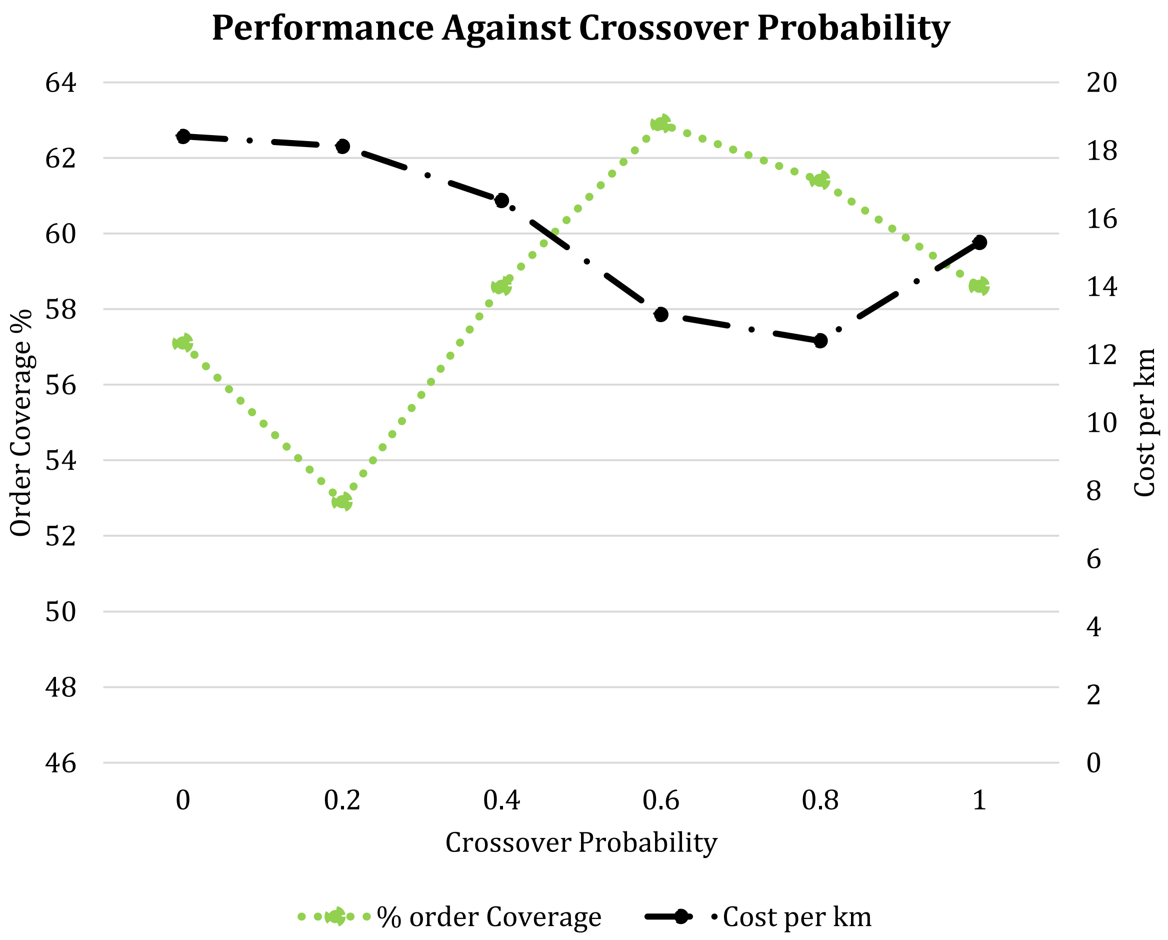
Impact of Delayed Jobs (5% Jobs Delayed)

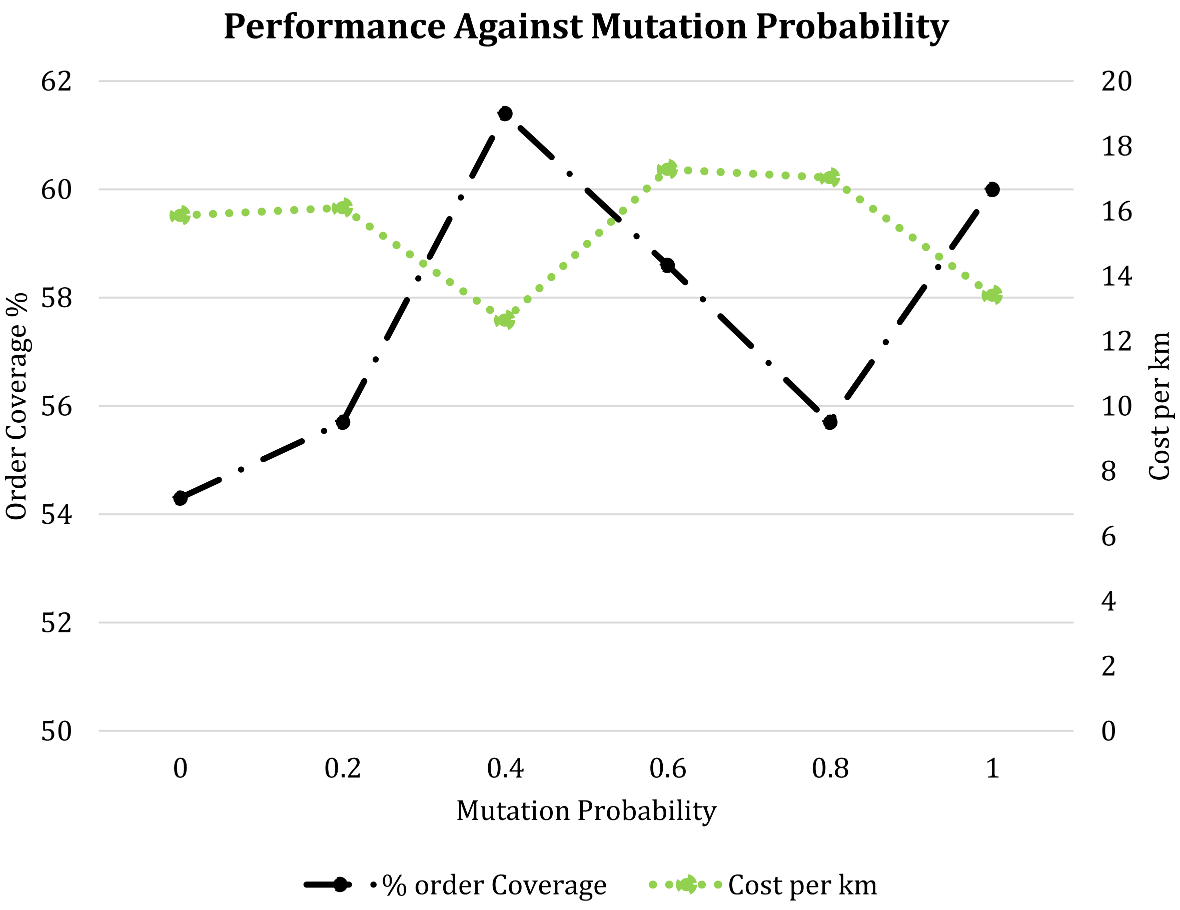
Delay (H)	0.5	0.75	1	2	4	8	10
No of Orders Affected	0	1	1	1	2	4	5
Percentage %	0	1.42	1.42	1.42	2.85	5.71	7.14



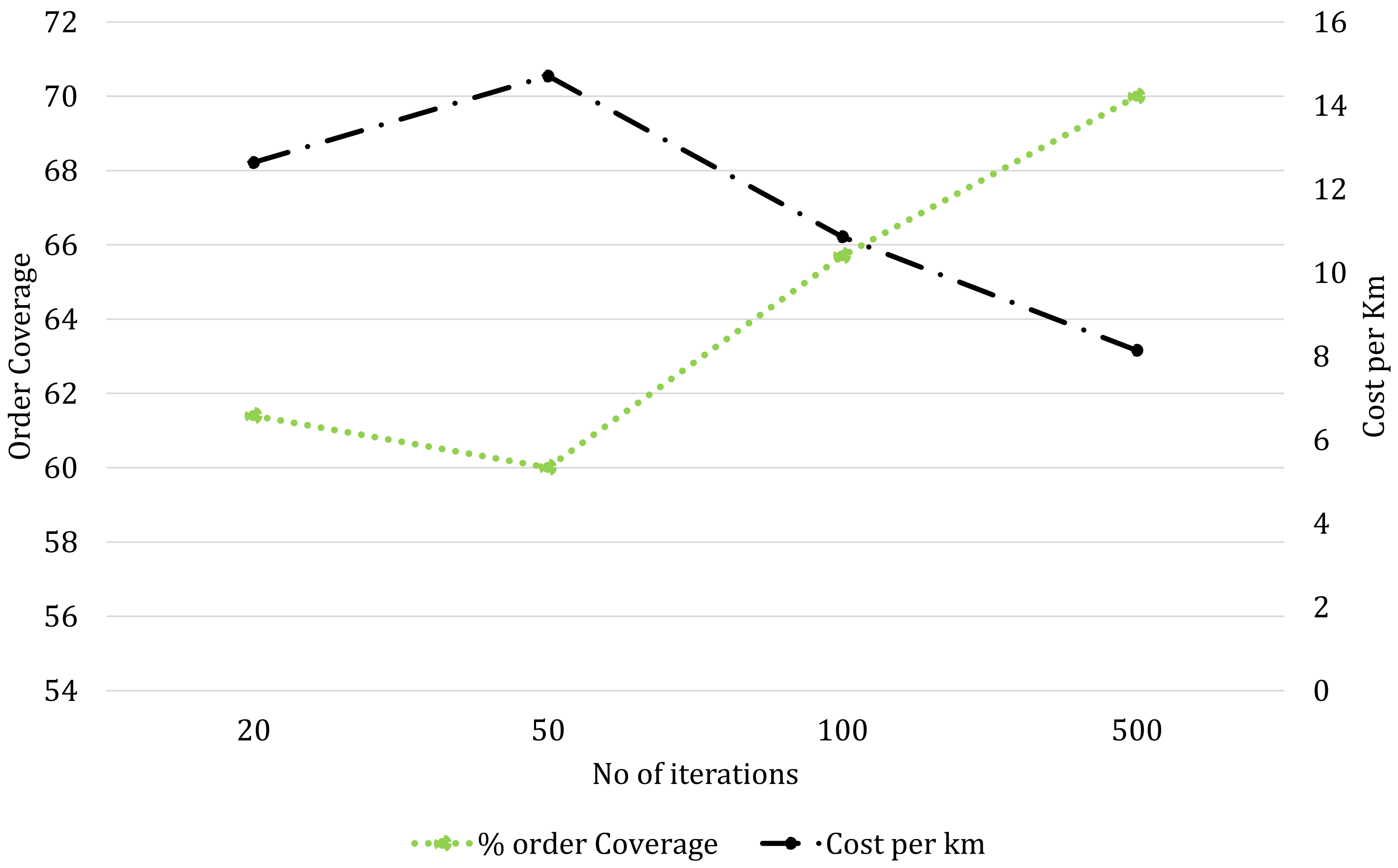
- Impact of delayed is less than 1.5%

Performance of GA with Different Parameter Values





Performance against Iteration Rate



Simulated Annealing vs. Genetic Algorithm

- Wednesday , Time window +/- 3

Algorithm	Best Performing Conditions	Order Coverage %	Cost per Km	Computation Time
Simulated Annealing	Cooling Rate : 0.9 Initial temperature : 10000 Termination condition : 1	87.1	7.8	31.87s
Genetic Algorithm	Crossover probability : 0.6 Mutation probability :0.4 No of iterations :500	70.0	8.14	1h

Summary

- Automated truck and driver scheduling while satisfying multiple constraints and objectives
- Use a rule checker and scheduler for truck and driver scheduling
- Simulation results using a workload derived from a real case study show;
  - Proposed solution can maximize order coverage and minimize cost
  - Having some flexibility in delivery time enhances both order coverage and cost
- Solution can be customized according to
  - Days of schedule , No of jobs , Time window
- Plans to improve order coverage & capture last minute delivery requests

Thank You

chami.16@cse.mrt.ac.lk

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Annex : Cooling Rate against Solutions

Cooling Rate		0.003	0.006	0.009	0.03	0.06	0.09	0.3	0.6	0.9
SA Execution Time (s)		2.38	2.30	2.45	3.82	25.21	7.12	14.22	22.64	135.22
Optimized Solution	Job Coverage %	75.71	75.71	78.57	78.57	78.57	82.86	82.86	80.00	88.57
	Cost per km	12.85	9.32	10.60	11.42	6.74	10.18	10.15	7.71	8.30
Initial Solution(Before SA)	Job Coverage %	28.57	50.00	62.86	28.57	60.00	47.14	58.57	50.00	55.71
	Cost per km	26.40	23.74	16.24	27.61	15.91	30.36	18.35	22.61	23.10
Manual Solution	Job Coverage %	41.43	41.43	41.43	41.43	41.43	41.43	41.43	41.43	41.43
	Cost per km	24.26	24.26	24.26	24.26	24.26	24.26	24.26	24.26	24.26