Optimization of Truck and Driver Scheduling Using Simulated Annealing

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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

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

<table>
<thead>
<tr>
<th>1. Truck Availability Constraint</th>
<th>$\forall v \in V; v^t_{\text{status}} \neq \text{ON_LEAVE} \rightarrow v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Driver Availability Constraint</td>
<td>$\forall d \in D; d^t_{\text{status}} \neq \text{ON_LEAVE} \rightarrow d$</td>
</tr>
</tbody>
</table>
| 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:  
  $o_{\text{Early_Start_Time}} < t_1 < o_{\text{Late_Start_Time}} \cap o^v_{\text{Early_End_Time}} < t_2 < o^v_{\text{Late_End_Time}}$ |
| 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:  
  $o_{\text{Early_Start_Time}} < t_1 < o_{\text{Late_Start_Time}} \cap o^d_{\text{Early_End_Time}} < t_2 < o^d_{\text{Late_End_Time}}$ |
### Constraints and Conditions (Cont.)

<table>
<thead>
<tr>
<th>5. Working hour constraint</th>
<th>( d_{\text{cum_working_time}}^{\text{day}} &lt; d_{\text{max_working_time}}^{\text{day}} )</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>6. Resting hour conditions</th>
<th>rest((i, j))</th>
</tr>
</thead>
</table>
|                            | \( = \begin{cases} 
15\text{mts,} & t(i, j) \leq 270\text{mts} \\ 
(t(i, j) \times 0.4872 - 101.544), & 270\text{mts} < t(i, j) < 1440\text{mts} \\ 
600\text{mts,} & t(i, j) \geq 1440\text{mts} 
\end{cases} \) |
Objectives

❑ Primary Objective
  □ Deliver as many orders as possible in right time with right quality

❑ Secondary Objective
  □ $\text{Min } \sum_{o \in O, v \in V} (c_{v,d}^o)$
  □ Where:
    ■ $c_{v,d}^o = c_{\text{travel}} + c_{\text{driver}} + c_{\text{vehicle}}$
    ■ $c_{\text{travel}} = \left( (v_{\text{ave mileage}}^{\text{with load}} \times \text{dist}(i,j)) + (v_{\text{ave mileage}}^{\text{no load}} \times \text{dist}(i,j)) \right) \times \text{fuel up}$
    ■ $c_{\text{driver}} = d_{\text{hourly rate}}^{t} \times d_{\text{travel time}}$
    ■ $c_{\text{vehicle}} = x \times \text{dist}(i,j)$
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 : Initial Solution

Scheduler

Rule Checker – Neighborhood Solutions

Simulated Annealing
Rule Checker
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”

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)

<table>
<thead>
<tr>
<th>Day</th>
<th>No of Orders</th>
<th>No of Available Trucks</th>
<th>No of Available Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>38</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>Tuesday</td>
<td>52</td>
<td>19</td>
<td>33</td>
</tr>
<tr>
<td>Wednesday</td>
<td>70</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>Thursday</td>
<td>60</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>Friday</td>
<td>46</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>Saturday</td>
<td>43</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>Sunday</td>
<td>35</td>
<td>13</td>
<td>28</td>
</tr>
</tbody>
</table>
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)

Order Coverage of SA (Wednesday)

Order Coverage of SA (Sunday)

Time window: +/- 3 with highest order coverage and lowest cost per Km
## Performance on Selected Days

<table>
<thead>
<tr>
<th></th>
<th>Optimized Solution</th>
<th>Initial Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wednesday</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Coverage %</td>
<td>82.9</td>
<td>47.1</td>
</tr>
<tr>
<td>Cost per Km</td>
<td>11.4</td>
<td>32.3</td>
</tr>
<tr>
<td><strong>Sunday</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Coverage %</td>
<td>91.4</td>
<td>51.4</td>
</tr>
<tr>
<td>Cost per Km</td>
<td>6.9</td>
<td>18.2</td>
</tr>
</tbody>
</table>
Optimum solution: Highest Order Coverage and Lowest Cost at +/-3H
Performance vs. Day

Order Coverage and Cost Throughout the Week

![Graph showing order coverage and cost per km throughout the week. Monday has the highest order coverage (%), followed by Thursday and Friday. Cost per km is lowest on Monday and highest on Wednesday. Saturday has the highest cost per km, while Tuesday has the lowest.](image-url)
Impact of Delayed Jobs (5% Jobs Delayed)

<table>
<thead>
<tr>
<th>Delay (H)</th>
<th>0.5</th>
<th>0.75</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Orders Affected</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Percentage %</td>
<td>0</td>
<td>1.42</td>
<td>1.42</td>
<td>1.42</td>
<td>2.85</td>
<td>5.71</td>
<td>7.14</td>
</tr>
</tbody>
</table>

Impact of delayed is less than 1.5%
Performance of GA with Different Parameter Values

Performance Against Crossover Probability

Performance Against Mutation Probability
Performance against Iteration Rate

![Graph showing relationship between number of iterations, order coverage, and cost per km.](image-url)
Simulated Annealing vs. Genetic Algorithm

- **Wednesday**, Time window +/- 3

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Best Performing Conditions</th>
<th>Order Coverage %</th>
<th>Cost per Km</th>
<th>Computation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Annealing</td>
<td>Cooling Rate : 0.9 &lt;br&gt; Initial temperature : 10000 &lt;br&gt; Termination condition : 1</td>
<td>87.1</td>
<td>7.8</td>
<td>31.87s</td>
</tr>
<tr>
<td>Genetic Algorithm</td>
<td>Crossover probability : 0.6 &lt;br&gt; Mutation probability : 0.4 &lt;br&gt; No of iterations : 500</td>
<td>70.0</td>
<td>8.14</td>
<td>1h</td>
</tr>
</tbody>
</table>
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

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- Acknowledgement
  - Nimbus Venture (Pvt) Ltd.
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## Annex: Cooling Rate against Solutions

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