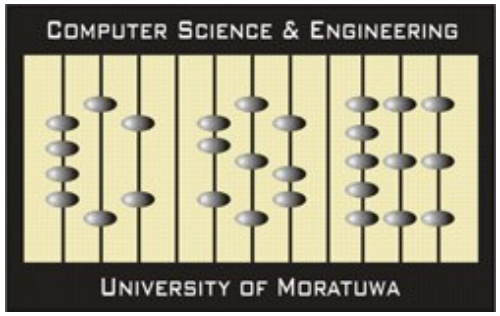

Automated Multi-Plant Scheduling of Ready-Mixed Concrete Trucks

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Research Contribution

- Ready-Mixed Concrete (RMC) truck scheduling is mainly handled manually by experienced batching plant staff.
- Significant cost savings can be achieved by automating the scheduling process of RMC trucks.
- Developed a model to optimize scheduling of RMC trucks using a Rule Checker and Simulated Annealing.
- Proposed solution could assign jobs to plants and trucks while maximizing both the job coverage and profit up to 21% and 13%

Background

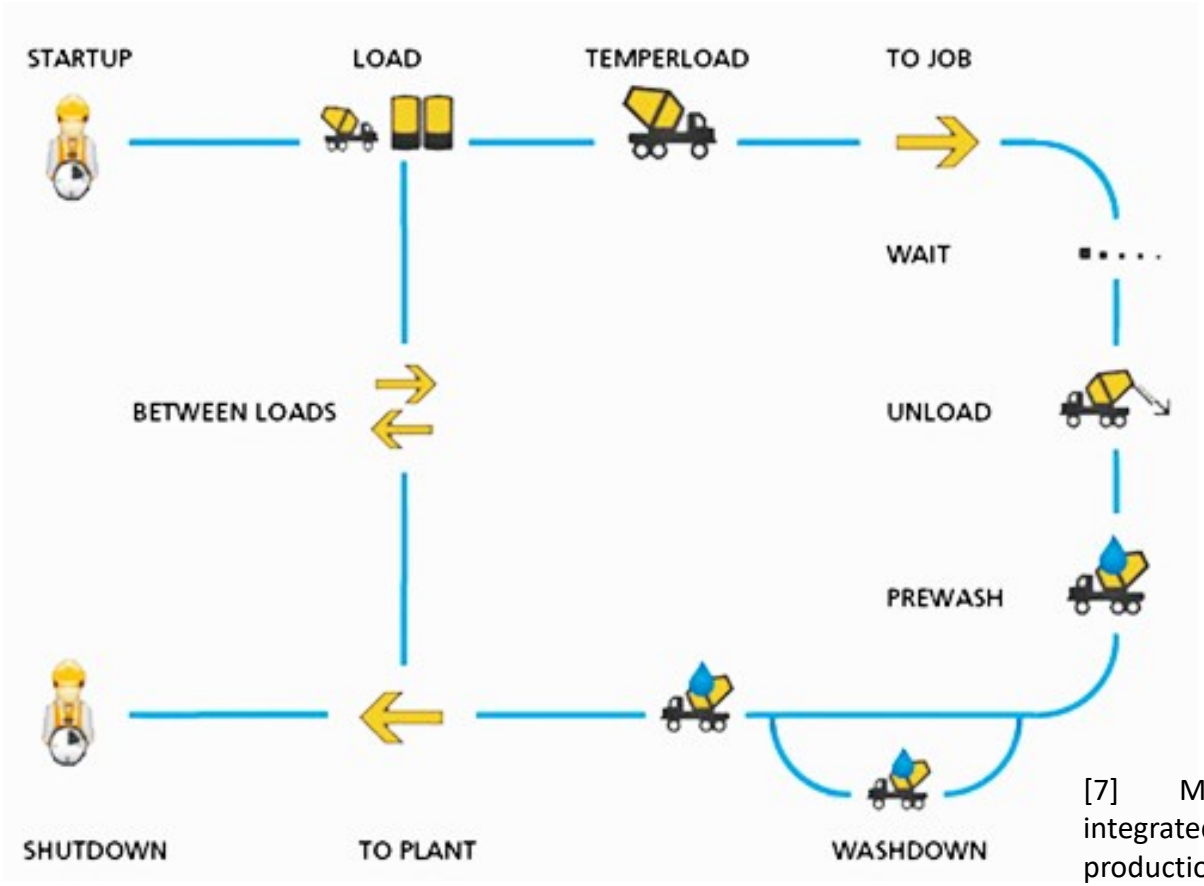
About 5% of all concrete transported via RMC trucks is returned to plant [8]

- Some returned as concrete **doesn't meet specifications [8]**
- Others are returned, as they are not delivered **within 1.5 hours** as per ASTM C-94 specification for RMC [8]
- Scheduling practices, route selection, and driver behavior lead to delayed delivery and operational inefficiencies.

Vehicular data analytics can be used to reduce wastages and develop an optimized schedule and route plan for fleet

[8] F.-P. Corporation, "Savings & Applications Guide for Ready-Mixed Concrete : How to Use Fritz-Pak Products to Maximize Profits," p. 16, 2009.

RMC Delivery Process



Source: http://www.euroasia-hk.com/product/solutions/fleet-management-2/

- **ASTM C94 (ASTM 2000) specification** allows a maximum of 1.5 hours, or before drum has made 300 revolutions, whichever comes first. [7]

[7] M. Lu and H. C. Lam, "Simulation-optimization integrated approach to planning ready mixed concrete production and delivery: Validation and applications," *Proc. - Winter Simul. Conf.*, no. 1, pp. 2593–2604, 2009.

Related Work

- RMC scheduling is mostly handled by experts.

Summary of affective parameters in RMC

Specification of each order	Travel of truck(s)	Batch plant
Distance to batches	Travel time	Number of available trucks
Required amount of concrete	Unloading time	Capacity of available trucks
Spacing time between trucks	Return time	Available raw materials
Properties of required concrete	Location of project	Maximum production capacity
Time of first unload	Drivers' break times	Total number of assigned jobs

- **Genetic Algorithm** is proposed to solve the model.
  - Chromosomes consist of sequences of construction sites and vehicle orders and IDs.
- Considered only **Single Plant and Mixer.**
- Future work could focus on more complex problem of multiple plants, mixers, construction sites.

[1] M. Maghrebi, T. Waller, and C. Sammut, "Automation in Construction Matching experts decisions in concrete delivery dispatching centers by ensemble learning algorithms : Tactical level," *Autom. Constr.*, vol. 68, pp. 146–155, 2016.

[2] Maghrebi Mojtaba, Claude Sammut, and S. Travis Waller, "Feasibility Study of Automatically Performing the Concrete Delivery Dispatching Through Machine Learning Techniques," *Eng. Constr. Archit. Manag.*, vol. 22, no. 5, pp. 573–590, 2015.

Related Work (Cont…)

[4] Z. Liu, Y. Zhang, and M. Li, "Integrated scheduling of ready-mixed concrete production and delivery," *Autom. Constr.*, vol. 48, pp. 31–43, 2014.

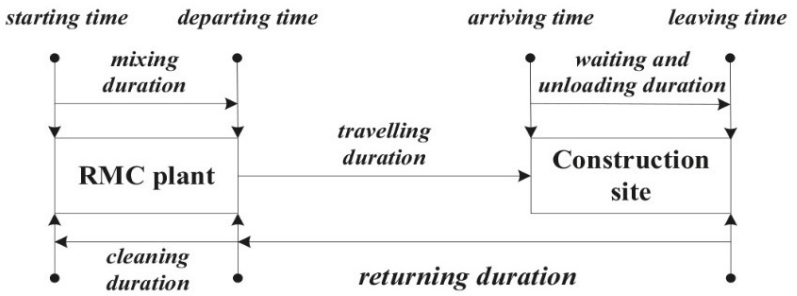


Fig. 4. Time flow of a truck.

- Approach is evaluated by simulation of real cases.
- **Sensitivity analysis** reveals effects of fleet size of available vehicle, cost rates, and time windows of construction sites.

Table 14
Results of simulations with different beginning times for construction sites.

	CS1	CS2	CS3	CS4	CS5	CS6	CS7	TT (min)	PT (min)	Total cost
Original time window	8:30	8:40	9:30	10:40	11:20	10:00	15:10	1138	46.5	1151.95
New time window	8:30	8:45	9:25	10:40	11:20	10:05	15:10	1138	45.5	1151.65
Change	0	+5	+5	0	0	+5	0	0	−1	−0.3

Motivation

- Distribute RMC from plants to sites.
- When an order is placed, assign plant and truck to deliver order while considering:
  - Order: Location, Time of unload.
  - Vehicle: Availability, Fuel Consumption, Operating hours.
  - External factors: Fuel unit price, Maintenance factor, traffic.
- Need to optimize the process → Maximize the Profit while reducing costs and Increase Job Coverage.

Problem Statement

Cover set of all jobs **J** with plants **P** and trucks **T**, such that profit is maximized across all the jobs.

Characteristics of Problem

Attribute	Characteristic of the Problem
Number of Plants	Multiple
Size of Available Fleet	Multiple
Type of Available Fleet	Homogeneous
Capacity of Available Fleet	Homogeneous
Nature of Demand	Pre-defined Delivery Time
Location of Demand	Known (Geographically Dispersed)
Costs	Vehicle Operating Cost, Waiting Cost

Objective

To cover set of all jobs **J** with plants **P** and trucks **T**, such that profit is maximized across all the jobs.

$$\forall j_{id} \in \mathrm{J}, \forall p_{id} \in \mathrm{P}, \mathrm{Max}\ (|j \text{ with assigned } p|)$$

$$Max \sum_{\substack{j \in \mathbf{J} \\ p \in \mathbf{P}}} (f_j - c_j)$$

Where;

$c_j = (c_{travel} + c_{waiting}) \times c_{liter}$

- $c_{travel} = (((j^{haul}_{distance} / t^{load}_{fuel\_cons}) \times e_{peak} / e_{off\_peak}) + ((j^{return}_{distance} / t^{no\_load}_{fuel\_cons}) \times e_{peak} / e_{off\_peak})) \times t_{maintenance}$
- $c_{waiting} = ((t^{unload}_{wait\_time} + t_{wash\_down}) / t^{idling}_{fuel\_cons}) \times t_{maintenance}$

$f_j = j_{total\_distance} \times c_{unit\_distance}$

- $j_{total\_distance} = j_{num\_truckloads} \times (j^{haul}_{distance} + j^{return}_{distance})$
- $|j_{num\_truckloads}| = \frac{j_{volume}}{t_{volume}}$

Constraints

Time restriction on delivery (r_{time}) as per ASTM C94 specification depends on properties of concrete.

- Varies according to special properties added to concrete during mixing stage.

Time Constraint for a truck *t*

$$\forall\ t_{id},\ p_{load\_time} + t_{haul\_time} + t_{unload\_time} \leq r_{time}$$

Range Constraint for a plant *p* can be defined as follows:

$$p_{range} = e_{speed\_max} \times r_{time}$$

Constraints (Cont…)

Job Area Constraint

$$j^{haul}_{distance} \leq p_{range}$$

Job Duration Constraint

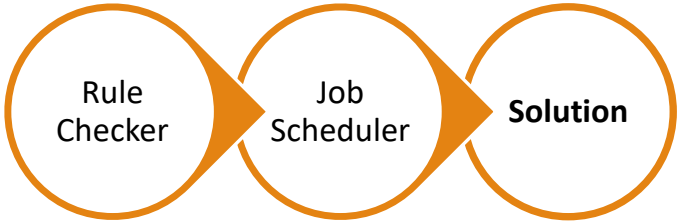
$$j^{i}_{job\_duration} \neq j^{j}_{job\_duration}, \forall^{i} \neq j$$

Travel Time Constraint per truck

$$\left(\sum_{i=1}^{n-1}\left(t^{i}_{haul\_time} + t^{i}_{return\_time}\right)\right) + \left(t^{j}_{haul\_time} + t^{j}_{return\_time}\right) \leq t^{\max\_day}_{time}$$

Proposed Solution

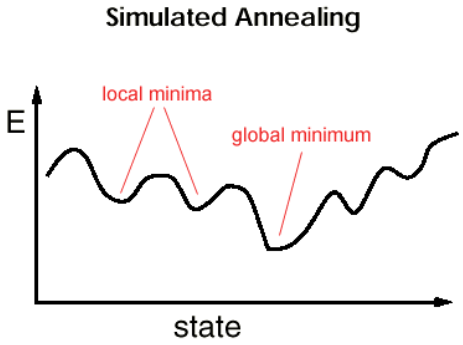
- Next day's schedule determined based on the already confirmed jobs and available plants and trucks.



- Solution consists of a rule checker that enforces constraints.
  - Reduces the search space for the job scheduler.
- Job Scheduler uses Simulated Annealing algorithm to find the optimal solution.
  - Optimization phase attempts maximize the job coverage as well as the overall profit.
- Analysis based on a workload derived from a real RMC company.
- Eliminates error-prone and labor-intensive resource allocation.

Simulated Annealing (SA)

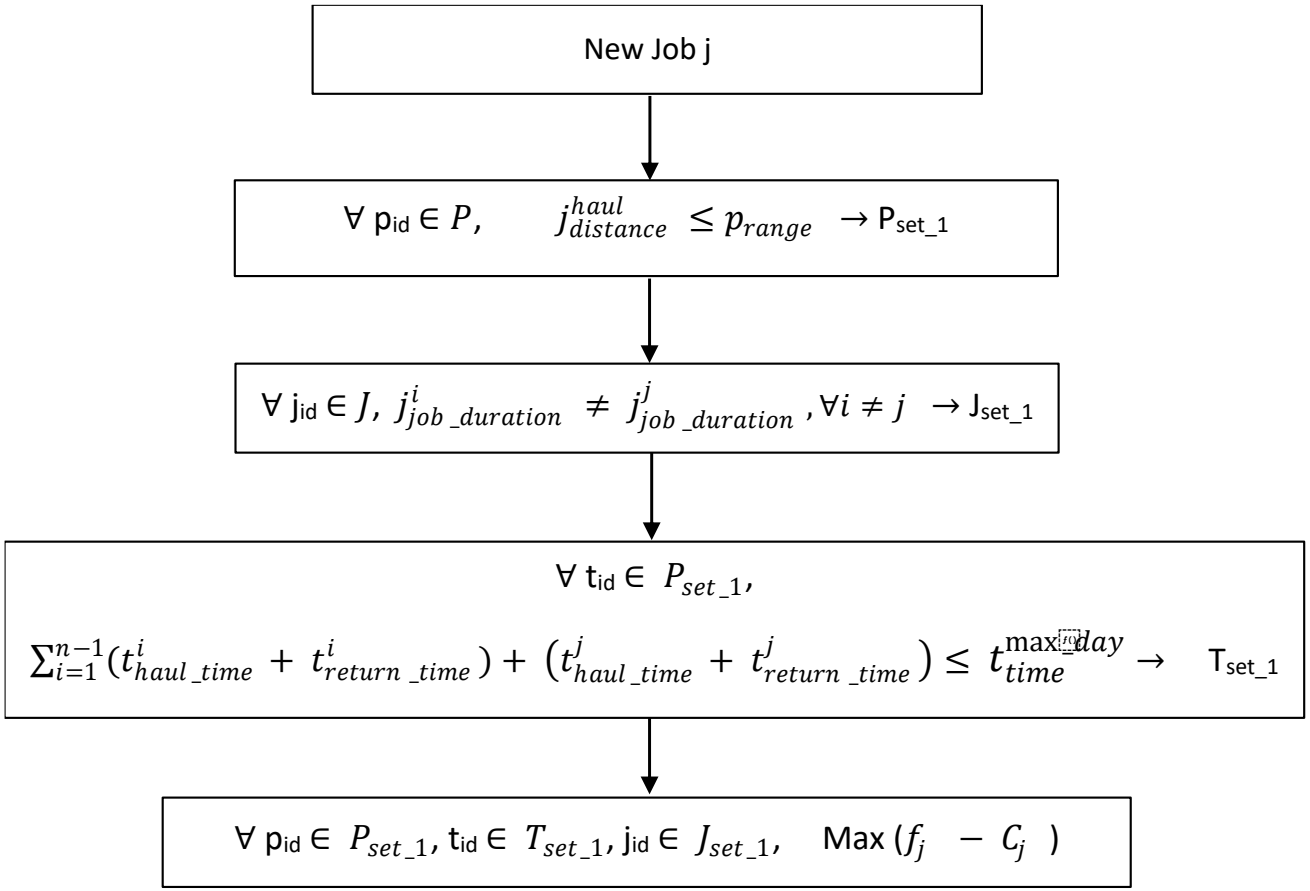
- Probabilistic technique for approximating global optimum of given function.
  - Powerful in solving complex combinatorial proble
  - Ability to customize algorithm.
  - Not depend on model constraints.
  - Very short computational time.
- SA had the highest accuracy [3].

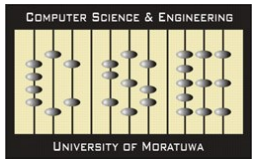


Search Algorithm of Bayesian Network	Accuracy
Simulated Annealing (SA)	80.73
Genetic Algorithm (GA)	77.04
Hill Climbing(HC)	77.65
K2	80.24
Look Ahead Hill Climbing (LAGD)	76.97
Repeated Hill Climbing (RHC)	78.33
Tabu Search (TS)	79.46

[3] M. Maghrebi and S. Travis Waller, "Exploring Experts Decisions in Concrete Delivery Dispatching Systems Using Bayesian Network Learning Techniques," *Proc. - 2nd Int. Conf. Artif. Intell. Model. Simulation, AIMS 2014*, pp. 103–108, 2014.

Rule Checker





Initial Configuration

Job Scheduler

- Initial temperature : 10000
- Cooling rate: 0.003
- Terminating condition

  temperature <1
- Buffer Time: ±5 Minutes
  - Buffer Time is the adjustment for the unload time

Objective Function

- r_{time} = 90 minutes
  - Assuming that no special property is added to the concrete
- e_{speed_max} = 30 kmh^{-1}
  - As per the Government Regulations for Special Purpose Vehicles
- $t_{maintenance}$ = 1.1

Cooling Rate and Initial Temperature was selected based on comparing the results of different initial temperatures and cooling rates by eliminating the sub optimal solutions

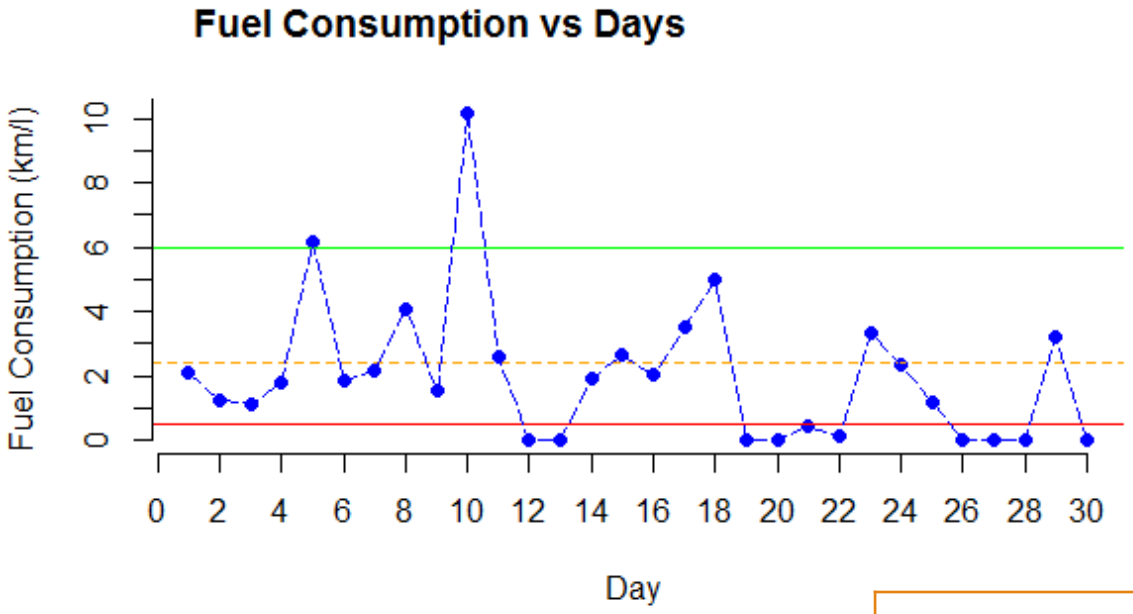
Four Solutions

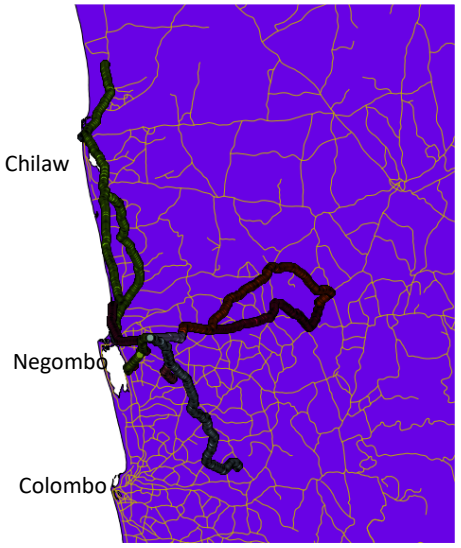
COMPARISON

Manual Solution	Solution 1	Solution 2	Solution 3
	Fixed Plant	**Fixed Plant with Time Window**	**Free to Move**
Job to plant/truck allocation basis	Job to plant/truck allocation basis	Job to plant/truck allocation basis	Trip to truck allocation basis
Sort jobs according to First Unload Time in ascending order	Enforce constraints and conditions	"Time of first unload" is adjusted with time windows to eliminate the job duration clashes	Enforce constraints and conditions with **enhanced search space**
Select plant which makes maximum profit for given job and assign to the plant	Assign a job to plant/trucks randomly	Same conditions and steps followed as same as "Fixed Plant" solution	Randomly assign a trip to truck
Eliminate the overlapping jobs	Job will be completely served by the assigned plant		Truck is allowed to move freely to another plant after completing a job
Repeat the process for all jobs while eliminating overlapping jobs at each step	Assigned plant will be available for another job only after completing the assigned job		Single job is served by multiple plants


Performance
Analysis

Truck Profile





Trip Plot

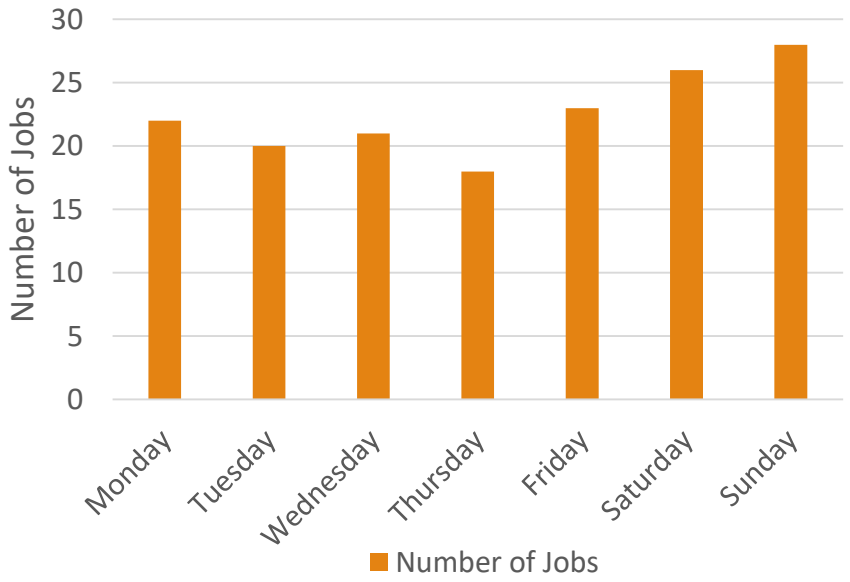
Some trucks with Capacitive Fuel sensors

Fuel Consumption includes, Idling at plant (after loading) + Trip (One-way and Return) + Idling at site (before unloading)

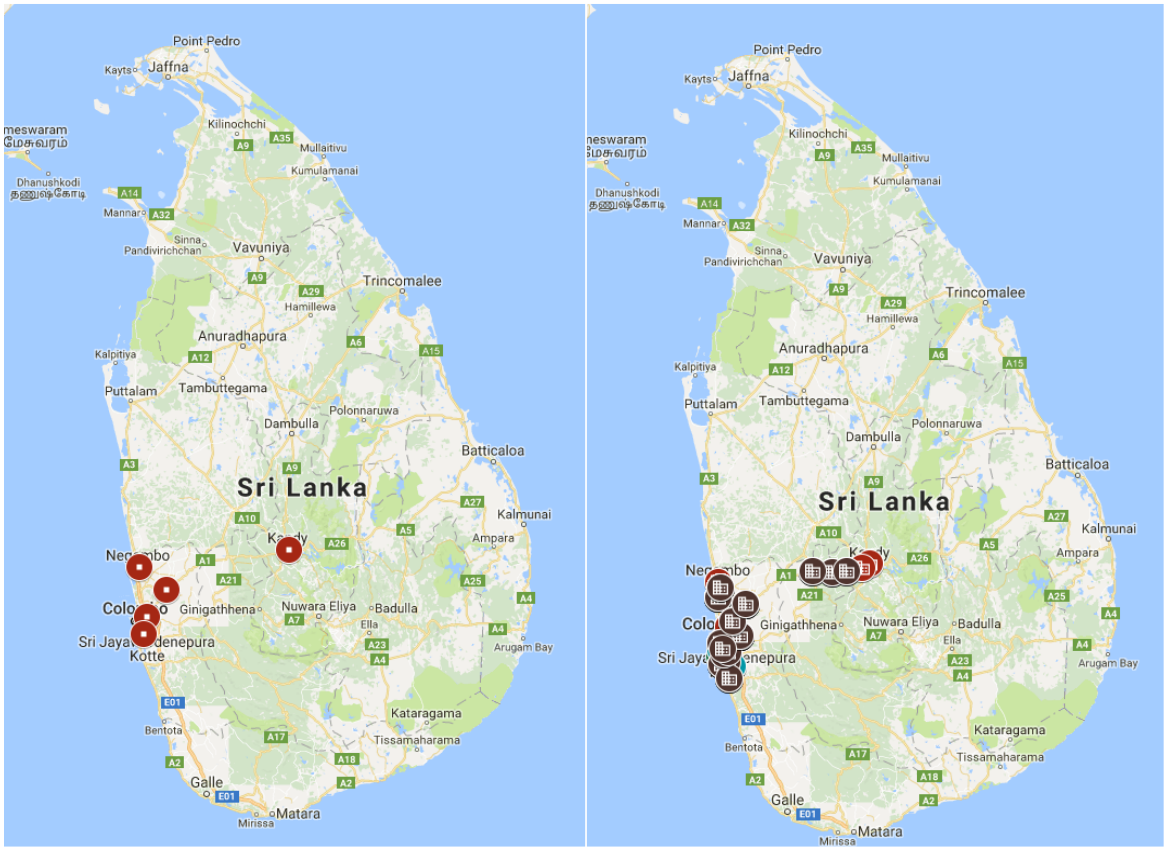
Total Distance Travelled	**3110 km**
Total Fuel Usage	1573 liters
Average Fuel Consumption (Per Day)	2.42 km/l
# of Inactive Days	8 Days

Dataset | Workload Creation

Day of the Week	Number of Jobs	Number of Available Trucks	Number of Trips
Monday	22	47	104
Tuesday	20	47	91
Wednesday	21	47	104
Thursday	18	47	90
Friday	23	47	105
Saturday	26	47	116
Sunday	28	47	125
Total	**158**		**735**



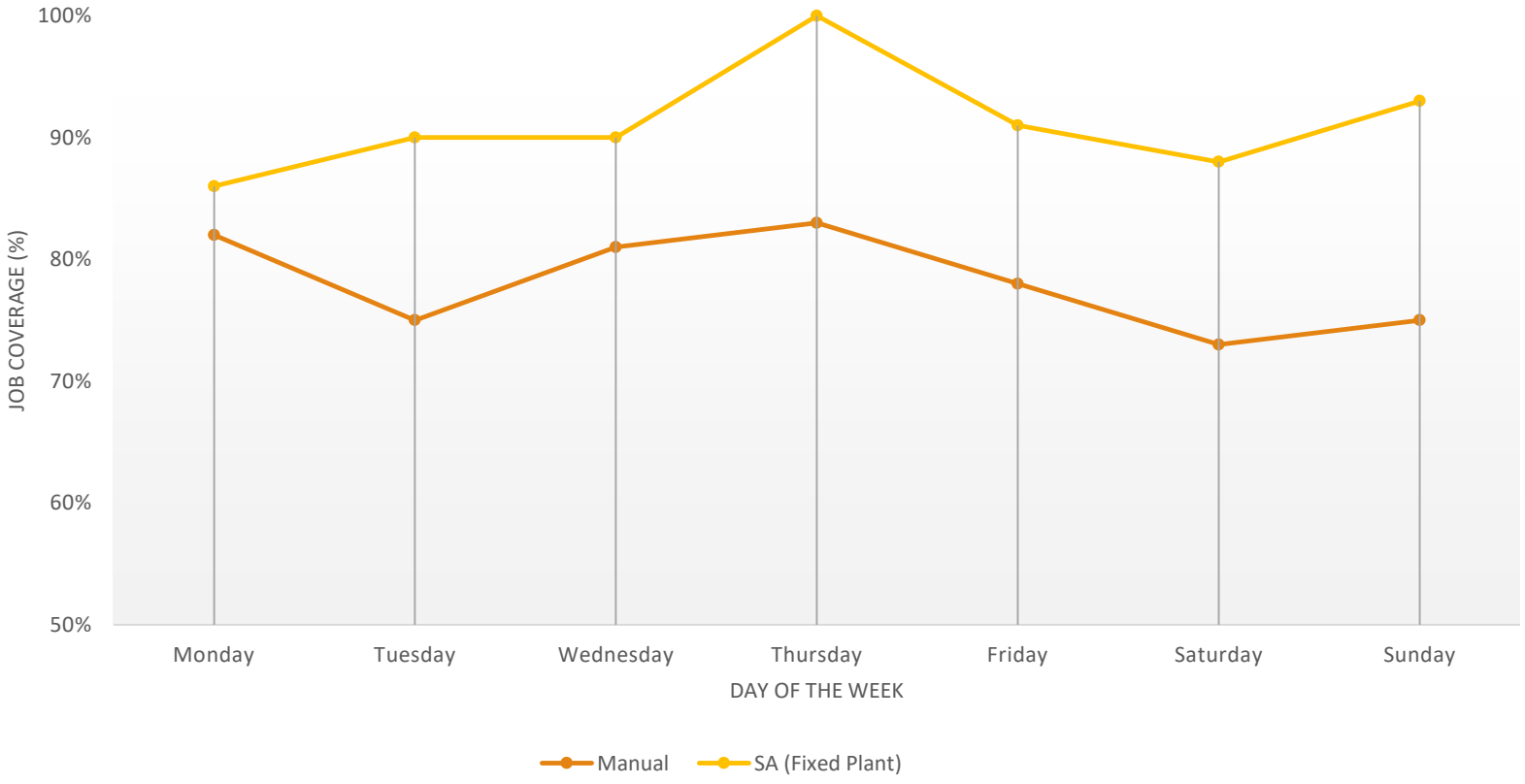
Distribution of Plant and Job Locations



Batching Plants

Jobs

Manual vs. Proposed Job Scheduling Performance (Fixed Plant Only)



Manual vs. Proposed Job Scheduling Performance
(Fixed Plant Only)

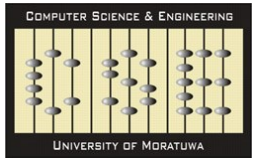
Day of the Week	Manual Job Scheduling		Proposed Job Scheduler	
			Fixed Plant	
	Profit (x10)	Job Coverage	Profit (x10)	Job Coverage
Monday	721	82%	791	86%
Tuesday	729	75%	754	90%
Wednesday	736	81%	736	90%
Thursday	567	83%	685	100%
Friday	881	78%	885	91%
Saturday	803	73%	924	88%
Sunday	910	75%	1034	93%

Results from Proposed Job allocation

With a Varying Time Window

- As jobs have buffer time and flexibility in adjusting time of first unload

Time Window (Min)	0	±15	±30	±45	±60
Monday					
Job Coverage	86%	91%	86%	91%	95%
Profit (x10)	791	830	808	814	864
Tuesday					
Job Coverage	90%	100%	95%	100%	100%
Profit (x10)	754	721	744	717	865
Wednesday					
Job Coverage	90%	100%	90%	90%	90%
Profit (x10)	736	750	724	765	733
Thursday					
Job Coverage	100%	94%	100%	89%	94%
Profit (x10)	685	642	687	633	637
Friday					
Job Coverage	91%	87%	87%	96%	91%
Profit (x10)	885	852	873	852	858
Saturday					
Job Coverage	88%	88%	85%	92%	88%
Profit (x10)	924	889	891	897	978
Sunday					
Job Coverage	93%	93%	93%	86%	93%
Profit (x10)	1034	990	1027	970	1060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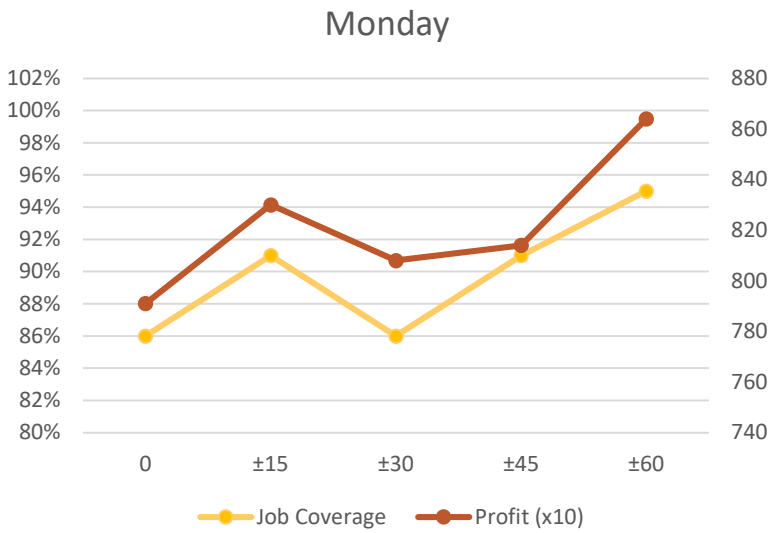
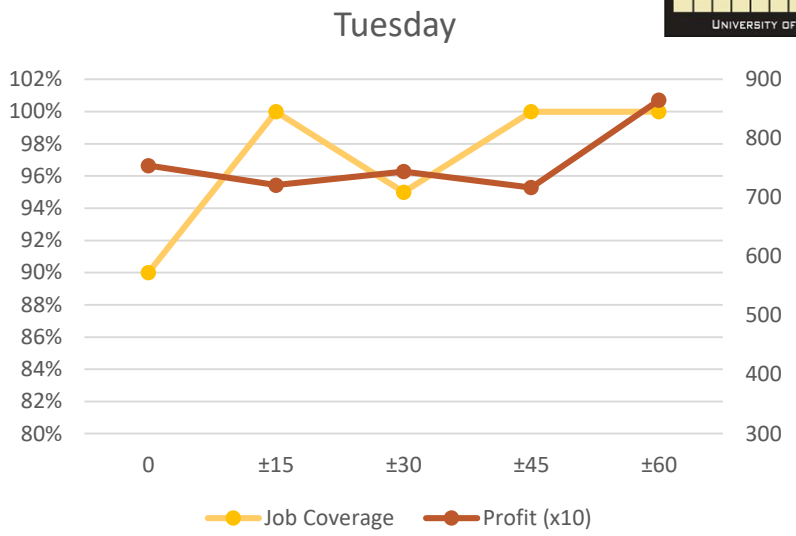

Monday
102%
100%
98%
96%
94%
92%
90%
88%
86%
84%
82%
80%
880
860
840
820
800
780
760
740
0
±15
±30
±45
±60
Job Coverage
Profit (x10)


Tuesday
102%
100%
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88%
86%
84%
82%
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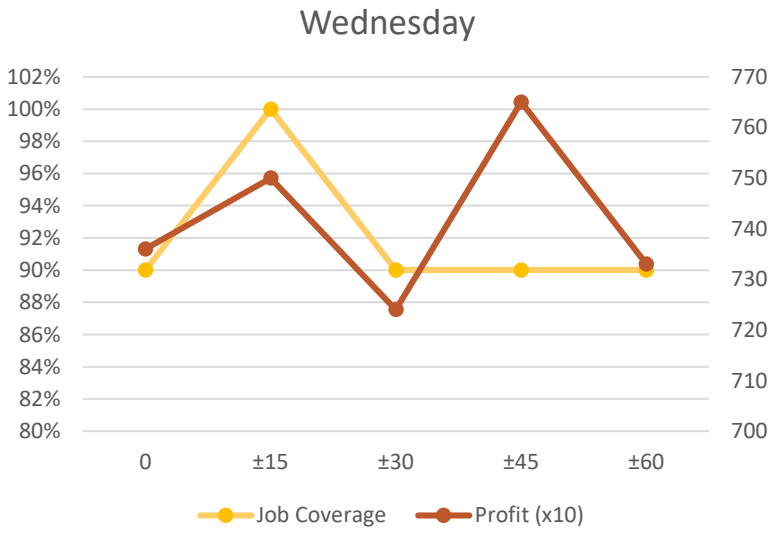
400
300
0
±15
±30
±45
±60
Job Coverage
Profit (x10)


Wednesday
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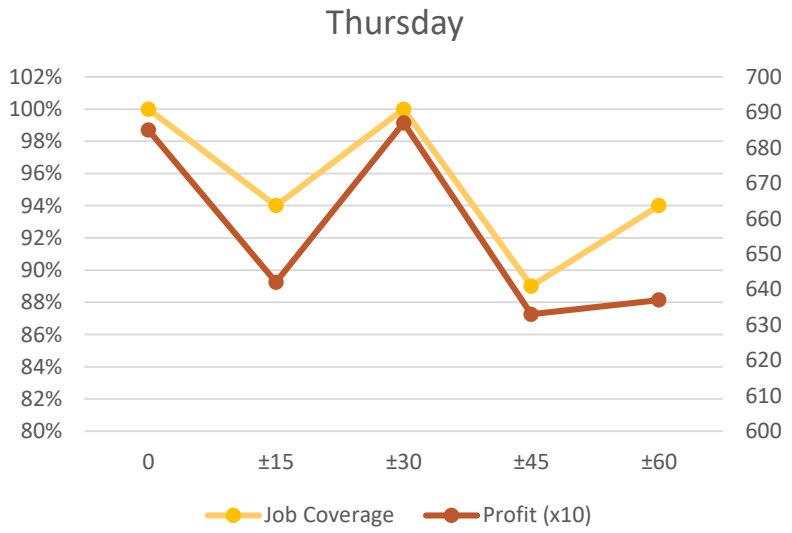
Job Coverage
Profit (x10)


Thursday
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90%
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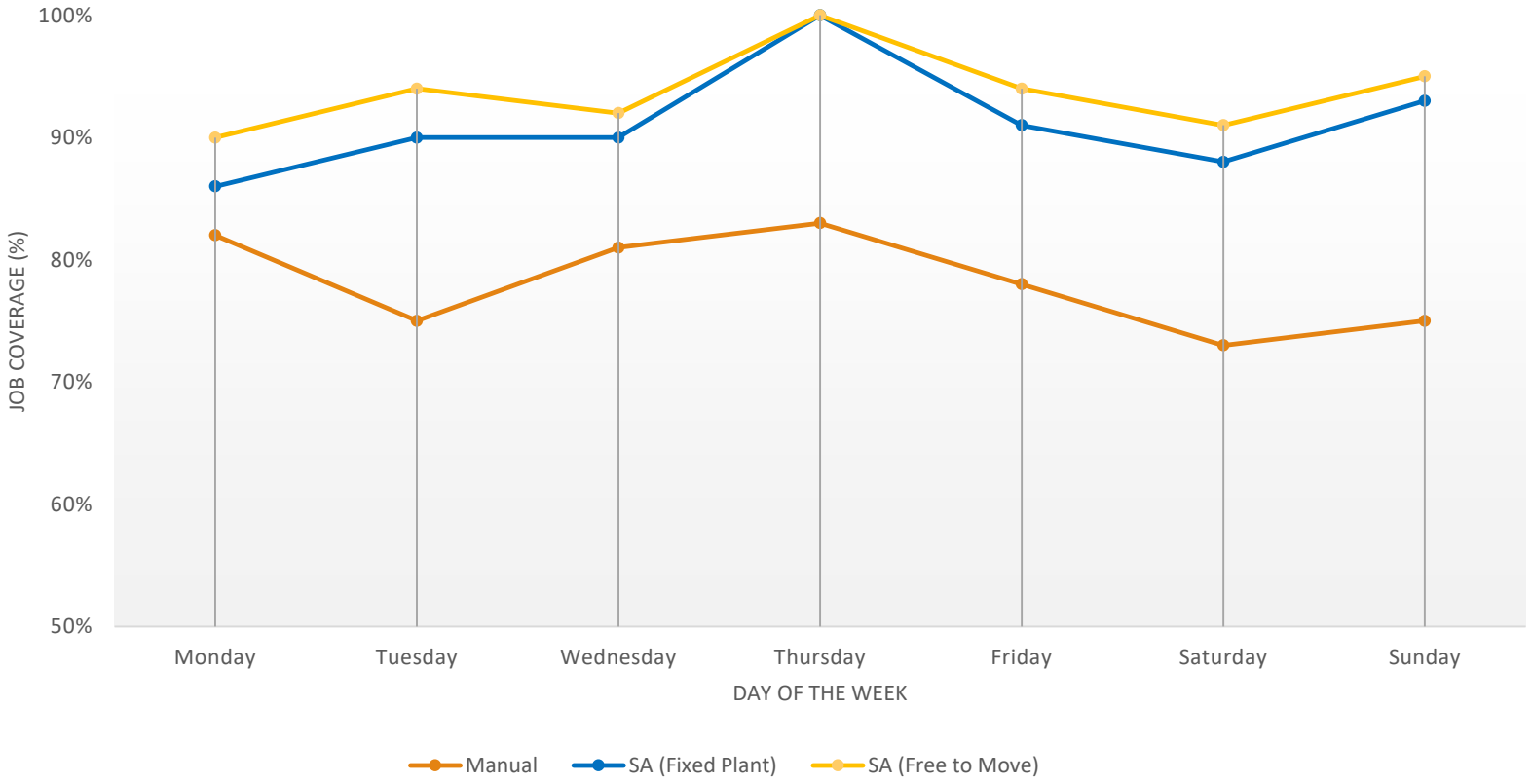
82%
80%
700
690
680
670
660
650
640
630
620
610
600
0
±15
±30
±45
±60
Job Coverage
Profit (x10)

Manual vs. Proposed Job Scheduling Performance
(Fixed Plant and Free to Move)

Day of the Week	Manual Job Scheduling		Proposed Job Scheduler			
			Fixed Plant		Free to Move	
	Profit (x10)	Job Coverage	Profit (x10)	Job Coverage	Profit (x10)	Job Coverage
Monday	721	82%	791	86%	812	90%
Tuesday	729	75%	754	90%	789	94%
Wednesday	736	81%	736	90%	785	92%
Thursday	567	83%	685	100%	710	100%
Friday	881	78%	885	91%	903	94%
Saturday	803	73%	924	88%	965	91%
Sunday	910	75%	1034	93%	1138	95%

Manual vs. Proposed Job Scheduling Performance
(Fixed Plant and Free to Move)



Summary of Results

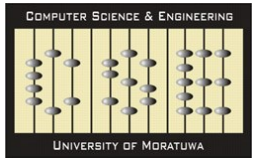
- Compared to the **Manual Job Allocation**,
  - Proposed solution increases the average job coverage and profit.

	Fixed Plant	Fixed Plant (With Time Window)	Free to Move
Average Job Coverage	13%	21%	16%
Profit	9%	13%	14%

- After adjusting the first unload time by a few 10s of minutes to reduce job conflicts.
  - Enhances average job coverage and profit to 21% and 13%.

Summary

- Proposed a rule engine and Simulated Annealing based automated solution to schedule RMC trucks.
  - Performance analysis based on a workload derived from a real RMC delivery company.
- Proposed solution could assign jobs to plants and trucks whil maximizing both the job coverage and profit.
- Solution could further improve job coverage and profit by allowing a time window to time of first unload and by supporting delivery of same job from multiple plants.
- We plan to extend solution to tolerate unexpected delays, capture last minute delivery requests, and support prioritized customers.



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Thank You

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