실시간정보를 이용한 배송배차계획시스템의 이론적배경

김용진 책임연구원 (교통개발연구원)

Hybrid Approaches to Solve Dynamic Fleet Management Problems

김용진

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Motivation

- Trucking industry occupies a large portion of the economy
  - 5% GDP
  - 81 % shipping cost (1997)
  - Carried $4.6 trillion worth of goods, over 900 billion ton-miles (1993)
  - Even a slight improvement of the operating efficiency in the trucking industry would greatly contribute to the overall economy

Motivation

- Demand side motivation
  - Customer-responsive, made-to-order manufacturing system
    - Inventory to retail sales ratio:1.58 (Jan. 1991)1.33 (Mar. 2000), 1.31 (July, 2000)
  - Growth in the electronic commerce and the Internet
    - On-line Internet ordering: over $10 billion (1998)
- Supply side
  - Availability of real-time information
    - Automatic Vehicle Location (AVL) system
    - Two-way communication system
- Potential of these technologies remains vastly underutilized.

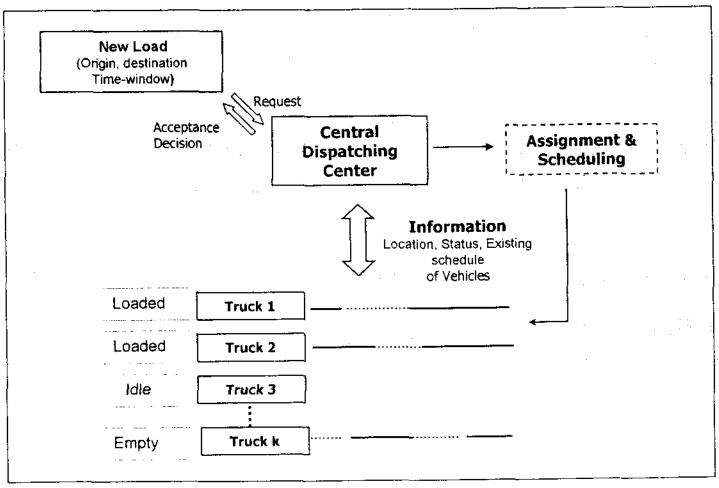
Problem Statement

- Demand information (origin, destination, time-windows) is revealed dynamically as the scheduled routes are executed
- Real-time information (location, status of vehicles) is available to a dispatcher
- A dispatcher can control all the activities of vehicles in real-time
- The dynamic nature of the problem forces a dispatcher to make a decision(at least acceptance decision) in a short time
- The principal focus of this study is to find good and computationally efficient ways, in which a commercial vehicle fleet operations manager serves dynamically requested time-sensitive demands for truckload pickup and delivery service

Decisions: dispatcher responsibility

- Acceptance/rejection decision
  - □ It is crucial with respect to the profit of the company
  - □ The cost to serve a demand varies depending on the existing demands in the queue of the system
  - □ Full assessment of each request in real-time is extremely hard
  - □ The decision should be made in a short time
- Assignment/Scheduling
  - □ Assign the accepted demands to the vehicles
  - □ Updating/modifying schedule till a demand is picked up
  - □ It is not necessary to inform the drivers of this decision until a driver completes his/her current job, except for the en-route diversion for a empty status vehicle

Conceptual Diagram



Commercial Vehicle Operation (CVO)

- CVO include all the operations associated with moving goods and passengers via commercial vehicles and the activities necessary to regulate the operations
- Economical incentive makes implementation of new technologies easier
- Fleet managers have authority to control the activities of the vehicles

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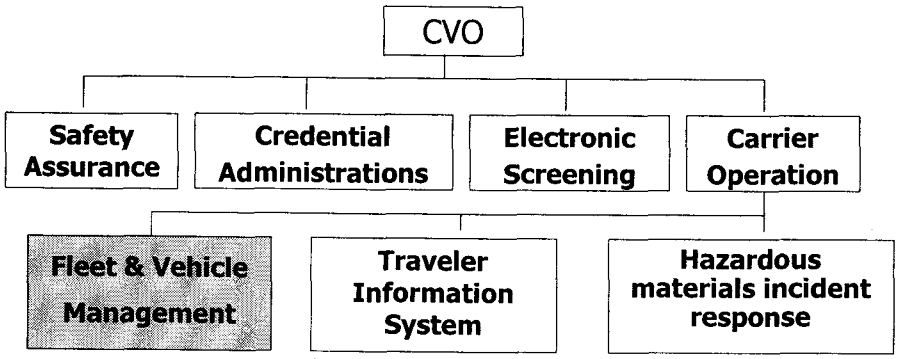
Commercial Vehicle Operation (CVO)



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Real-time information technology

- Real-time information is available to a dispatcher
- Auto Vehicle Location (AVL)
  - □ Leading Tech.: GPS
  - □ Worldwide location: latitude, longitude, altitude
  - □ 95% of the points fall within a radius of 6.3 meters after SA turn off
- Two-way Communication system

Background Review

- Classical problems
  - □ TSP (Traveling Salesman Problem)
  - □ VRP (Vehicle Routing Problem)
- Stochastic/Dynamic Vehicle Routing problems
  - □ Stochastic & Static
    - Stewart and Golden (1983), Berman and Simchi-Levi (1989)
    - Incorporates uncertainty explicitly into a model
  - □ Probabilistic TSP
    - Jaillet (1985, 1988), Bertsimas et al. (1990)
  - □ Review of Dynamic VRP
    - Psaraftis (1988), Golden and Assad (1986), Dejax and Crainic (1987), Powell, Jaillet, and Odoni (1995)

Classical problems

- Traveling Salesman Problem (TSP)
  - □ NP-hard Problem
  - □ It be extended to a lot of applications
  - □ Its general solution algorithm be used to solve other problems
- Vehicle Routing Problem
  - □ Describes certain aspects of the truckload trucking problem
  - □ VRP has various forms

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Variation of VRP

Crew Requirement	Pay structure: length of workday minimum and maximum on duty times overtime option
	Fixed or variable number of drivers
	Driver star times and locations
	Lunch or other breaks
	Multiple-day trips allowed
Scheduling Requirements	Assignment of customers to day of the week
	Time-windows for pickup/delivery (soft, hard)
	Open and close times
	Load/ unload (dwell) times
Data Requirements	Geographic database, road networks
	Customer addresses and locations
	Travel times
	Vehicle location information
	Customer credit and billing information

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Variation of VRP

(Assad, 1988)

Nature of Demand	Pure pickup or pure deliveries
	Pickups with backhaul option
	Single or multiple commodities
	Must serve all demands?
	Common carrier option
	Priorities for customers
Information on Demand	All demands known in advance?
	Many repeat demands
	Fixed frequencies for visits
	uncertain demands
	Real-time inflow of demands
Vehicle Fleet	Homogeneous fleet or multiple vehicle types
	Weight and capacity restrictions
	Compartments
	Loading restrictions/ equipment
	Vehicle type/ site dependencies
	Vehicle type/ commodity compatibility
	Fixed or variable fleet size
	Fleet based at single depot or multiple terminals

Dynamic VRP

Psaraftis (1988)

- Time dimension is essential
- Problem may be open-ended
- Future information may be imprecise or unknown
- Near-term events are more important
- Information update mechanisms are essential
- Reassignment decisions may be warranted
- Faster computation times are necessary
- Indefinite deferment mechanisms are essential
- Objective function may be different
- Time constraints may be different
- Flexibility to vary vehicle fleet size is lower
- Queueing considerations may become important

Review: Solution Approaches

- Stochastic approaches
  - Incorporates uncertainty explicitly into a model Powell (1986,1987, 1988,1996), Frantzeskakis and Powell (1990) Powell & Frantzeskakis(1994), Bertsimas and Van Ryzin (1991, 1993)
- Fast local operation
  - Easy to implement and shows fast computation time
  - Regan, Mahmassani and Jaillet (1995, 1996a, 1996b, 1997, 1998), Powell, Towns and Marar (2000)

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Review: Solution Approaches

- Sophisticated Static Procedure
  - Seek local optimum routing schedule
  - Yang, Jaillet, and Mahmassani (2000, 2002)
  - Powell, Snow, and Cheung (2000)
- Meta-heuristics
  - Tabu search
    - Badeau, Guertin, Gendreau & Potvin (1997), Gendreau, Guertin, Potvin & Taillard (1999), Ichoua, Gendreau and Potivin (2000)
  - Genetic Algorithm
    - Jung and Haghani (2000): static pickup-and delivery with TW
  - Simulate Annealing
    - Chiang and Russell (1996) : static VRPTW

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Objectives

- To maximize profitability and service quality
- Profit
  - □ Acceptance decision
  - □ Routing/assignment decision
    - To minimize the empty distance (cost) for the accepted demands
- Service quality
  - □ Response time: demand arrival ~ customer receives the acceptance/ rejection decision
  - □ Lateness: the time elapsed between the arrival of a demand and its eventual pickup time
  - □ Delay: latest pickup time ~ actual pickup time

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Objectives: Mathematical form

$$V^* = \max_{\pi \in \Pi} E[\sum_{i=1}^{\dot{N}} D_i^{\pi} (R_i - \beta(\varphi_i^{\pi} + l_i))]$$

$$V^* = \max_{\pi \in \Pi} E[\sum_{i=1}^{\dot{N}} D_i^{\pi} (R_i - \beta(\varphi_i^{\pi} + l_i) - \gamma\, l_i (\delta_i - \tau_i^{cr})^+]$$

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Basic Approach

- To solve the successive local problems as close to optimality as possible
- Combine a *Heuristic local rule* and *Optimization-based routing*
  - □ Heuristic local rule Provide fast response to the customer(acceptance decision) and initial schedule, and requires rrelatively short computing time
  - □ Optimization-based routing using MIP model improves service schedule of accepted demands, but requires long computation time
- Evaluation methodology: Simulation Experiment

MIP Formulation I

$$\min \sum_{k=1}^{K} \sum_{i=1}^{N} d_{0i}^{k} x_{k,K+i} + \sum_{i=1}^{N} (\alpha\, x_{K+i,K+i} + \sum_{j=\{1,..N\}, j\neq i} d_{ij} x_{K+i,K+j})$$

subj to

$$\sum_{v=1}^{K+N} x_{uv} = 1 \qquad \forall\, u = 1, \ldots, K+N \qquad (1)$$

$$\sum_{v=1}^{K+N} x_{vu} = 1 \qquad \forall\, u = 1, \ldots, K+N \qquad (2)$$

$$x_{uv} = 0,1 \qquad \forall\, u, v = 1, \ldots, K+N \qquad (3)$$

$$-\sum_{k=1}^{K} (d_{0i}^{k} + \beta_k) x_{k,K+i} + \delta_i \geq 0 \qquad \forall\, i = 1, \ldots, N \qquad (4)$$

$$(l_i + d_{ij}) x_{K+i,K+i} - T x_{K+i,K+j} - \delta_i + \delta_j \geq -T + l_i + d_{ij} \qquad \forall\, i, j = 1, \ldots, N \qquad (5)$$

$$\tau_i^{-} \leq \delta_i \leq \tau_i^{+} \qquad \forall\, i = 1, \ldots, N \qquad (6)$$

MIP Formulation II

$$Min \sum_{k=1}^{K}\sum_{i=1}^{N} d_{0i}^{k} x_{k,K+i} + \sum_{i=1}^{N}(\rho l_i \, x_{K+i,K+i} + \sum_{j=\{1..N\}, j\neq i} d_{ij} x_{K+i,K+j}) + \theta \sum_{i=1}^{N} l_i \, \omega_i$$

subj to

$$\sum_{v=1}^{K+N} x_{uv} = 1 \qquad \forall\, u = 1, \ldots, K+N \qquad (1)$$

$$\sum_{v=1}^{K+N} x_{vu} = 1 \qquad \forall\, u = 1, \ldots, K+N \qquad (2)$$

$$-\sum_{k=1}^{K} (d_{0i}^{k} + v^{k}) x_{k,K+i} + \delta_i \geq 0 \qquad \forall\, i = 1, \ldots, N \qquad (3)$$

$$(l_i + d_{ij}) x_{K+i,K+i} - M x_{K+i,K+j} - \delta_i + \delta_j \geq -M + l_i + d_{ij} \qquad \forall\, i, j = 1, \ldots, N \qquad (4)$$

$$B + \omega_i - \delta_i \geq B \xi_i - \tau_i^{cr} \qquad \forall\, i = 1, \ldots, N \qquad (5)$$

$$\omega_i \geq 0 \qquad \forall\, i = 1, \ldots, N \qquad (6)$$

$$x_{uv} \in \{0,1\} \qquad \forall\, u, v = 1, \ldots, K+N \qquad (7)$$

$$\tau_i^{-} \leq \delta_i \leq \tau_i^{+} \qquad \forall\, i = 1, \ldots, N \qquad (8)$$

Problem Settings

- Large fleet problem with moderate demand rate
  - □ Various partitioning strategies are proposed to tackle the complexity of the large size problem
- Highly congested request rate for large fleet
  - □ Analyze the relationship between computation time and vehicle movement during this time
  - □ Real time acceptance/rejection decision with filtering process
- Multi classes demand problem
  - □ It accommodates various customer requirement for delivery service
  - □ More generalized/improved acceptance decision process and routing schedule will be presented

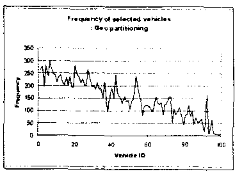
Large fleet problem: partitioning

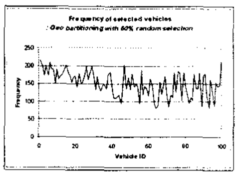
- Problem specification
  - Moderate demand arrival rate is assumed
  - Large fleet : 100 vehicles
- Apply the hybrid two phases strategy whenever a new demand arrives
  - Initial Assignment : local heuristic rule for a initial schedule & acceptance decision
  - Reassignment : Optimization based procedure to improve the schedule
- Due to the large size fleet, only a subset of vehicles and their associated demands are selected as candidates for the reassignment
- How can we choose the high potential candidates ?

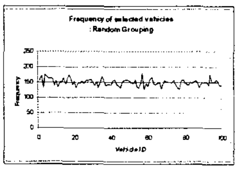
Geographical Partitioning

- To exploits the schedule of previous decision epoch rather than to totally re-optimize the schedule
- The problem setting (location & status of vehicles) at the previous decision epoch is similar to the current decision epoch
  - New load, served demands during the inter-arrival time
- Initial assignment changes only one vehicle's schedule
- Select the close neighbor vehicles and their demands to the vehicle, to which the new demand is assigned as candidates for reassignment

Frequency Of Selected Vehicles







- Geographic partitioning shows good performance in local sense; big improvement from the initial schedule
- However, it shows bad performance in global sense
- It tends to select vehicles with long task queue
- Biased selection in the geographic partitioning loses the opportunity of reassigning demands to diverse vehicles
- Balanced selection can be achieved by combination with Random selection (hybrid partitioning)

Dynamic Control

- The congested arrivals produce big local problem
- Cutting the size at some critical point can avoid the extremely long computation time.
- The loads, whose future scheduled pickup times are earlier than the time criterion are removed form the candidate pool.
- Cut-off criterion increases gradually from 0 until the reassignment pool size decreases to its predefined point.

Numerical Results

Strategy	Empty distance [mile]	Lateness (min)	Comp. time [sec]	# of candidate demands for Phase II	Violation (%)
Initial assignment only	11.75	117.7	2.06 ± 0.25		3.4
Random Partitioning	8.70	104.4	5.04 ± 18.59	20.6	6.8
Geographic	8.91	112.8	66.47 ±140.22	28.7	28.4
Hybrid Partitioning	8.46	104.2	4.3 ±11.01	20.8	6.6
Dynamic hybrid partitioning	8.43	104.95	3.47 ±7.02	20.4	5.9

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Comparison with RAPID-SL

- Powell, Snow, and Cheung (2000)

	Inter arrival time/ veh = 90min			Inter arrival time/ veh = 60 min		
		RAPID-SL			RAPID-SL	
	D40-22	I	II	D40-22	I	II
Total Empty Time	159.3	139.8	151	184.6	134.8	144.6
Total Loaded Time	1033.5	957.1	986.9	960.7	907.4	935.5
Total Idle Time	488.5	551.2	506.4	186	194.6	160.1
Total Empty Distance	7965	6990	7548	9232	6740	7231
Total Loaded Distance	51676	47855	49346	48034	45372	46776
# of served demands	1000	895	952	935	897	836
Profit	**$28,016**	**$26,164**	**$26,786**	**$24,999**	**$24,743**	**$25,347**

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Over-Saturated Demand Condition

- Problem setting:
  - Large fleet 100 vehicles
  - Over-saturated demand condition
- To present a dynamic adaptive dispatching (***DAD***) strategy to utilize the computation capability fully while keeping customer's response time within acceptable limits
- To develop an intelligent acceptance decision process
- To develop a filtering procedure, which improves the system's efficiency by providing greater opportunity for reassignment of existing routes

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Numerical Results: TPD vs. DAD

	Iteration	Total Empty Distance [mile]	Total Loaded Distance [mile]	# of served demands	Lateness [min]	Profit
TPD	1	11236.1	53724.8	1090	161.4	$ 18,442.1
	2	11520.0	53699.0	1062	161.0	$ 18,264.0
	3	11430.3	54034.7	1092	162.4	$ 18,526.6
	4	11628.6	52700.6	1047	160.8	$ 17,573.1
	5	11099.6	53609.6	1074	161.0	$ 18,447.3
average		**11382.9**	**53553.8**	**1073.0**	**161.3**	**$ 18,250.6**
DAD	1	10734.3	54346.8	1083	161.4	$ 19,119.9
	2	10896.5	54141.9	1067	161.5	$ 18,898.4
	3	10793.4	54597.3	1093	160.4	$ 19,244.1
	4	10849.0	53525.2	1055	160.0	$ 18,536.9
	5	10686.6	54146.5	1081	160.3	$ 19,021.0
average		**10791.9**	**54151.5**	**1075.8**	**160.7**	**$ 18,964.1**

TPD : Two Phase Dispatching system
Lateness: [demand arrival time, demand pickup time]

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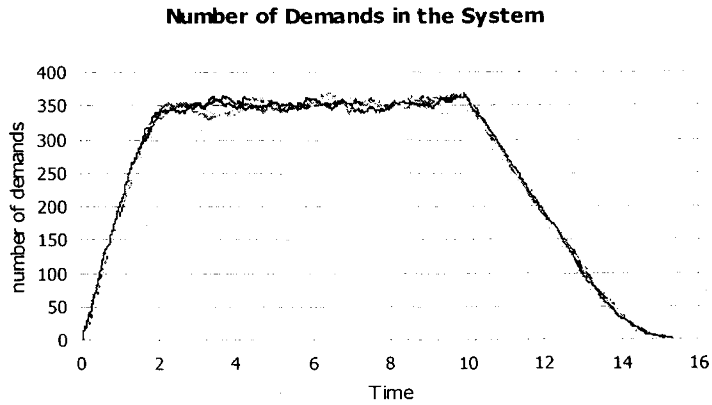
Response Time: TPD vs. DAD

	TPD	DAD
Mean	5.44	6.62
Standard Deviation	4.15	2.99
Minimum	1.25	1.25
Maximum	39.51	22.65

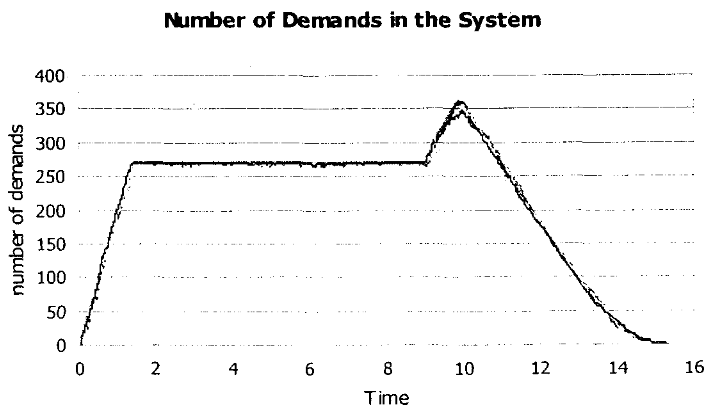
Filtering

- The 'Filtering' aims at controlling the total number of demands in the dispatching system
- Due to the time-windows of demands, the number of demands in the queue of the system is limited
- 'Holding capacity': the maximum number of demands waiting for service in the system
- Highly congested arrival causes the 'holding capacity' to completely fill up with the accepted demands
- When the 'holding capacity' is full, it is difficult to find reassignment opportunities to reduce the empty distance because there is not enough room for swapping and re-sequencing existing demands

Before Filtering



After Filtering



Performance of Algorithms

	Profit		# of served demands		Lateness [min]		Response time		Worst case response time [sec]
DAD	$18,964.06	*270.50*	1075.80	*14.87*	160.72	*0.69*	6.62	*2.99*	22.7
Filter 270	$20,077.76	*475.62*	1051.80	*21.78*	125.89	*0.92*	2.97	*2.88*	16.18
AddCost	$20,981.28	*436.89*	1087.20	*18.73*	121.20	*2.01*	3.04	*2.76*	18.36

Load Acceptance Decision with Priority Demand

- Problem setting: two types of demand are introduced
- Priority customers are time sensitive and requires express delivery service
  - □ They are willing to pay a premium for on-time, earlier delivery
  - □ Relatively narrow, hard time-window width
- Regular customers are more sensitive to price, and request the low-price service
  - □ wider and flexible time-windows where a penalty is charged in proportion to the amount of the delay

Feasibility Index

- The 'Feasibility Index' (*FI*) represents a system state in terms of the expected number of vehicles that can serve an unknown priority load
- If a load is feasible & a priority demand => accepted
- Regular demand: estimate *FI*
  - □ *FI* > *FI** => accept
  - □ O/W => rejected in order to increase *FI*
- Even though this estimation process does not explore all possible sequences, it provides the lower bound of the probability.

Numerical Results

6.25% of priority demand

Acceptance decision policy	Total Revenue (std.)	Total Cost (std.)	Over Time Cost (std.)	Total Profit (std.)	Total # of Served Demands (std.)	# of served Priority demands (std.)
Feasibility based acceptance	$56,663	$32,312	$5,340	$19,011	896.8 (70.9%)	25.8 (33.4%)
	(618)	(229)	(363)	(849)	(13.2)	(3)
Simple Filtering	$57,295	$31,937	$1,249	$24,109	920.8 (72.8%)	35.2 (45.6%)
	(412)	(449)	(205)	(484)	(10.1)	(5)
FI	$60,238	$32,316	$1,417	$26,505	910.4 (72.0%)	64.8 (83.9%)
	(460)	(134)	(78)	(489)	(11.7)	(7)

Numerical Results

25% of Priority demands

Acceptance decision policy	Total Revenue (std.)	Total Cost (std.)	Over Time Cost (std.)	Total Profit (std.)	Total # of Served Demands (std.)	# of served Priority demands (std.)
Feasibility based acceptance	$60,712	$32,485	$4,920	$23,307	900.2 (71.1%)	102.8 (33.1%)
	(572)	(223)	(232)	(492)	(6.3)	(4.5)
Simple Filtering	$61,622	$31,483	$1,267	$28,872	903.8 (71.4%)	139.8 (45.1%)
	(910)	(655)	(302)	(335)	(16.5)	(7.7)
FI	$68,219	$29,970	$415	$37,834	851.2 (67.3%)	267.2 (86.1%)
	(1090)	(535)	(98)	(804)	(13.2)	(11.2)

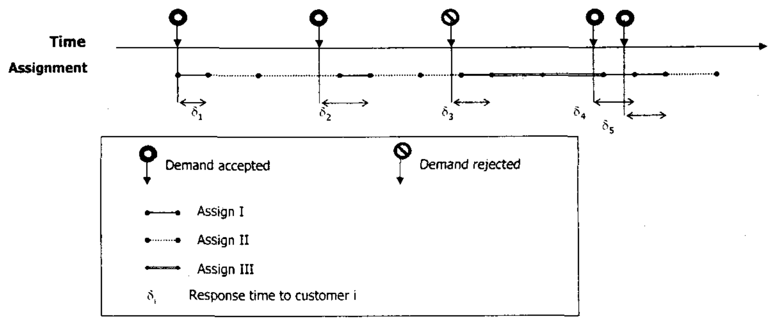
Conclusion

- State and formulate the dynamic fleet management problem taking advantage of real-time information on vehicle locations and states
- Two MIP formulations are developed for local snapshot problems
  - homogeneous demands/ two types of demand corresponding various customer requirements
- Variations of the hybrid dynamic decision policies are developed according to the problems settings
  - Satisfy the dynamic operational requirements: quick response to a customer and full utilization of the computational resources

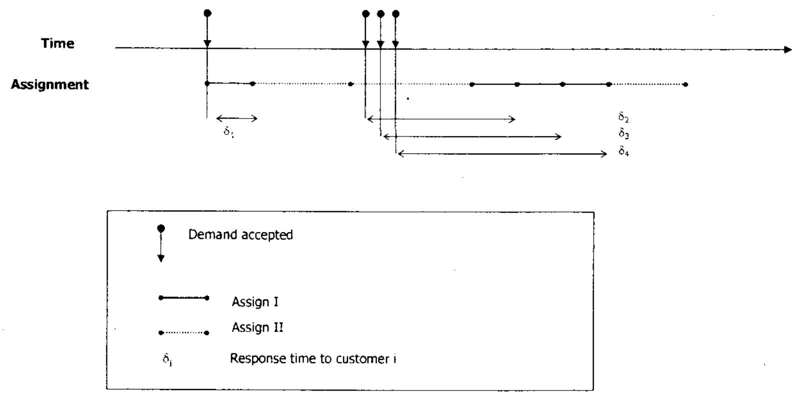
Conclusion

- Partitioning strategies provide a solution approaches to a problem managing a large fleet of vehicles
- Various real-time acceptance/ rejection decision policies are developed corresponding to a range of demand situations
- In order to evaluating the effectiveness of developed policies, a simulation framework is developed
- And, a simple local heuristic approach (Regan, 1997) and RAPID-SL (Powell, Snow, & Cheung, 2000) algorithm are coded and implemented in this simulation framework as benchmark policies

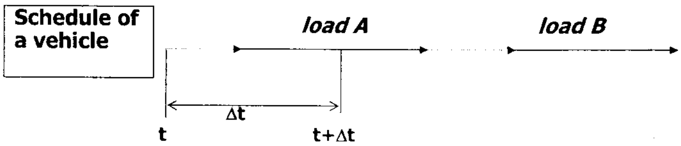
Dynamic Adaptive Dispatching



Worst-case Response Time

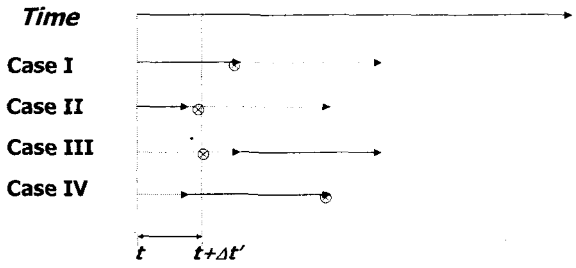


Vehicle Movement & Assignment Execution Time



- Avoid infeasible assignment
- Δt is not predictable in advance
- We need to predefine the maximum computation time for a single application
- The associated local snap shot problem should use updated vehicle locations and status

Updated Locations for Local Problem



⊗: Updated location of a vehicle
$\Delta t'$: Predefined maximum computation time

- Use updated location at the time indicated as ⊗

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