INTERMODAL PASSENGER TRAVEL WORKSHOP
MONTREAL, CANADA

RESEARCH ON INTERMODAL TRANSPORTATION

May 31- June 1, 2012

Presented by Paul Schonfeld

Contents

- ☐ Selected Research on Intermodal Transportation
- ☐ Integration of Conventional and Flexible Bus Services
- ☐ General Thoughts on Intermodal Passenger Transportation

Selected Research on Intermodal Transportation

Selected Research

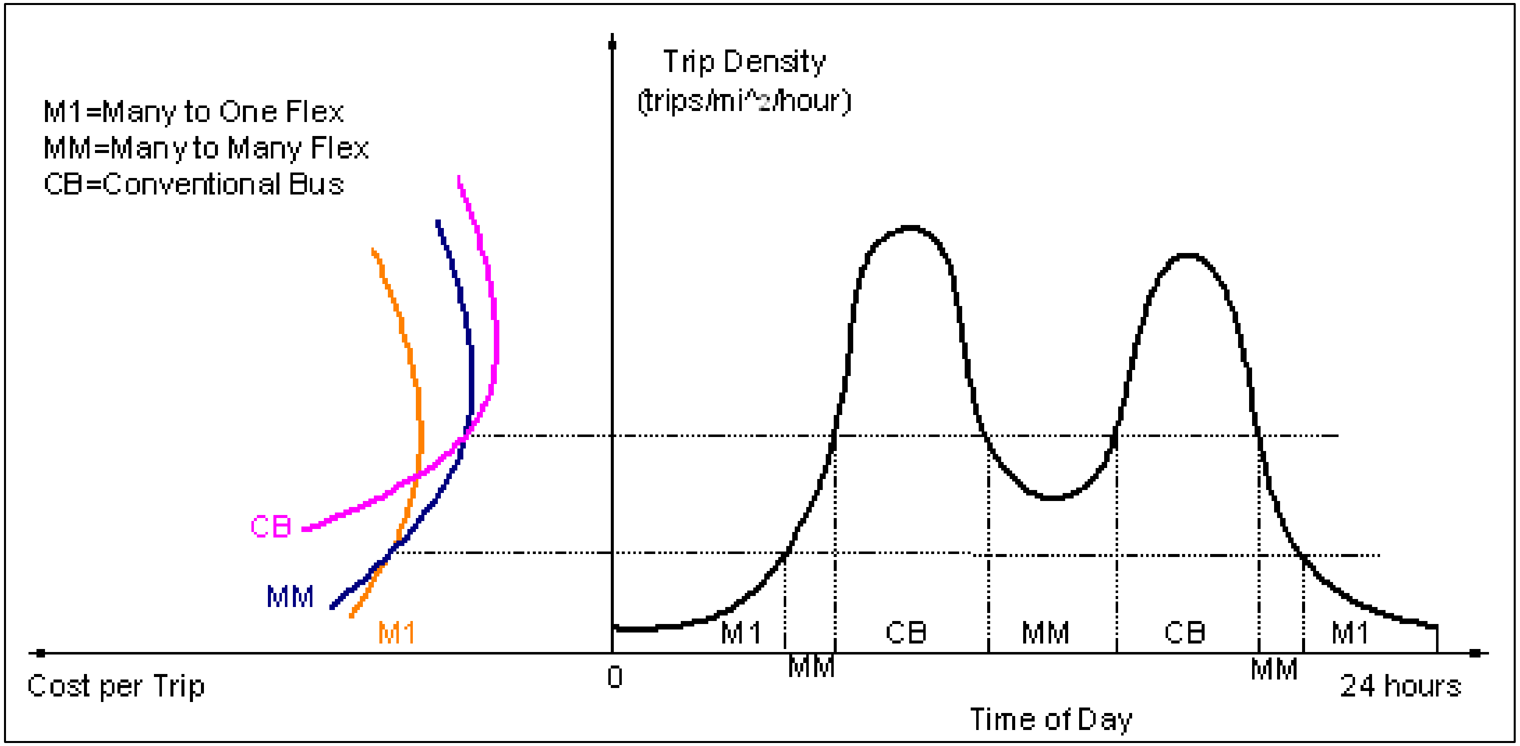
- Transfers in transportation terminals, with K. T. Lee, C. Chang, Y. M. Kim
- Optimization of intermodal transit networks, with Steven Chien
- Transfer coordination in transit networks, with Ching Jung Ting
- Air express network design with hub sorting, with Somnuk Ngamchai
- Intermodal transfer coordination in logistic networks, with Frank Chen
- Integration of conventional and flexible bus services, with Edward Kim
- Scheduling under uncertainty for logistic systems, with Nikola Markovic
- Recovery from major disruptions in multi-terminal logistic systems, with N. Markovic
- Coordination of dial-a-ride, taxi, and conventional transit systems, with E. Kim and N. Markovic

Integration of Conventional and Flexible Bus Services

By Edward Kim and Paul Schonfeld

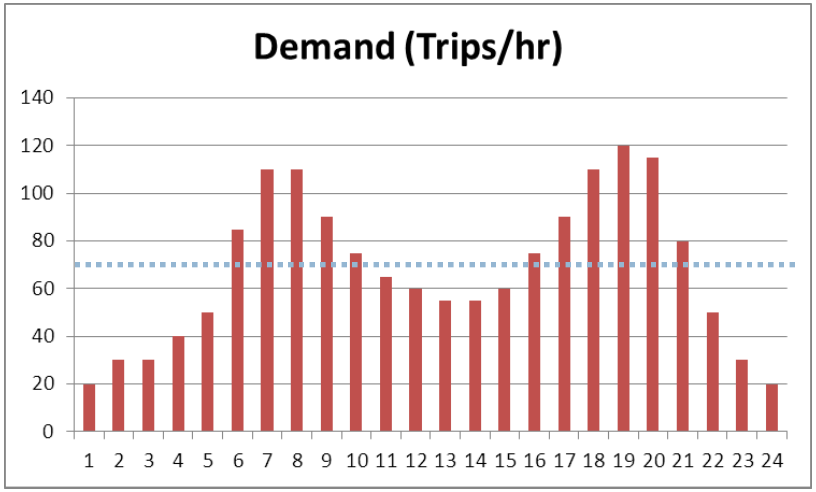
Background & Motivation

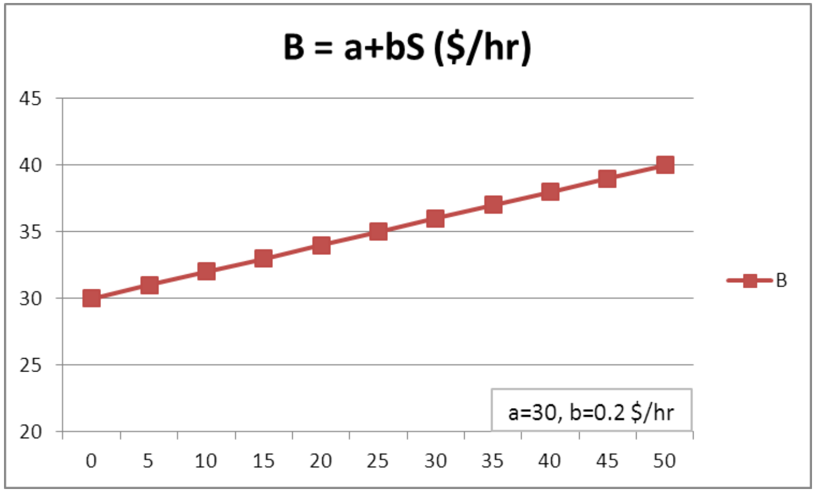
- Conceptual Basis for Transitions among Service Types



Background & Motivation

- Typical demand distribution ➔ How to serve it ?
  - Optimize bus frequencies
- Bus size ?





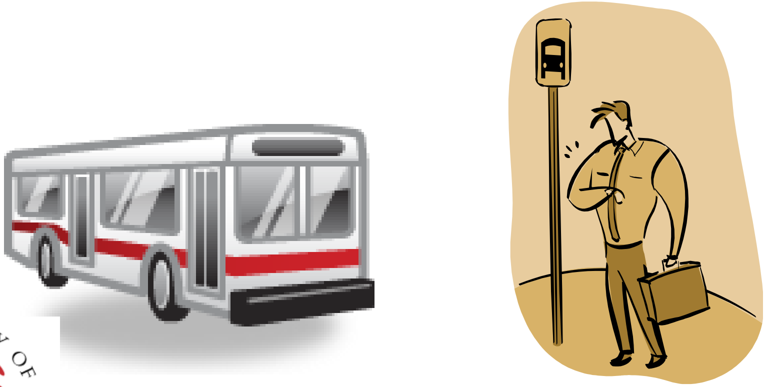
Background & Motivation

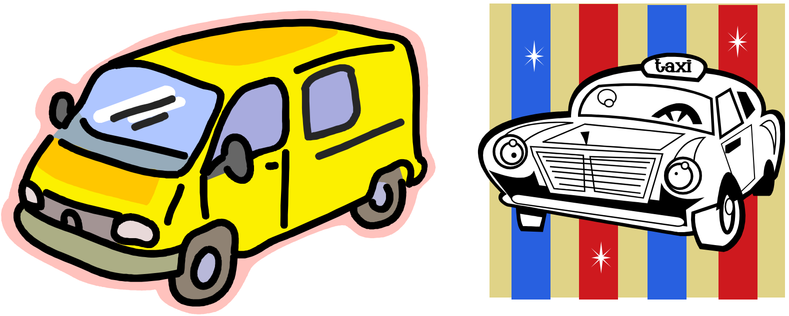
Conventional Bus
(=Fixed Route, Fixed Schedule Service)

- Includes access cost
- Lower avg. supplier cost
- Suitable for high demand densities

Flexible Bus
(= Demand-Responsive Service)

- Door-to-door service
- Expensive (usually)
- Suitable for low demand densities





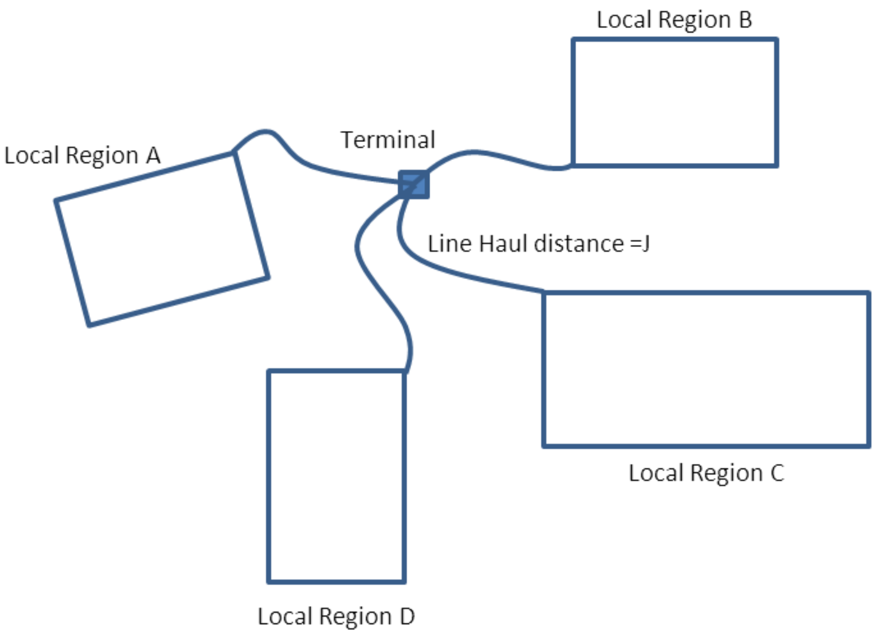
Scope

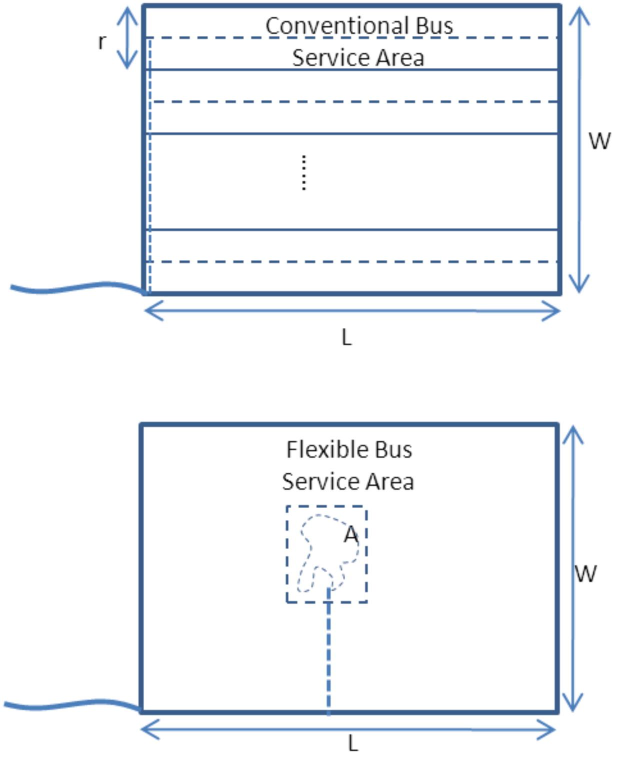
- Formulate Cost Functions for Bus Services
  - Single Fleet Conventional Bus
  - Single Fleet Flexible Bus
  - Mixed Fleets Conventional Bus
  - Mixed Fleets Flexible Bus
  - Mixed Fleets Variable-Type Bus

- Find Solutions
  - Bus Size(s), Route Spacing(s), Service Area(s), Headway(s), Fleet Size(s)…

Service Descriptions

- ☐ Conventional Bus vs. Flexible Bus





Assumptions

- For both conventional and flexible bus
  - All service regions are rectangular
  - Terminal is connected to each region's nearest corner
  - Demand is fixed w.r.t. service quality and price
  - Bus size is optimized throughout system
  - Average waiting times are half the headways
  - Bus layover times are negligible
  - Average speed includes stopping times
  - External costs are assumed to be negligible

Assumptions (2)

- For conventional bus
  - Region k is divided into N parallel zones with width r (=W/N)
  - Demand Q is uniformly distributed over service area
  - Buses stop every d miles along the route
- For flexible bus
  - Region k is divided into N' equal zones, A=LW/N'
  - Each zone should be "fairly compact and fairly convex"
  - Buses operate on preset schedules
  - Tour departure headways are equal for all zones in region and uniform within each period
- For details, see references

SFC Cost Formulation

- Service Cost = Operator Cost + User Cost
  - Operator cost = bus operating cost
  - User cost = in-vehicle cost + waiting cost + access cost
  - $$SC_c^{ki} = \frac{D^k W^k (a+bS_c)}{r^k V_c^i h_c^{ki}} + \frac{v_v L^k W^k Q^{ki} M^k}{V_c^i} + \frac{v_w L^k W^k Q^{ki} h_c^{ki}}{2} + \frac{v_x L^k W^k Q^{ki} (r^k+d)}{4V_x}$$
- Optimal Headway and Fleet Size
  - $$h_{c\,opt}^{ki} = \min\left\{\frac{S_c l_c}{rL^k f Q^{ki}}, \sqrt{\frac{2D^k(a+bS_c)}{v_w L^k r^k Q^{ki} V_c^i}}\right\}$$
  - $$F_c^{ki} = \frac{D^k W^k}{r^k h_{c\,opt}^{ki} V_c^i}$$

Detailed SFC Cost Formulation

- Fleet Size
  - $F_c = \frac{DW}{rh_cV_c}$,where $D = 2J/y + W/z + 2L$
- Maximum Allowable Headway
  - $h_c = \frac{S_cl_c}{rLfQ}$
- Operating Cost
  - $C_{oc} = F_cB$
  - $B = a + bS_c$
  - $C_{oc} = \frac{D(a+bS_c)LWfQ}{l_cV_cS_c} = \frac{DW(a+bS_c)}{V_crh_c}$

Detailed SFC Cost Formulation (2)

- In-vehicle Cost
  - $C_{vc} = v_v LWQt$
- Average travel time per passenger trip:
  - $t = \frac{J}{yV_c} + \frac{W}{2zV_c} + \frac{L}{2V_c} = \frac{M}{V_c}$,where M=J/y + W/2z + L/2
- In-vehicle Cost
  - $C_{vc} = v_v LWQ \frac{M}{V_c}$

Detailed SFC Cost Formulation (3)

- Waiting cost
  - Average waiting cost is assumed half the headway
  - $C_{wc} = v_w LWQ \frac{h_c}{2} = v_w LWQ \frac{S_c l_c}{2rLfQ} = \frac{v_w W S_c l_c}{2rf}$
- Access Cost
  - Average access distance to the nearest route = r/4
  - Access distance alongside the route to the nearest bus stop = d/4
  - $C_{xc} = \frac{v_x LWQ(r+d)}{4V_x}$

SFF Cost Formulation

- Service Cost = Operator Cost + User Cost
  - Operator cost = bus operating cost
  - User cost = in-vehicle cost + waiting cost
  - $SC_f^{ki} = \frac{L^k W^k \left(a+bS_f\right)(D_f^k+\emptyset A^k \sqrt{\frac{Q^{ki}h_f^{ki}}{u})}}{A^k V_f^i h_f^{ki}} + \frac{v_v L^k W^k Q^{ki}(D_f^k+\emptyset A^k \sqrt{\frac{Q^{ki}h_f^{ki}}{u})}}{2V_f^i} + \frac{v_w L^k W^k Q^{ki} h_f^{ki}}{2}$
- Optimal Headway and Fleet Size
  - $h_{f\,opt}^{ki} = min\left\{\frac{S_f l_f}{A^k Q^{ki}}, h_{f\,min}^{ki}\right\}$
  - $F_{f\,opt}^{ki} = \frac{L^k W^k (D_f^k+\emptyset A^k \sqrt{Q^{ki}h_{f\,opt}^{ki}/u)}}{V_s A^k h_{f\,opt}^{ki}}$

Detailed SFF Cost Formulation

- Optimal Tour Distance (Stein, 1978; Daganzo, 1984)
  - $D_c = \varnothing\sqrt{nA} = \varnothing A\sqrt{\frac{Qh}{u}}$, where $n = \frac{AQh}{u}$, $\varnothing = 1.15$
- Average round trip time
  - $T = 2\left(\frac{L+W}{2zV} + \frac{J}{yV}\right) + \frac{D_c}{V} = \frac{D_f + \varnothing A\sqrt{\frac{Qh}{u}}}{V}$, where $D_f = \frac{L+W}{z} + \frac{2J}{y}$
- Fleet Size
  - $F = \frac{LWT}{Ah} = \frac{LW\left(D_f + \varnothing A\sqrt{\frac{Qh}{u}}\right)}{VAh}$

Detailed SFF Cost Formulation (2)

- Operating Cost
  - $C_o = FB = \frac{LW\left(D_f + \emptyset A\sqrt{\frac{Qh}{u}}\right)}{VAh}(\mathrm{a} + \mathrm{bS})$
- In-vehicle Cost
  - $C_v = \frac{vLWQT}{2} = \frac{vLWQ}{2}\left(\frac{D_f + \emptyset A\sqrt{\frac{Qh}{u}}}{V}\right) = \frac{vLWQ(D_f + \emptyset A\sqrt{\frac{Qh}{u}})}{2V}$
- Waiting Cost
  - $C_o = vLWQ\frac{h}{2}$

MFC Cost Formulation

- Mixed Fleet Conventional Bus ?
  - Provide two sizes of conventional buses
- Threshold Demand Matrix
  - Set large conventional bus service cost and small conventional bus service cost equal, then obtain:
    - $Q_t^{ki} = \frac{v_w l^2 S_l S_s V_c^i}{2aD^k r^k L^k f^2}$
  - If demand Q is larger then Q_t^{ki}: provide larger bus
  - Otherwise, small bus

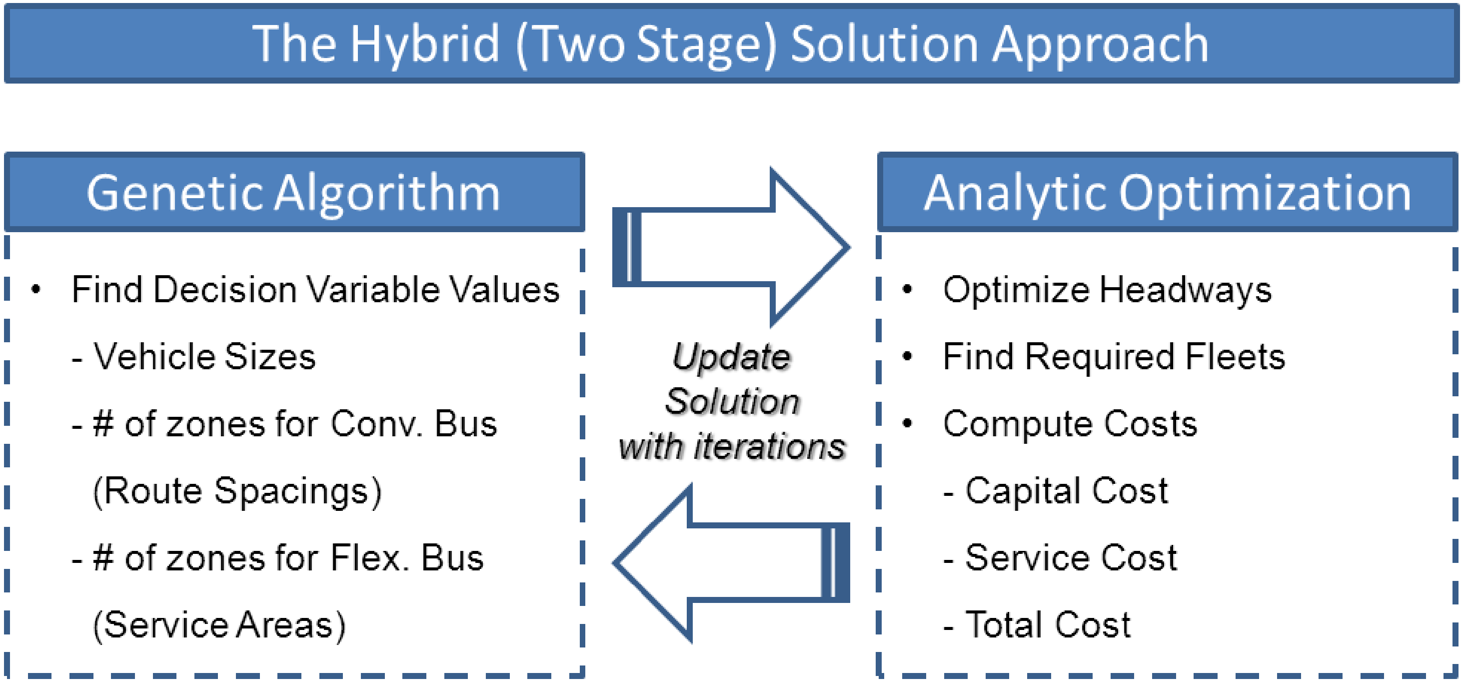
Number of Optimized Variables

Decision Variables

- k+1 up to 2k+2 variables
- Apply Integer Genetic Algorithm

Dependent Variables

- Analytic optimization applied



The Hybrid (Two Stage) Solution Approach

Genetic Algorithm

- Find Decision Variable Values
  - Vehicle Sizes
  - # of zones for Conv. Bus (Route Spacings)
  - # of zones for Flex. Bus (Service Areas)

Update Solution with iterations

Analytic Optimization

- Optimize Headways
- Find Required Fleets
- Compute Costs
  - Capital Cost
  - Service Cost
  - Total Cost

Base Case Inputs

Demand (trips/mile^2/hour)				
Region Period	A	B	C	D
1	70	80	60	55
2	30	35	40	40
3	10	15	30	15
4	5	7.5	10	5
Time(hours)				
Region Period	A	B	C	D
1	4	4	4	4
2	6	6	6	6
3	8	8	8	8
4	6	6	6	6
Region	A	B	C	D
Line-haul Distance (miles)	4	5	3	5
Length of Region (miles)	3	2	4	5
Width of Region (miles)	4	5	3	3

Base Case Results -SFC

	Vehicle Size				Route Spacing for Conventional Bus			
	Single Fleet Conventional Bus				A	B	C	D
	30				1.00	1.00	0.75	0.75
	Conventional Bus Headway (hours)				Conventional Bus Fleet Assignment (buses)			
Region Period	A	B	C	D	A	B	C	D
1	0.141	0.154	0.153	0.144	18	20	17	24
2	0.169	0.206	0.158	0.153	10	10	11	15
3	0.338	0.294	0.173	0.255	5	7	10	9
4	0.422	0.411	0.347	0.459	4	5	5	5
	Conventional Bus Cost ($/hour)				Operation Cost × Time			
Region Period	A	B	C	D	A	B	C	D
1	3581.93	3645.33	2903.51	3775.33	14327.73	14581.33	11614.02	15101.33
2	1533.20	1597.06	1757.02	2386.22	9199.20	9582.33	10542.11	14317.33
3	692.67	861.45	1414.80	1154.11	5541.33	6891.62	11318.40	9232.89
4	430.73	537.58	656.40	548.56	2584.40	3225.50	3938.40	3291.33
Total Operation Cost ($/day) = 145289.27, Total Capital Cost ($/day) = 9085, Total Cost ($/day) = 154374.27								

Base Case Results -SFF

	Vehicle Size				Service Area for Flexible Bus			
	Single Fleet Flexible Bus				A	B	C	D
	19				3.00	2.50	3.00	3.00
	Flexible Bus Headway (hours)				Flexible Bus Fleet Assignment (buses)			
Region Period	A	B	C	D	A	B	C	D
1	0.090	0.094	0.098	0.115	38	37	32	41
2	0.139	0.156	0.119	0.129	16	15	18	25
3	0.295	0.240	0.138	0.228	7	9	15	13
4	0.379	0.421	0.266	0.459	5	5	7	6
	Flexible Bus Cost ($/hour)				Operation Cost × Time			
Region Period	A	B	C	D	A	B	C	D
1	3536.44	3449.17	2920.60	3889.67	14145.75	13796.68	11682.39	15558.68
2	1343.78	1347.03	1592.10	2280.22	8062.695	8082.155	9552.63	13681.3
3	603.98	721.93	1268.52	1080.88	4831.873	5775.41	10148.17	8647.04
4	376.32	457.32	567.73	512.66	2257.946	2743.901	3406.406	3075.932
Total Operation Cost ($/day) = 135448.96, Total Capital Cost ($/day) = 16206, Total Cost ($/day) = 151654.96								

Base Case Results -MFC

	Vehicle Size				Route Spacing for Conventional Bus			
	Large Conv. Bus		Small Conv. Bus		A	B	C	D
	40		27		1.00	1.00	0.75	1.00
	Large Conventional Bus Headway (hours)				Small Conventional Bus Headway (hours)			
Region Period	A	B	C	D	A	B	C	D
1	0.000	0.000	0.000	0.144	0.127	0.154	0.144	0.000
2	0.000	0.000	0.000	0.000	0.169	0.187	0.158	0.132
3	0.000	0.000	0.000	0.000	0.338	0.294	0.173	0.215
4	0.000	0.000	0.000	0.000	0.422	0.411	0.347	0.431
	Large Conventional Bus Fleet Assignment (buses)				Small Conventional Bus Fleet Assignment (buses)			
Region Period	A	B	C	D	A	B	C	D
1	0	0	0	18	20	20	18	0
2	0	0	0	0	10	11	11	13
3	0	0	0	0	5	7	10	8
4	0	0	0	0	4	5	5	4
	Mixed Fleet Conventional Bus Service Cost ($/hour)				Operation Cost × Time			
Region Period	A	B	C	D	A	B	C	D
1	3571.00	3633.33	2892.00	3842.83	14284.00	14533.33	11568.00	15371.33
2	1527.20	1587.21	1750.42	2412.23	9163.20	9523.28	10502.51	14473.41
3	689.67	857.25	1408.80	1126.99	5517.33	6858.02	11270.40	9015.93
4	428.33	534.58	653.40	519.74	2570.00	3207.50	3920.40	3118.43
Total Operation Cost ($/day) = 144897.08, Total Capital Cost ($/day) = 8743, Total Cost ($/day) = 153640.08								

Base Case Results -MFF

	Vehicle Size				Service Area for Flexible Bus			
	Large Flex. Bus		Small Flex. Bus		A	B	C	D
	22		17		3.00	2.50	3.00	3.00
	Large Flexible Bus Headway (hours)				Small Flexible Bus Headway (hours)			
Region **Period**	A	B	C	D	A	B	C	D
1	0.097	0.105	0.000	0.000	0.000	0.000	0.094	0.101
2	0.000	0.000	0.000	0.000	0.139	0.156	0.110	0.129
3	0.000	0.000	0.000	0.000	0.295	0.240	0.138	0.228
4	0.000	0.000	0.000	0.000	0.379	0.338	0.266	0.459
	Large Flexible Bus Fleet Assignment (buses)				Small Flexible Bus Fleet Assignment (buses)			
Region **Period**	A	B	C	D	A	B	C	D
1	36	34	0	0	0	0	33	45
2	0	0	0	0	16	15	19	25
3	0	0	0	0	7	9	15	13
4	0	0	0	0	5	6	7	6
	Mixed Fleet Flexible Bus Service Cost ($/hour)				Operation Cost × Time			
Region **Period**	A	B	C	D	A	B	C	D
1	3559.10	3466.35	2907.78	3889.18	14236.40	13865.41	11631.12	15556.72
2	1337.38	1341.03	1582.63	2270.22	8024.29	8046.15	9495.77	13621.30
3	601.18	718.33	1262.52	1075.68	4809.47	5746.61	10100.17	8605.44
4	374.32	447.65	564.93	510.26	2245.95	2685.89	3389.61	3061.53
Total Operation Cost ($/day) = 135121.84, Total Capital Cost ($/day) = 16233 , Total Cost ($/day) = 151354.84								

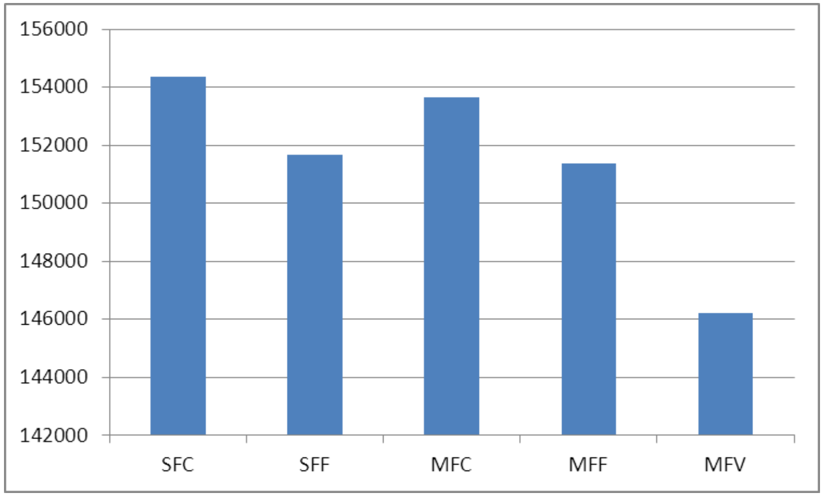
Base Case Results -MFV

	Vehicle Size		Route Spacing for Conv. Bus				Service Area for Flex. Bus			
	Large Conv. Bus	Small Flex. Bus	A	B	C	D	A	B	C	D
	31	16	1.00	-	0.75	0.75	4.00	3.33	4.00	7.50

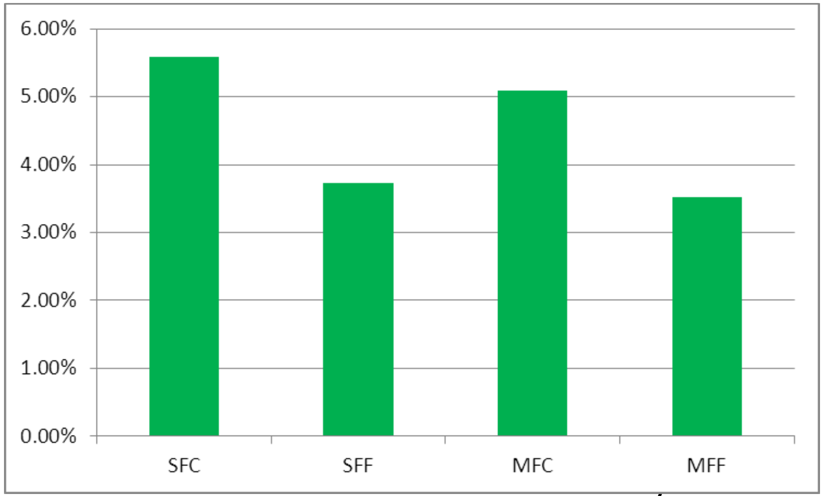
	Large Conventional Bus Headway (hours)				Small Flexible Bus Headway (hours)			
Region **Period**	A	B	C	D	A	B	C	D
1	0.141	0.000	0.153	0.150	0.000	0.060	0.000	0.000
2	0.000	0.000	0.000	0.153	0.125	0.127	0.092	0.000
3	0.000	0.000	0.000	0.000	0.240	0.224	0.114	0.135
4	0.000	0.000	0.000	0.000	0.404	0.338	0.218	0.298
	Large Conventional Bus Fleet Assignment (buses)				Small Flexible Bus Fleet Assignment (buses)			
Region **Period**	A	B	C	D	A	B	C	D
1	18	0	17	23	0	45	0	0
2	0	0	0	15	15	15	19	0
3	0	0	0	0	7	8	15	12
4	0	0	0	0	4	5	7	5
	Mixed Fleet Bus Service Cost ($/hour)				Operation Cost × Time			
Region **Period**	A	B	C	D	A	B	C	D
1	3585.53	3576.37	2906.91	3774.82	14342.13	14305.48	11627.62	15099.28
2	1330.98	1320.51	1593.94	2389.22	7985.91	7923.05	9563.62	14335.33
3	573.37	690.51	1258.39	1034.28	4586.97	5524.10	10067.11	8274.24
4	359.07	423.46	541.43	439.51	2154.44	2540.74	3248.55	2637.04
Total Operation Cost ($/day) = 134215.62, Total Capital Cost ($/day) = 11991 , Total Cost ($/day) = 146206.62								

Base Case Results Comparison

Total Cost ($/day)



MFV cost savings compared to

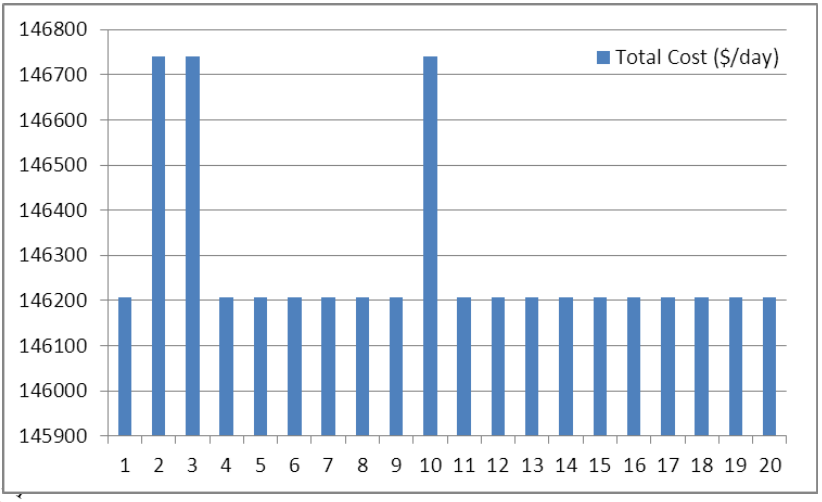


- Savings = (Mode-MFV)/MFV

How Reliable Are the Solutions?

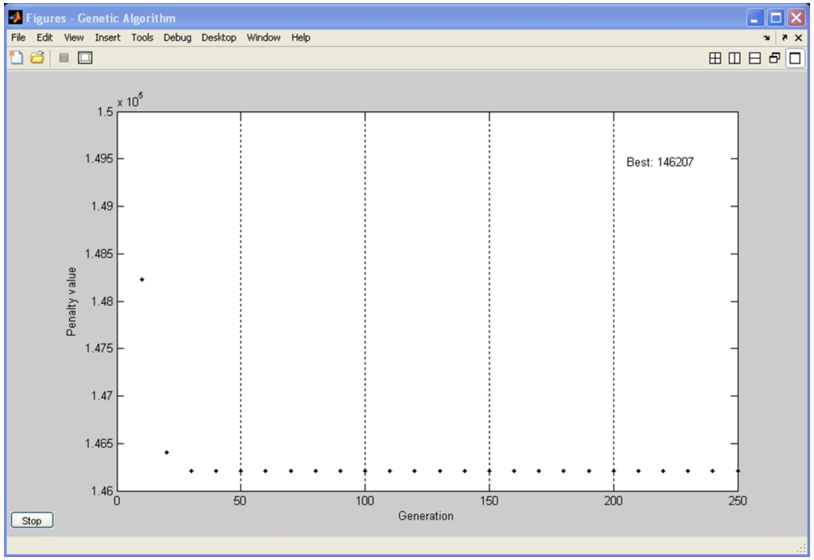
Reliability of IGA

- ☐ 17 of 20 runs find consistent solutions (0.3% difference)



Convergence of IGA to the MFV

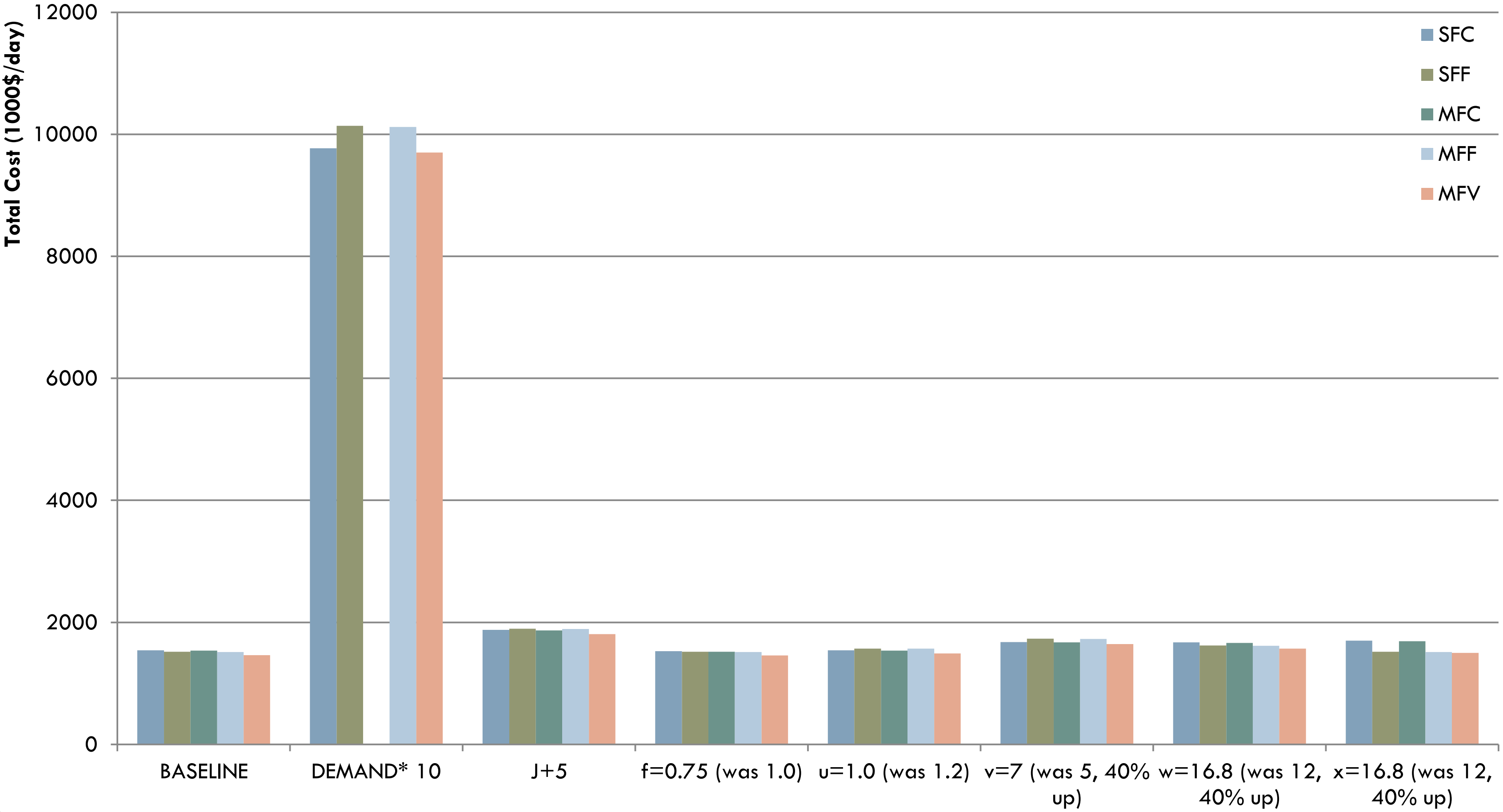
- ☐ Converge within 50 generations



Sensitivity Analysis - Results

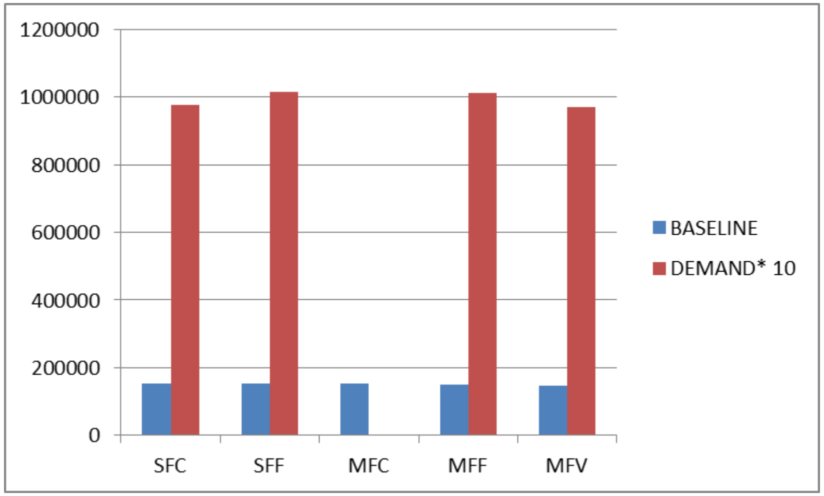
	MFV		SFC		SFF		MFC		MFF
BASELINE	146206.6		154374.3		151655.0		153640.1		151354.8
MFV Savings			5.29%		3.59%		4.84%		3.40%
DEMAND* 10	970303.3		977175.0		1014112.7				1011816.9
MFV Savings			0.70%		4.32%				4.10%
Changes from BASELINE	563.65%		532.99%		568.70%				568.51%
J+5	180483.5		187482.2		189549.9		186763.2		189123.3
MFV Savings			3.73%		4.78%		3.36%		4.57%
Changes from BASELINE	23.44%		21.45%		24.99%		21.56%		24.95%
f=0.75 (was 1.0)	145617.9		152701.0		151655.0		151944.6		151354.8
MFV Savings			4.64%		3.98%		4.16%		3.79%
Changes from BASELINE	-0.40%		-1.08%		0.00%		-1.10%		0.00%
u=1.0 (was 1.2)	149177.0		154374.3		156989.6		153640.1		156738.1
MFV Savings			3.37%		4.98%		2.90%		4.82%
Changes from BASELINE	2.03%		0.00%		3.52%		0.00%		3.56%
v=7 (was 5, 40% up)	164279.6		167704.6		173325.4		166970.4		172979.7
MFV Savings			2.04%		5.22%		1.61%		5.03%
Changes from BASELINE	12.36%		8.64%		14.29%		8.68%		14.29%
w=16.8 (was 12, 40% up)	156887.3		166984.0		161966.6		166226.8		161532.3
MFV Savings			6.05%		3.14%		5.62%		2.88%
Changes from BASELINE	7.31%		8.17%		6.80%		8.19%		6.72%
x=16.8 (was 12, 40% up)	150176.0		170069.8		151655.0		169213.4		151354.8
MFV Savings			11.70%		0.98%		11.25%		0.78%
Changes from BASELINE	2.71%		10.17%		0.00%		10.14%		0.00%

Sensitivity Analysis - Summary

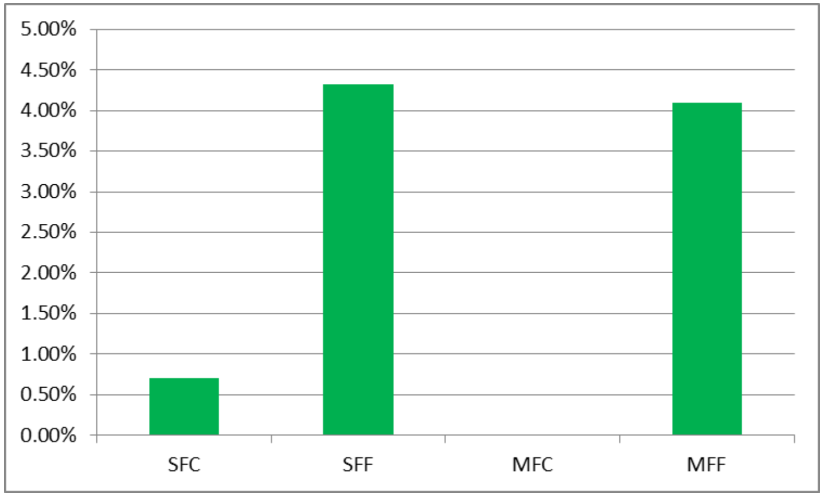


SA(1) : Demand × 10

Total Cost ($/day)



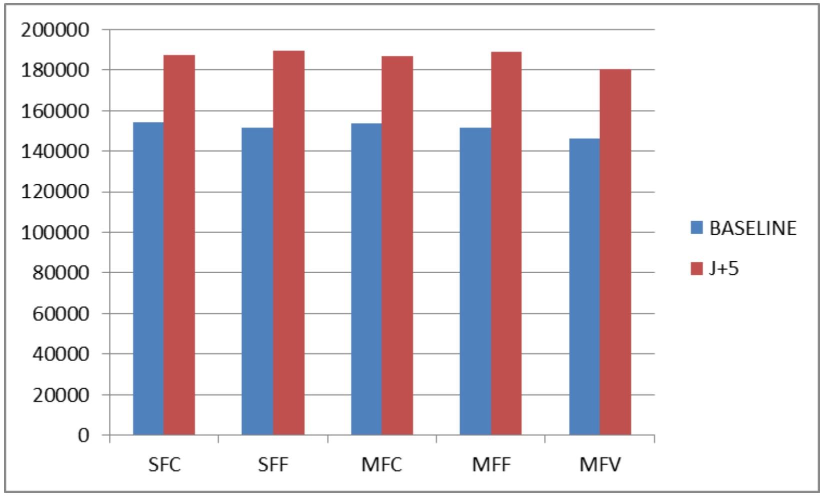
MFV cost savings compared to



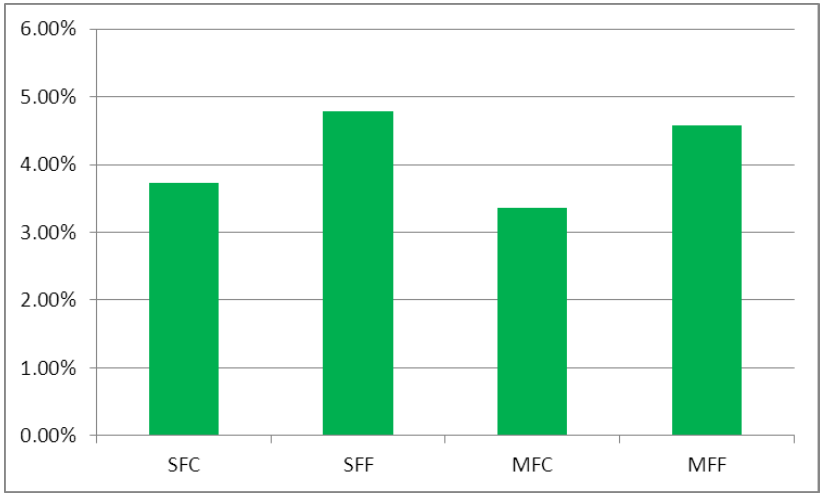
- Savings = (Mode-MFV)/MFV

SA(2) : J + 5

Total Cost ($/day)



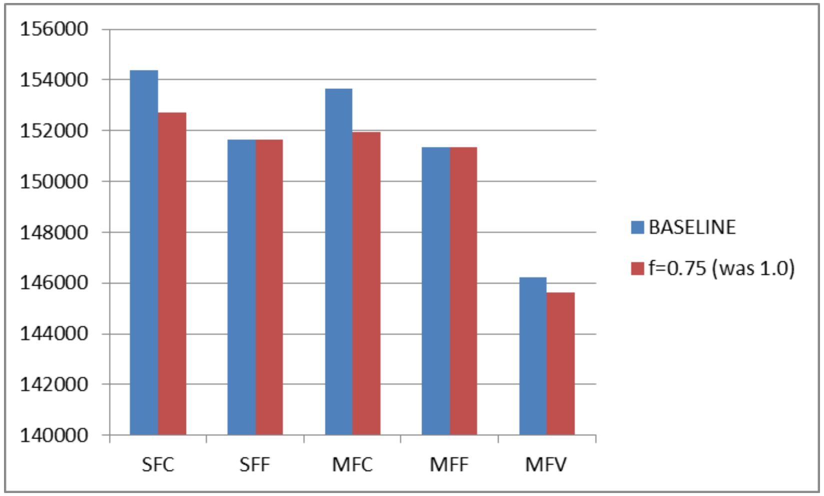
MFV cost savings compared to



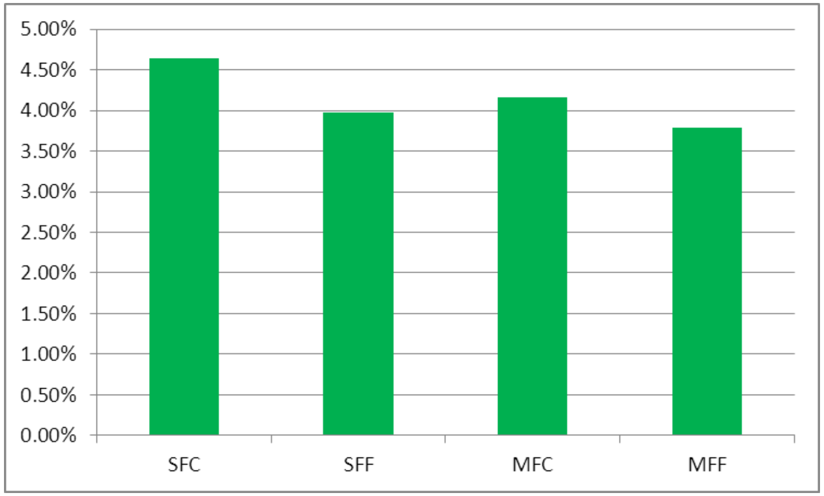
- Savings = (Mode-MFV)/MFV

SA(3) : f=0.75

Total Cost ($/day)



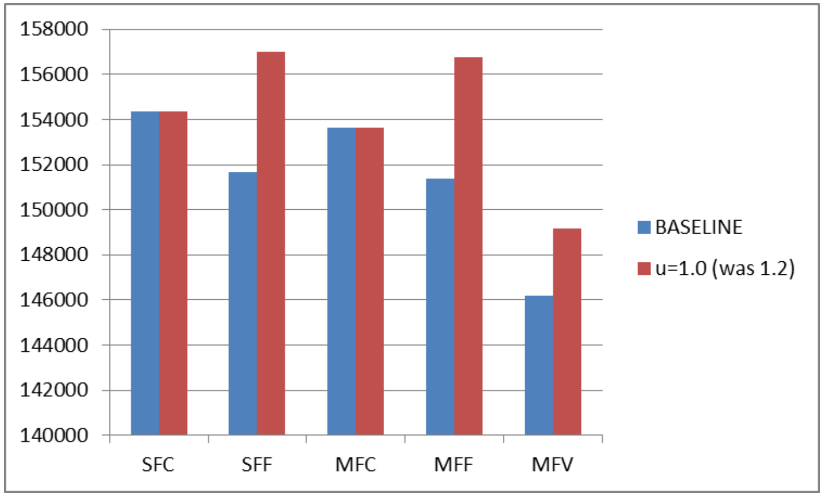
MFV cost savings compared to



- Savings = (Mode-MFV)/MFV

SA(4) : u=1.0

Total Cost ($/day)

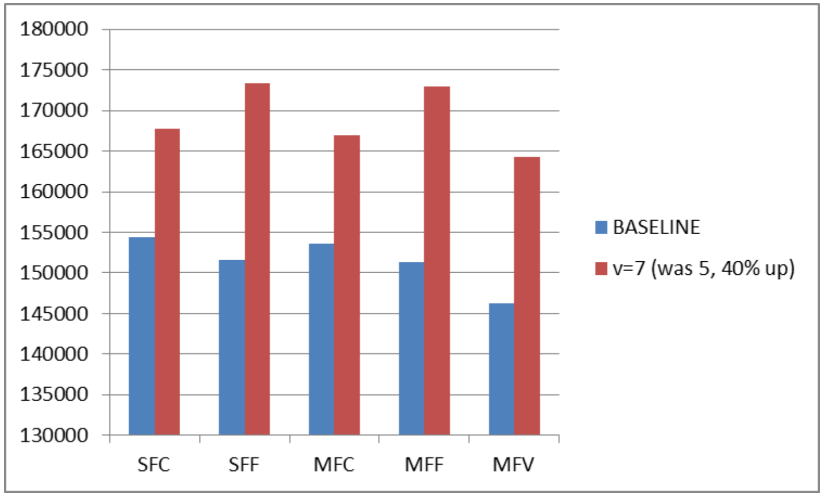


MFV cost savings compared to

- Savings = (Mode-MFV)/MFV

SA(5) : v=7

Total Cost ($/day)

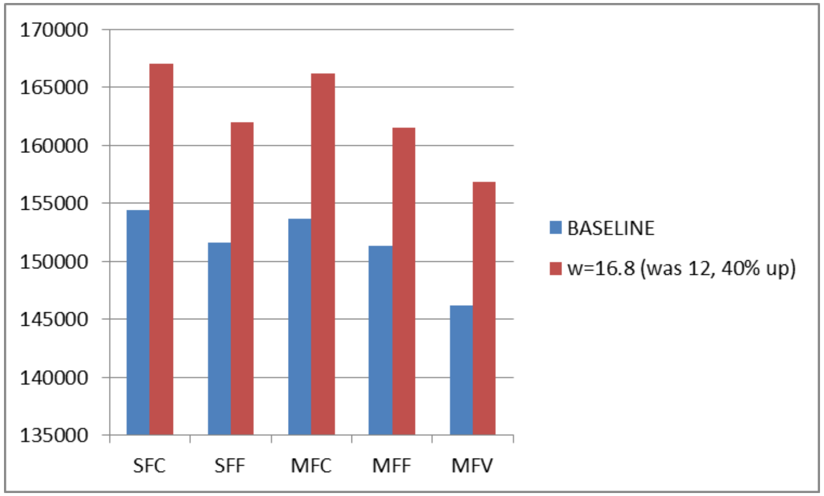


MFV cost savings compared to

- Savings = (Mode-MFV)/MFV

SA(6) : w=16.8

Total Cost ($/day)

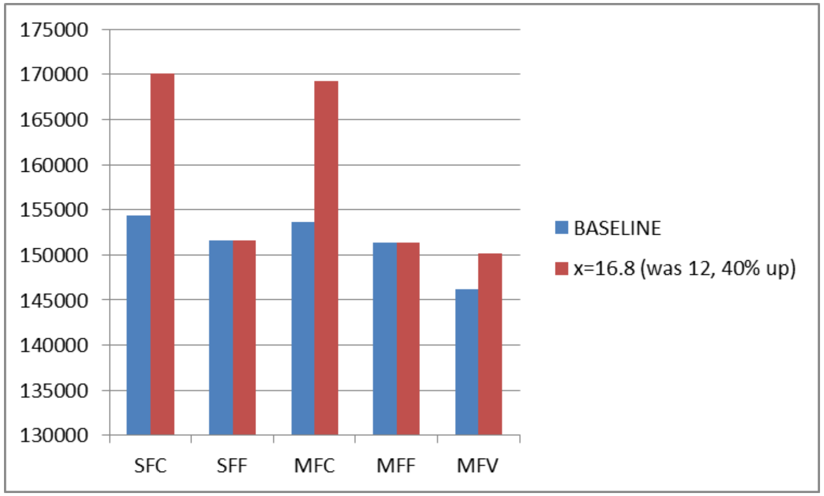


MFV cost savings compared to

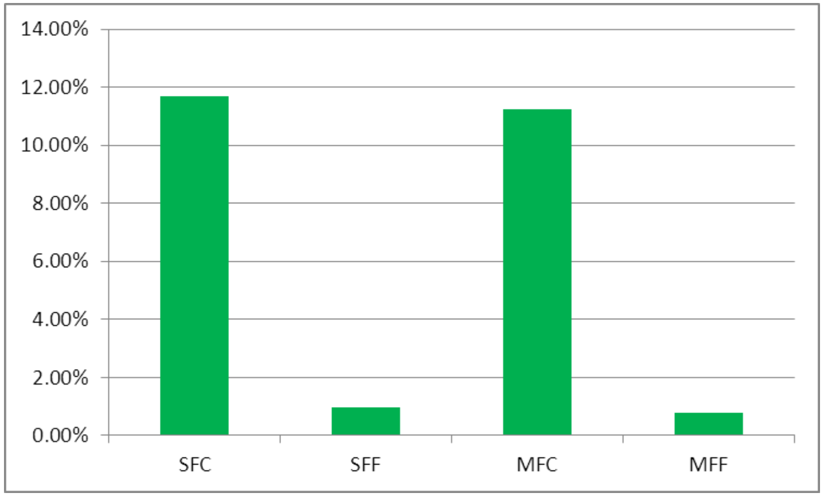
- Savings = (Mode-MFV)/MFV

SA(7) : x=16.8

Total Cost ($/day)



MFV cost savings compared to



- Savings = (Mode-MFV)/MFV

Contributions & Future Studies

- Contributions
  - Non-linear Mixed Integer Cost Functions are formulated and solved with a hybrid (IGA + Analytic Optimization) approach
  - Mixed Fleet Variable Type Bus (MFV) is shown to have the least cost among five alternative bus operations
- Further Studies
  - Optimize bus stops with non-uniform demand
  - Coordinated passenger transfers at terminal

Questions ?

- Contact Info
  - Edward Kim: mkim27@gmail.com, 301-405-3160
  - Paul Schonfeld: pschon@umd.edu, 301-405-1954

- Key References:
  - Kim, M. and Schonfeld, P., Mixed Fleet Variable Type Bus Operation with Alternatives, under review
  - Kim, M. and Schonfeld, P., 2012. Conventional, Flexible, and Variable-Type Bus Services, *Journal of Transportation Engineering*, Vol. 138, No. 3

APPENDIX- MFF Cost Formulation

- Mixed Fleet Flexible Bus ?
  - Provide two sizes of flexible bus services
- Threshold Demand Matrix
  - Set large flexible bus service cost and small flexible bus service cost equal, then obtain:
    - $Q_t^{ki} =$

$$\frac{\frac{L^k W^k (a+bS_l)\left(D_f^k+\O\sqrt{\frac{S_l l A^k}{u}}\right)}{V_f^i l S_l}+\frac{v_v L^k W^k\left(D_f+\O\sqrt{\frac{A^k S_l l}{u}}\right)}{2V_f^i}-\frac{L^k W^k (a+bS_s)\left(D_f^k+\O\sqrt{\frac{S_s l A^k}{u}}\right)}{V_f^i l S_s}-\frac{v_v L^k W^k\left(D_f+\O\sqrt{\frac{A^k S_s l}{u}}\right)}{2V_f^i}}{\frac{v_W L^k W^k l}{2A^k}(S_l-S_s)}$$

  - If demand Q is larger then Q_t^{ki}: provide larger bus
  - Otherwise, small bus

APPENDIX- MFV Cost Formulation

- Mixed Fleet Variable-Type Bus ?
  - Provide Large conventional bus for high demands
  - Provide small flexible bus for low demands
- Threshold Demand Matrix
  - Set large conventional bus service cost and small flexible bus service cost equal, then obtain:
    - $$Q_t^{ki} = \frac{\frac{v_W}{2}\left\{\frac{S_f l_f}{A^k} - \frac{S_c l_c}{r^k f L^k}\right\}}{\left\{\frac{D^k f(a+bS_c)}{V_c^i S_c l_c} - \frac{(a+bS_f)(D_f+\emptyset\sqrt{A^k S_f l_f/u})}{V_f^i S_f l_f} + \frac{v_v M^k}{V_c^i} - \frac{v_v(D_f+\emptyset\sqrt{A^k S_f l_f/u}}{2V_f^i} + \frac{v_x(r^k+d)}{4V_x}\right\}}$$
  - If demand Q is larger then Q_t^{ki}: provide larger bus
  - Small bus, otherwise

APPENDIX- Capital Cost Formulation

-
- Fleet Size Matrix $= \begin{bmatrix} F_c^{11} & \cdots & F_c^{k1} \\ \vdots & \ddots & \vdots \\ F_c^{1i} & \cdots & F_c^{ki} \end{bmatrix} \rightarrow \begin{bmatrix} \sum_{i=1} F_c^{ki} \\ \vdots \\ \sum_{i=i} F_c^{ki} \end{bmatrix}$
- Required Total Fleet Size (vehicles/day)

  $= max\{\sum_{i=1} F_c^{ki}, \ldots, \sum_{i=i} F_c^{ki}\}$
- Capital Cost $= (a_c + b_c S_c) \times Total\ Fleet\ Size$
- Apply also for flexible bus

General Thoughts on Intermodal Passenger Transportation

General Thoughts on Intermodal Passenger Transportation

- Transportation modes vary greatly in their characteristics and suitability for particular applications
- The modes with high speed and capacity should usually rely on modes with lower speed and lower infrastructure requirements for local collection & distribution of passengers. That requires transfers.

Advantages of Transportation System with Intermodal Transfers

- No need for direct routes among all origin - destination pairs
- Concentrate passengers on major routes with faster and/or lower cost modes
- Improve utilization of infrastructure
- Reduce negative impact, e.g. congestion, energy use, emissions and accidents

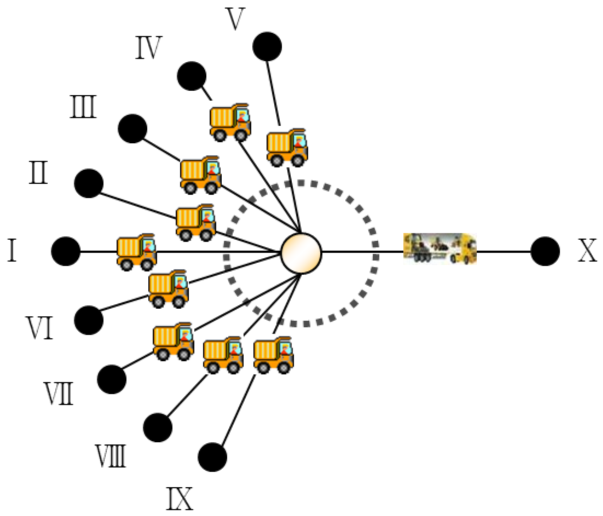
- Transfer coordination ***<u>may</u>*** be desirable for **<u>some</u>** vehicle pairs at transfer terminals, depending on route characteristics, expected wait times at transfer terminals and elsewhere, variability of travel times, slack times needed in schedules, information on vehicle locations vehicle arrival times, connecting passengers and passengers waiting downstream, and effects induced elsewhere in the system.

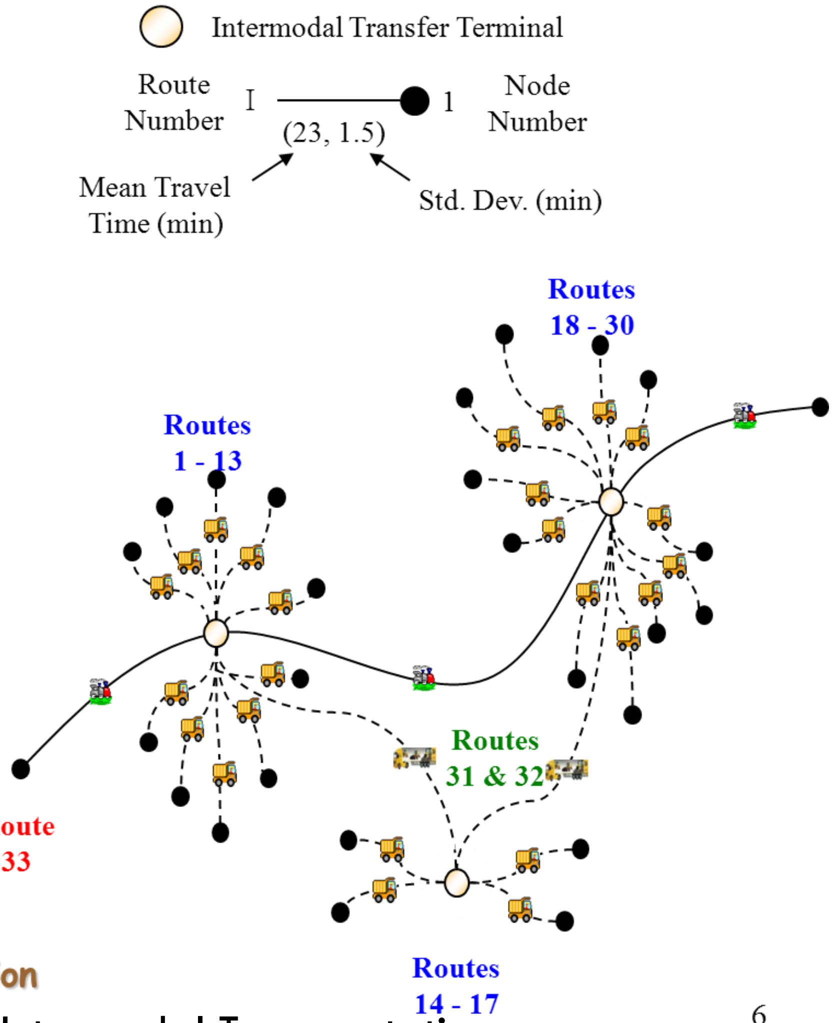
Main Components of Optimization Methods for Integrated Intermodal Systems

- Network design, including location of transfer terminals
- Schedule optimization, with optimized slack times
- Real-time dispatching decisions for ready vehicles, considering delay propagation through networks

Multi-Hub Intermodal Network

Case 1 Network Configuration

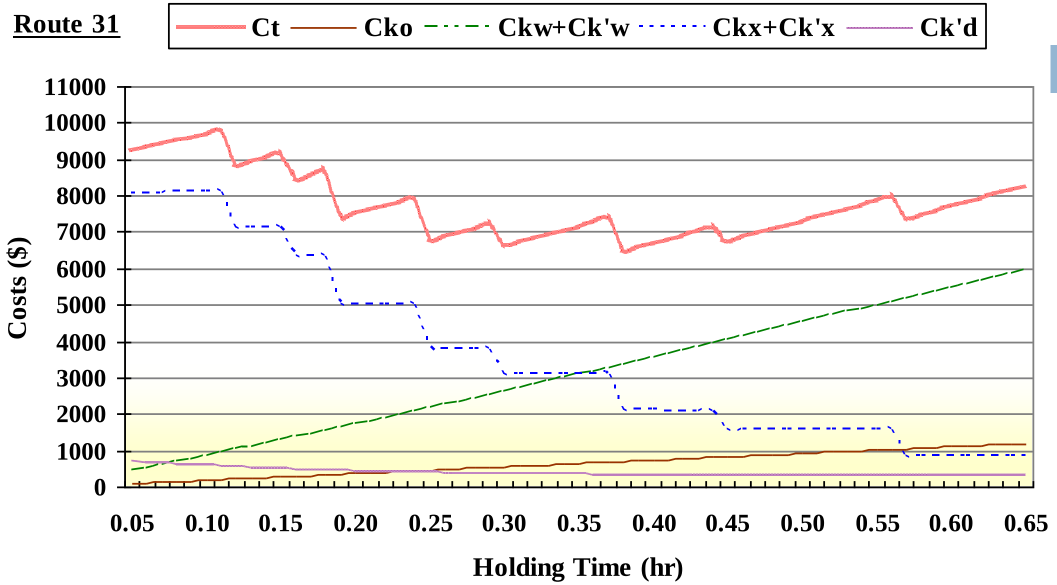


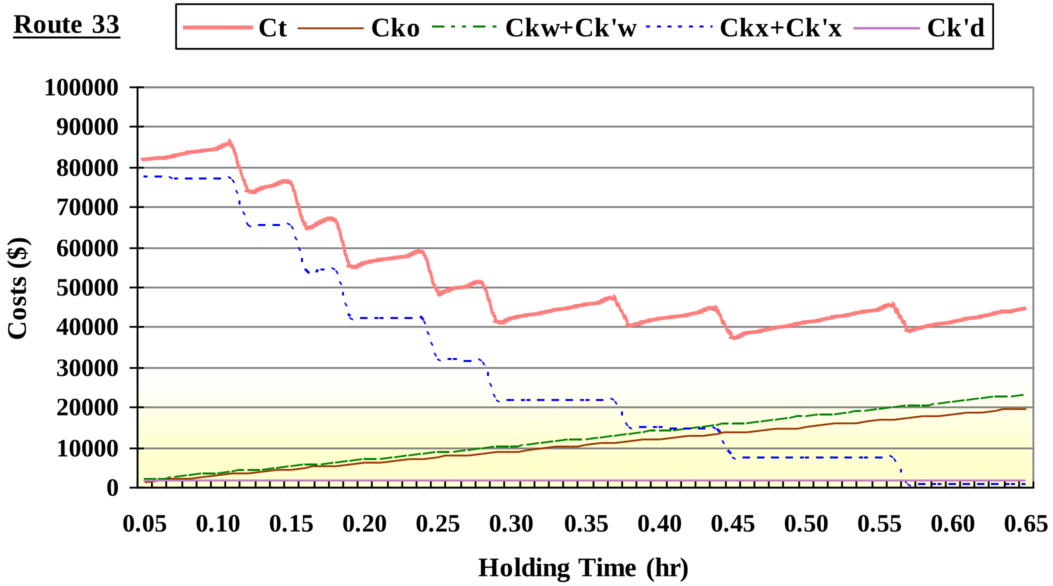


Case 2 Large Network Configuration

Real-Time Dispatching

- The optimized holding time (T31) is 22.21 (min), which indicates that the ready vehicle should wait until the 6th late vehicle (from Route 1) arrives.
- The optimized holding time (T33) is 26.874 (min), which means that the ready vehicle should wait until the 7th late vehicle (from Route 6) arrives.





Transfer Coordination in Logistic Networks

Frank Chen and Paul Schonfeld

Dept. of Civil Engineering

March 28, 2011

Modeling and Performance Assessment of Intermodal Freight Transportation Timed Transfer Systems

Motivation

Mode of Transportation	Shipment Characteristics by Mode in Ton-miles		
	2002 (million)	2007 (million)	Percentage Change
Single Modes	**2,867,938**	**2,894,251**	**0.9**
Truck	**1,255,908**	**1,342,104**	**6.9**
Rail	**1,261,612**	**1,344,040**	**6.5**
Water	**282,659**	**157,314**	**-44.3**
Air	**5,835**	**4,510**	**-22.7**
Multiple Modes	**225,715**	**416,642**	**84.6**

- **Data Source: 2007 Commodity Flow Survey, U.S. DOT, RITA, BTS Special Report**

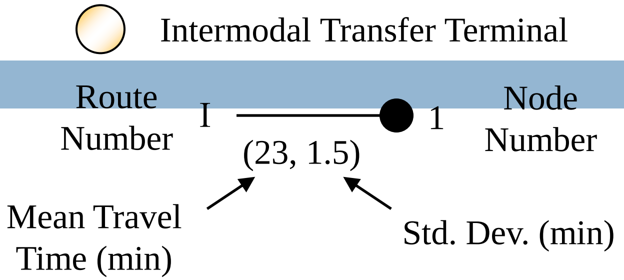
Motivation

- Advantages of an intermodal timed transfer system
  - Eliminating direct routes connecting all origin-destinations pairs and concentrating cargos on major routes with faster (e.g. airplanes) or lower cost (e.g. container ships) modes
  - Improving the utilization of existing transportation infrastructure
  - Reducing the requirements for warehouses and storage areas due to poor connections
  - Reducing other impacts, including traffic congestion, fuel consumption, emissions, and accidents

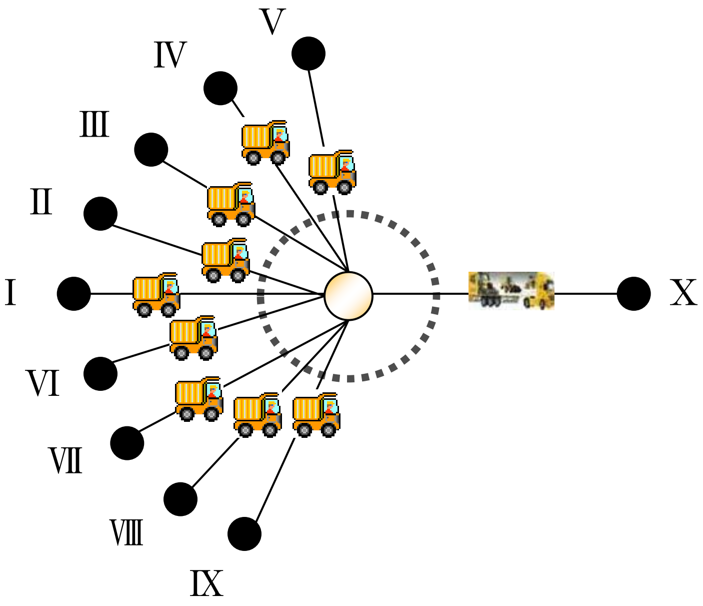
Solution Approaches

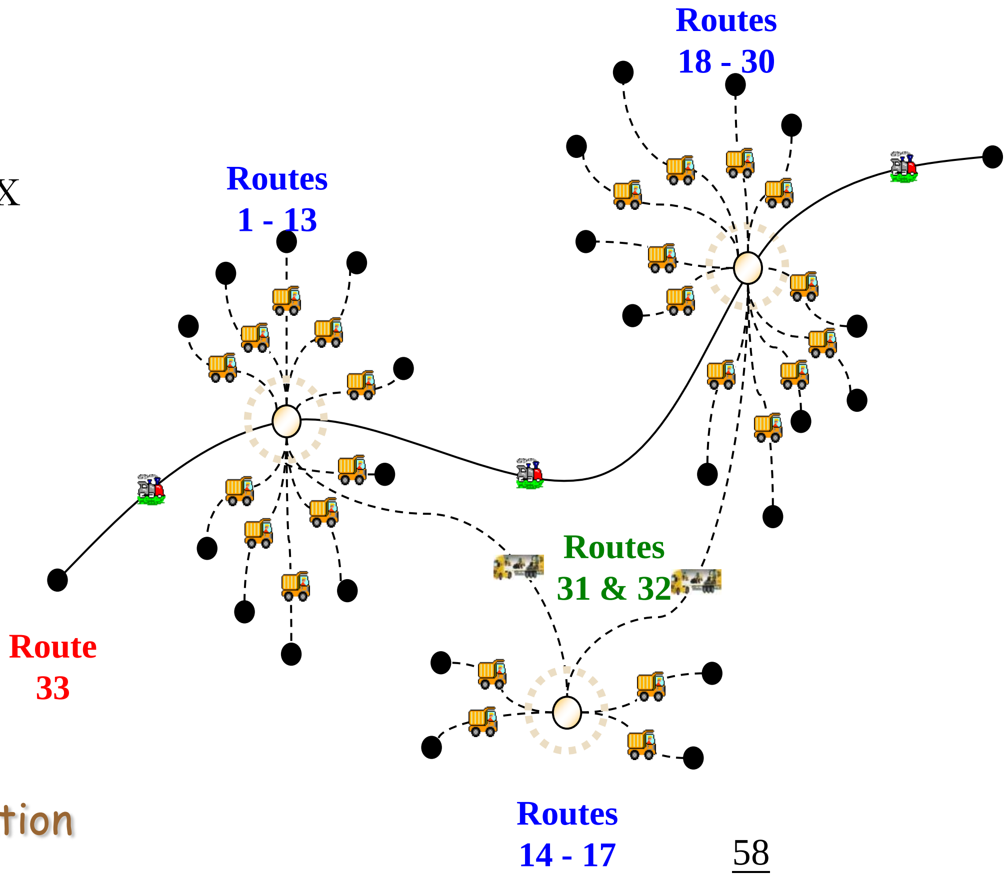
- GA, SQP, and Hybrid GA – SQP Algorithm

Algorithms	Advantages	Disadvantages
GA	(1) Global search pattern (2) No need to calculate Gradient and Hessian (3) Suitable for large-scale problems with many local optima	(1) Converge slowly during the final gen. (2) Generate many infeasible solutions (3) Longer program running time (4) Different random seeds may lead to different final solutions
SQP	(1) Provide quick and robust solutions	(1) Easily trapped in local optima (2) Sensitive to different initial estimates (3) Unsuitable for large-scale problems
GA - SQP	(1) Global search pattern (GA) with faster local convergence (SQP) (2) Generate robust solutions (3) Suitable for large-scale problems with many local optima	(1) Longer program running time than pure SQP



Case 1 Network Configuration





Case 2 Large Network Configuration

Model Applications

- Optimized results for different policies in case 1

Slack Time	Coordinated (GA)	Coordinated (GA-SQP)
S_1^1	0.0326	0.0170
S_2^1	0.0756	0.0557
S_3^1	0.0321	0.0300
S_4^1	0.1064	0.0170
S_5^1	0.0209	0.0229
S_6^1	0.0217	0.0466
S_7^1	0.0203	0.0175
S_8^1	0.0793	0.0246
S_9^1	0.0535	0.0558
S_{10}^1	0.0500	0.0500

Costs ($ / hr)	Uncoord	Coord/GA	Coord/GA-SQP
Operating Cost	10382	12496	12485
Dwell Cost	5216	4444	4447
Loading / Unloading	10	9	9
Cargo Processing	9	7	7
Non-transfer Cost	15617	16956	16948
Inter-cycle	--	0	0
Slack time	--	661	509
Miss-connection	--	1724	1958
Connection delay	--	442	328
Transfer Cost	5216	2827	2795
Total System Cost	20833	19783	19743

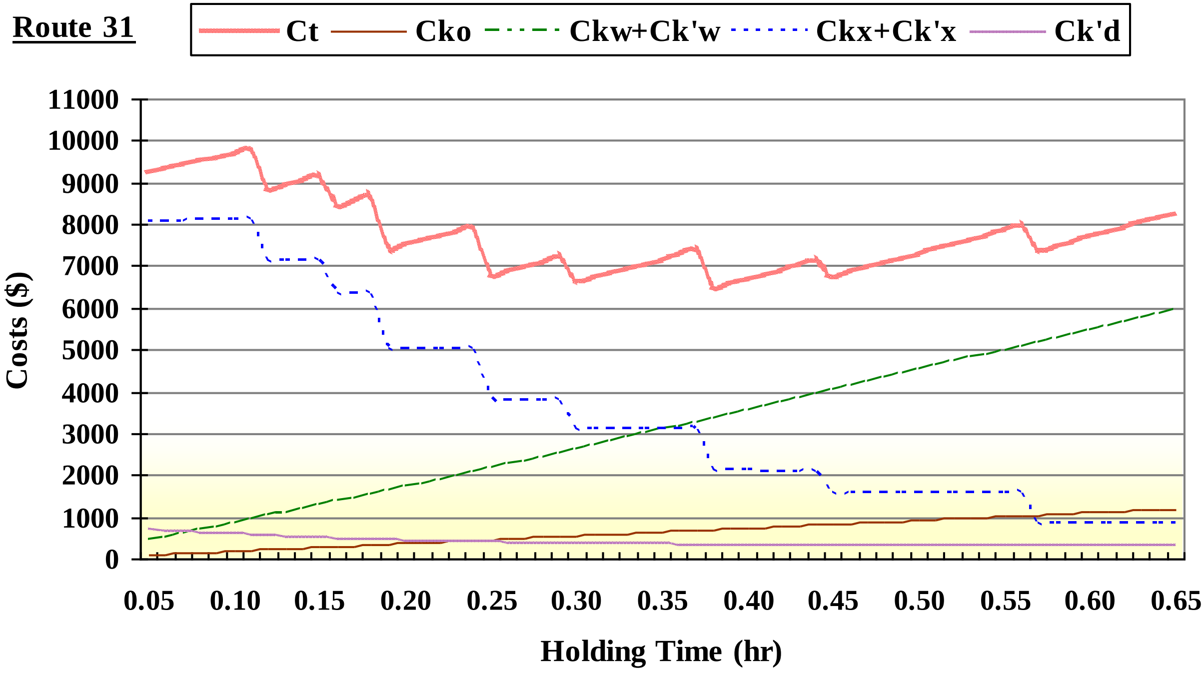
Dispatching Problem Statement

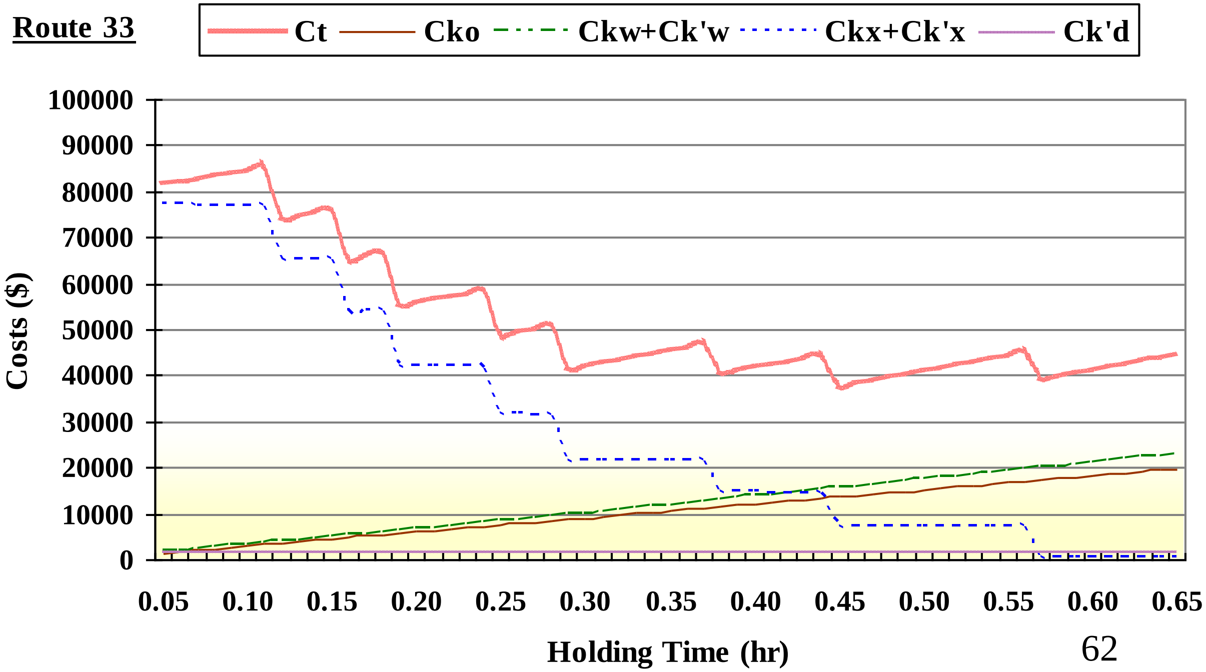
- A real-time dispatching control model is developed to alleviate schedule disruptions.
- Disruptions may sometimes affect the system operations, and the previous optimal plan may become non-optimal or even infeasible.
- When disruptions occur, we mainly consider how to adjust or re-optimize the original plan to adapt the changing environment and how to get back on track soon while effectively using our available resources.
- The control model determines through an optimization process which ready outbound vehicles should wait for which late inbound ones.

Inbound route delay information in Case 2

Inbound Route (From)	Route Travel Time (min)		(To) Outbound Truck Route 31 (Unit: lb / hr)		(To) Outbound Rail Route 33 (Unit: lb / hr)		Delay Information (min)	
	Mean	Std. Dev.	m = 1	m = 2	m = 1	m = 2	Mean	Std. Dev.
1	97	8.6	503	1081	1311	2817	23	0.4
2	60	5.3	551	1185	1937	4166	12	0.3
3	68	7.4	302	649	1674	3598	18	0.35
4	104	10.5	189	406	1752	3767	--	--
5	53	5.5	303	652	1714	3688	10	0.25
6	93	8.8	243	523	1395	3000	27.5	0.45
7	85	9.1	382	821	2145	4612	--	--
8	64	7.2	520	1118	1688	3630	15.5	0.3
9	83	7.7	378	812	1356	2915	--	--
10	41	4.5	366	786	1696	3647	7.5	0.25
11	32	3.6	524	1127	2221	4775	--	--
12	56	4.8	381	820	2036	4378	--	--
13	99	10.1	380	817	1289	2772	35	0.5

- The optimized holding time (T_{31}) is 22.21 (min), which indicates that the ready vehicle should wait until the 6_{th} late vehicle (from Route 1) arrives.
- The optimized holding time (T_{33}) is 26.874 (min), which means that the ready vehicle should wait until the 7_{th} late vehicle (from Route 6) arrives.



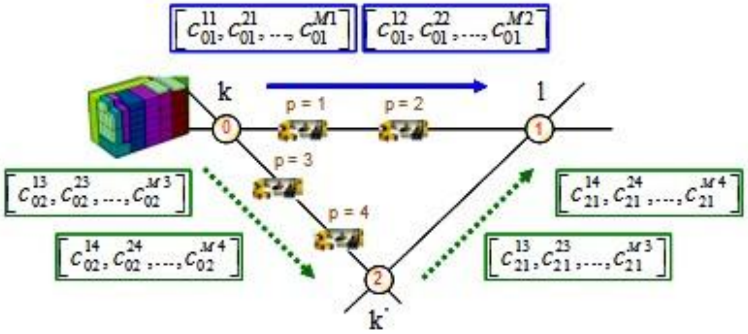


Model Development

- Optimized problem for distributing missed-connection cargos at transfer terminals
  - Applies to cargos left over due to missed connections caused either by the no-holding decisions or arrivals after the ready vehicles have been dispatched
  - The mathematical model describing the re-distributing plan is formulated based on the well-known location choice problem (Revelle and Laporte, 1996).

$$Min \quad \omega = \sum_{m \in M} \sum_{\substack{k,l \in N \\ k \neq l}} \sum_{p \in n_p} c_{kl}^{mp} \pi^p \alpha_{kl}^{mp} \beta^p$$

$$+ \sum_{p \in n_p} \lambda^p \beta^p$$



- Assume some candidate pick-up vehicles including one rail train (p = 1) and three container trucks (p = 2~4) can move those cargos from terminal 1 to terminals 2 and 3.

- In general, most cargos are re-assigned to candidate vehicles based on their shortest path (e.g. terminal 1 – 3 or terminal 1 – 2).

- Certain cargos with higher time value (m = 1) are re-assigned to farther path (i.e. terminal 1 – 3 – 2) so as to minimize total shipping time (i.e. longer travel time but much shorter dwell time.)

Missed-Transfer Cargos Left at Terminal 1				
(From) Terminal 1	**(To) Terminal 2 (Unit: lb)**		**(To) Terminal 3 (Unit: lb)**	
	m = 1	**m = 2**	**m = 1**	**m = 2**
6	**--**	**--**	**494**	**1,063**
13	**2,621**	**5,636**	**773**	**1,661**
Candidate Delivery Vehicles for Re-Distribution				
Vehicle ID	**p = 1**	**p = 2**	**p = 3**	**p = 4**
Space (lb)	**50,000**	**2,250**	**2,400**	**2,000**
Optimized Re-Distribution Results				
(From) Terminal 1	**(To) Terminal 2 (Unit: lb)**		**(To) Terminal 3 (Unit: lb)**	
	m = 1	**m = 2**	**m = 1**	**m = 2**
p = 1	**--**	**5,636**	**--**	**--**
p = 2	**983**	**--**	**1,267**	**--**
p = 3	**1,638**	**--**	**--**	**762**
p = 4	**--**	**--**	**--**	**1,982**

Future Research Plan

- Analyze and test a contra-flow network reconfiguration and resilience approach in the simulated environment during the phases of post-disaster response, recovery, and management.
- Develop mitigation plans of traffic delays arising during the nonrecurring congestion in time-dependent, stochastic and dynamic environments.
- Improve the above GIS-based applications for emergency disaster logistics management plans.
- Simulate and optimize various intermodal logistics problems with real-world applications.