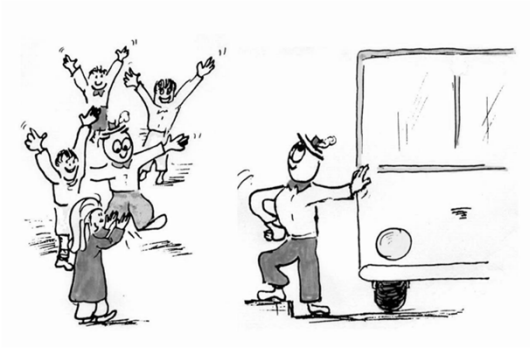
Tutorial: Scheduled Service Management

The 20th ISTTT at Noordwijk, The Netherlands
July 16, 2013

Outline:

1. **Overview - Planning Elements**
2. **Motivation**
3. **Frequency Determination**
4. **Optional Timetables**
5. **Vehicle Scheduling**
6. **Exercise**



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1

The Roots of Curiosity: Being a Bus Driver 1967-1971

From first-hand experience: There are only 3 jokes on Bus Drivers…The remainder is indeed true

2

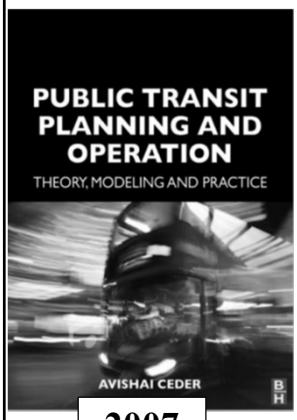
Why we need better Public-Transport Systems ?

Japan

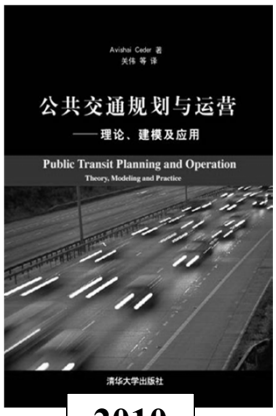
Los Angeles, USA

3

Book by (1) Elsevier (UK, Oxford), 2007
(2) Tsinghua Publishing House (Chinese), June 2010
(3) Taylor and Francis (UK, London), 2nd Edition, early 2014

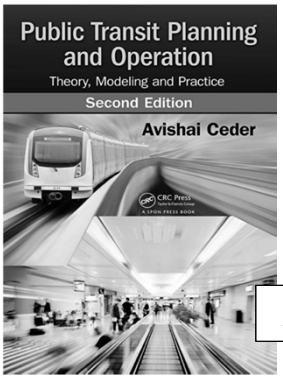


2007



2010

How to get rid of problems related to public transport operations planning ?



2014

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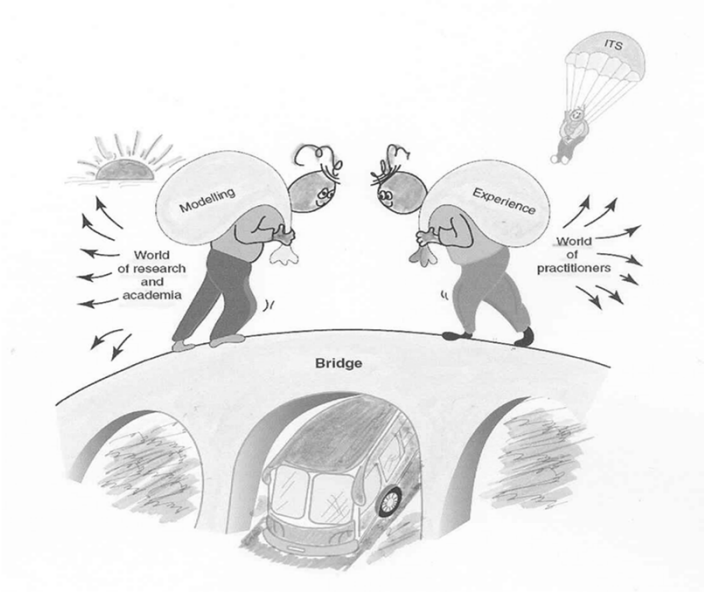
Purpose



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Dreams and Reality

Some men see things as they are and say: "why?". I dream things that never were and say "why not?!" (George Bernard Shaw)

Lost of time = Frustration
Road accidents
Air pollution and noise

… if so, why not public transportation?

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Public Transport Planning

A. **<u>Long Range</u> (> 3 Years)**
Major Capital Investment
Major Institutional Changes

B. **<u>Medium Range</u> (1 - 3 Years)**
Bus Network Structure
Network Size
Fleet Size
Fare Policy

C. **<u>Short Range</u> (< 1 Year)**
Route Structure
Service Frequency
Vehicle and Crew Scheduling

D. **<u>Control</u> (Real Time)**
Revise Route of Specific Vehicle
Revise Schedule of Specific Vehicle

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Illusion – where is the baby (new born ideas) ?

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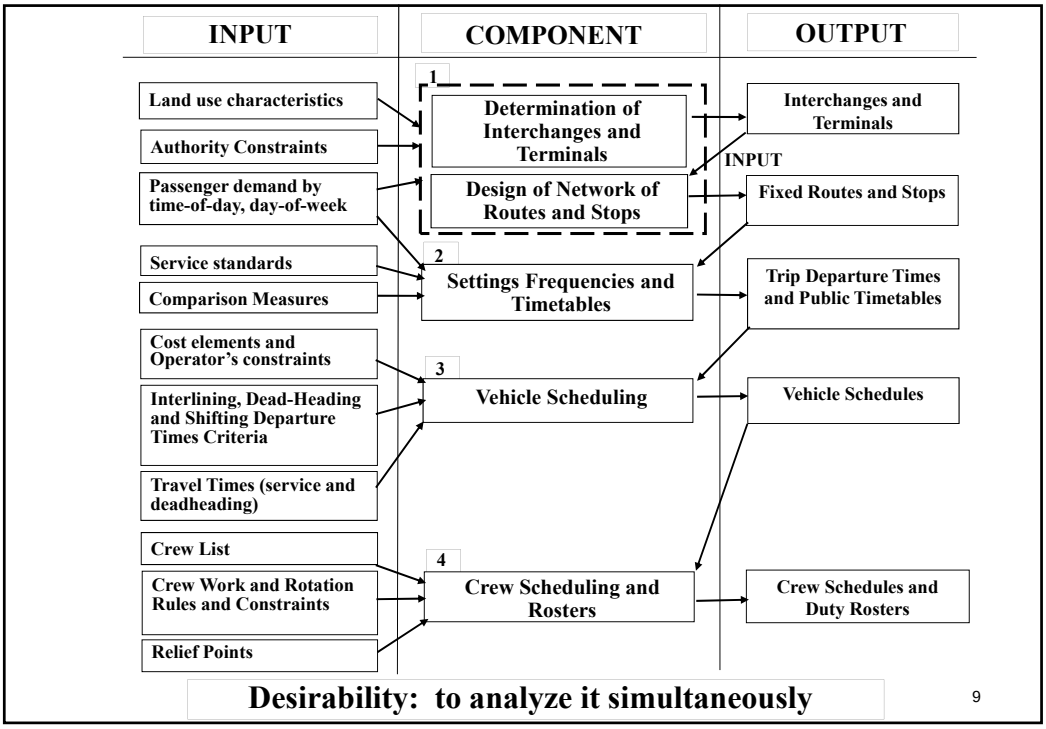

Four Phases of the Transit Operations Planning Process

Phase 1: Network Route Design

- Aim is to satisfy the demand (varies by hour, day, week, season, year) which reflects – business, industrial, cultural, educational, social, and recreational needs

Phase 2: Setting Timetables

- For each route to meet variation in the demand
- To perform coordination between routes
- To comply with frequency constraints

Phase 3: Scheduling Vehicles to Trips

- To list all daily chains of trips (some dead-heading) for a vehicle
- To consider appropriate trip time
- To fulfill the timetable requirements
- To satisfy operational requirements (refueling, maintenance, etc.)

Phase 4: Assignment of Drivers

- To comply with union and operational constraints (rest period, preferences, shift splitting, shift length, etc.)
- To deal with problems resulting from various pay scales, and human satisfaction needs

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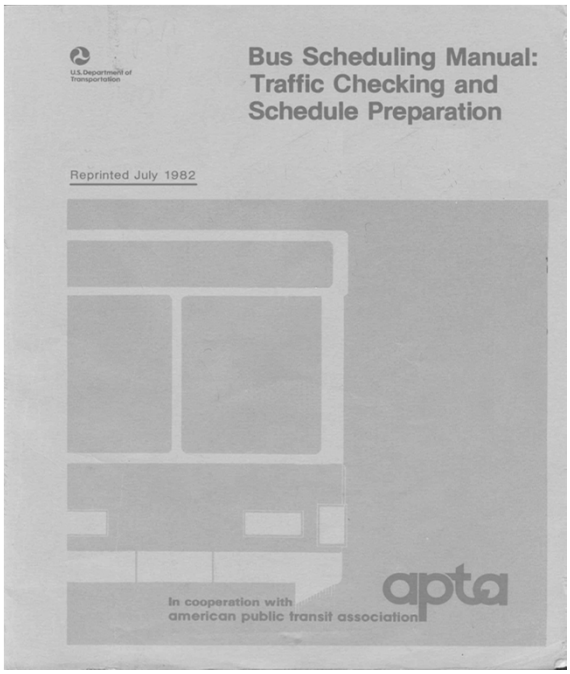
U.S. Department of Transportation
Bus Scheduling Manual:
Traffic Checking and
Schedule Preparation
Reprinted July 1982
In cooperation with
american public transit association
apta

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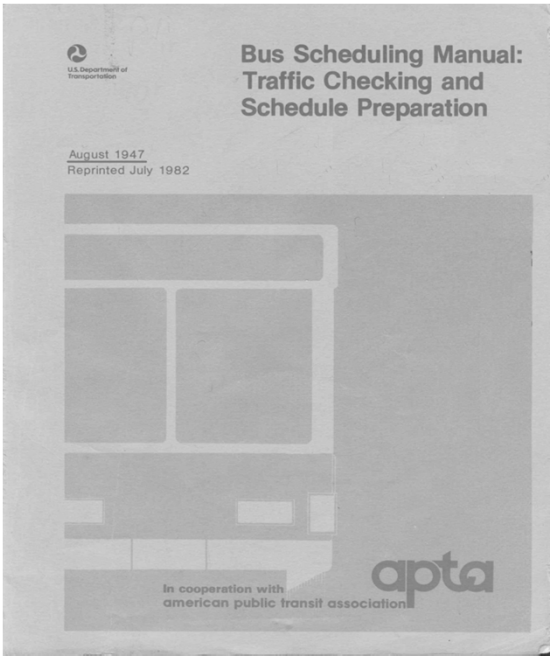
U.S. Department of Transportation
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apta

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Seek for better understanding between modelers and operators
Goethe saying: ”Everyone hears (and see) only what he understands”

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Objectives for Frequency Setting

(1) Setting of vehicle frequencies to:

- **Maintain Adequate Service quality.**
- **Minimize the Number of Vehicles in the Schedule**

(2) Allocating Efficiently the Cost to Gather Passenger Load Data

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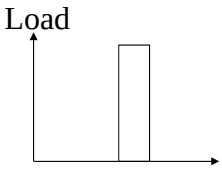
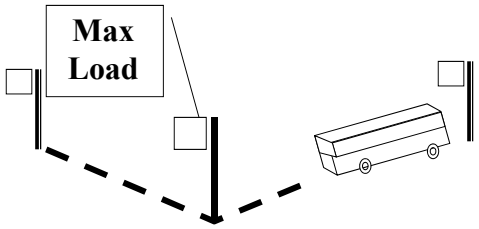
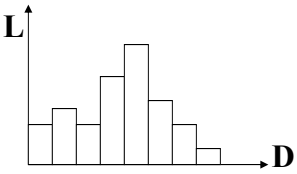
POINT CHECK (Max Load)

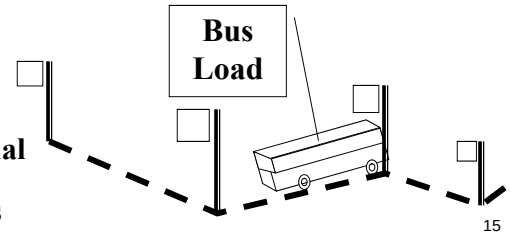




RIDE CHECK (Load Profile)



Question: Whether the additional information gained justifies the expenses



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Frequency Determination

FREQ=max (**Freq by method, see below** , **Minimum Freq (Inverse of policy headway)**)

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Two Point Check Methods (for period j)

METHOD 1	$(FREQ)_j = \dfrac{(\text{Load at } \textbf{Daily} \text{ Max Load Point})_j}{(\text{Desired Occupancy})_j}$
METHOD 2	$(FREQ)_j = \dfrac{(\text{Load at } \textbf{Hourly} \text{ Max Load Point})_j}{(\text{Desired Occupancy})_j}$

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Two Ride Check Methods (for period j)

METHOD 3	$(FREQ)_j = \max\left[\dfrac{\text{Area in Pass-Miles (km)}_j}{\left(\text{Desired Occupancy}\right)_j \times \left(\text{Route Length}\right)} , \dfrac{\text{Load at Hourly Max Load Point}_j}{\text{Veh Capacity}} \right]$
METHOD 4	**Same as Method 3, but with the constraint that only in a certain portion of route length can the load exceed the product:** **[(Frequency)$_j$ x (Desired Occupancy)$_j$]**

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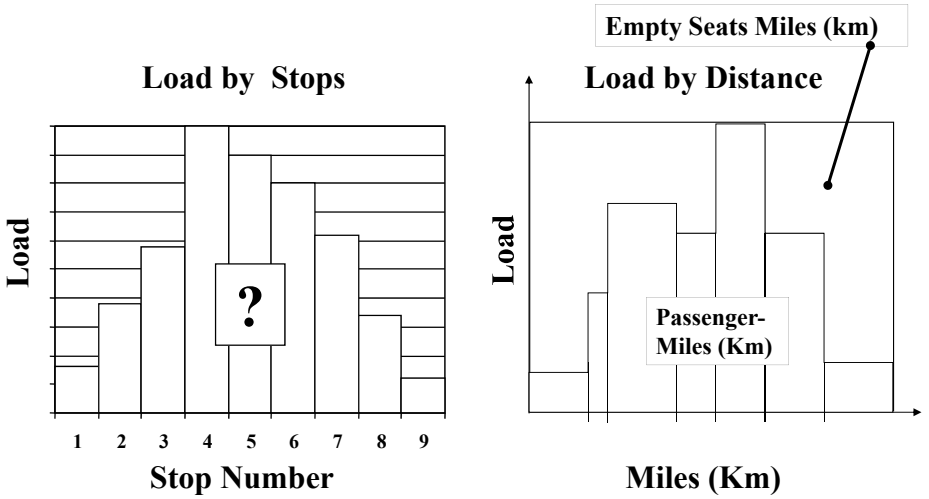
Load Profile
(Common vs. Meaningful)



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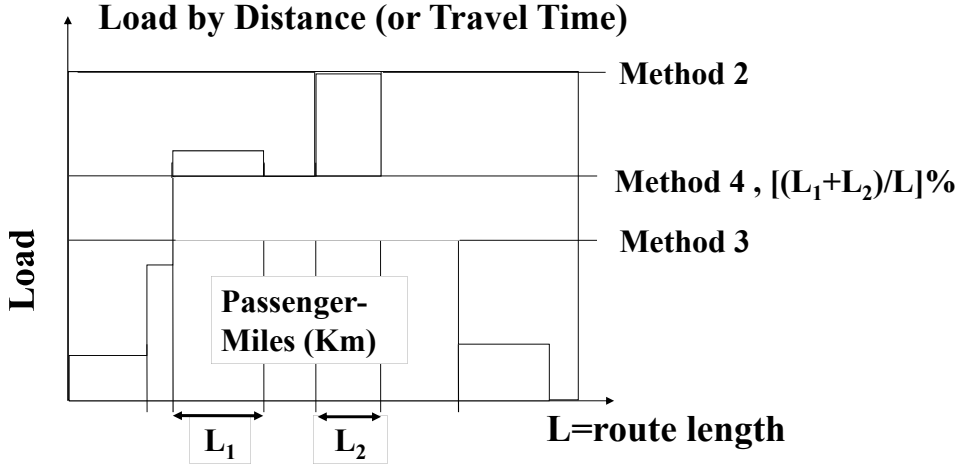
Load Profile



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Basic Input Data of Example

Distance (km) between stops	Stop Name	Loads in each time Period 6 -7 am	7 - 8	8 - 9	Total Load
0	Departure Terminal	77	261	118	456
3	Stop 1	132	323	294	749
2	Stop 2	119	411	231	761
2	Stop 3	116	387	273	776
3	Arrival Terminal				
Number of observed Scheduled Buses		2	6	4	
Desired Occupancy (Load Factor or Load standard)		50	65	65	
Policy Headway (minutes)		30	30	30	
Single mean round trip time, including layover and turn around times (minutes)		55	67	55	
Bus Capacity (Number of seats +max allowable standees)		80			
Area under the load profile (passenger-km)		1081	3412	2223	

Calculated

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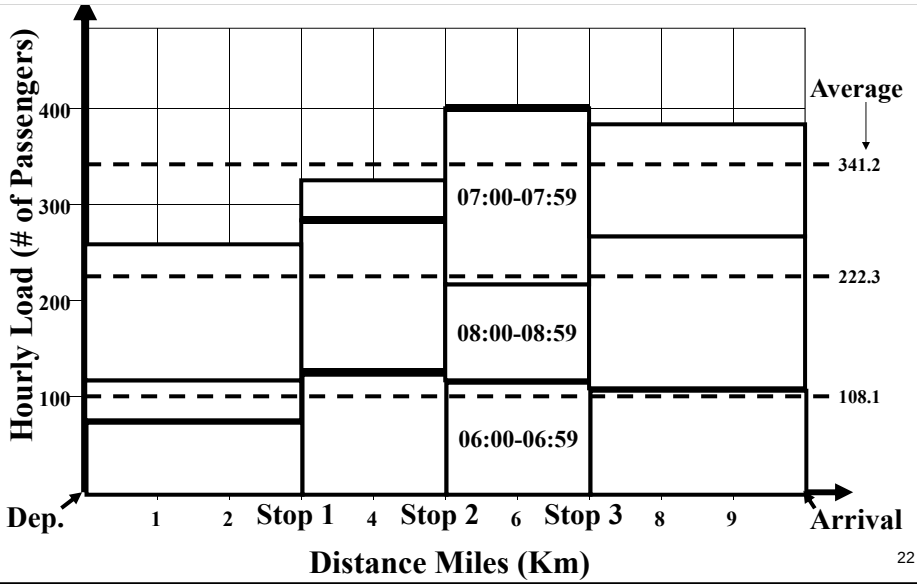
Graphic Representation of the Example Load Profiles with the Determinant Load Value for Method 3



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Frequency and Headway Results of Example Problem

Time Interval	Method 1		Method 2		Method 3		Method 4 (20%)	
	F	H	F	H	F	H	F	H
06:00-06:59	2.32	26	2.64	23	2.16	28	2.38	25
07:00-07:59	5.95	10	6.32	9	5.25	11	5.95	10
08:00-08:59	4.20	14	4.52	13	3.67	16	4.20	14

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Current Practice

1. **Running times are established for each route**
2. **The calculated bus speeds are examined (to correct special cases of speeding-up and slowing-down)**
3. **Headways are determined at the peak point**
4. **Initial departure times are set at the peak point**
5. **Departure times are set at all route time points**
6. **The departure times are adjusted at the peak point (to include practical elements)**
7. **The final route Timetable is completed**
8. **Updating and transfer to marketing**

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Current Practice Example:

- **LA Metro files include 40,000 trips. The data is collected manually and then key punched**
- **About 40% of the scheduler's time is devoted to data entry and proofreading generated reports**

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Objectives

- Evaluate alternative timetables in terms of required resources
- Improve the correspondence of vehicle departure time with passenger demand while minimizing resources
- Improve timetables for synchronization
- To permit in timetable construction procedure, direct bus frequency changes for possible exceptions (known to the scheduler) which do not rely on passenger demand data
- To allow the construction of timetables with headway smoothing techniques (similar to that performed manually) in the transition segments between adjacent time periods
- Integrate different headway setting and different timetables construction methods

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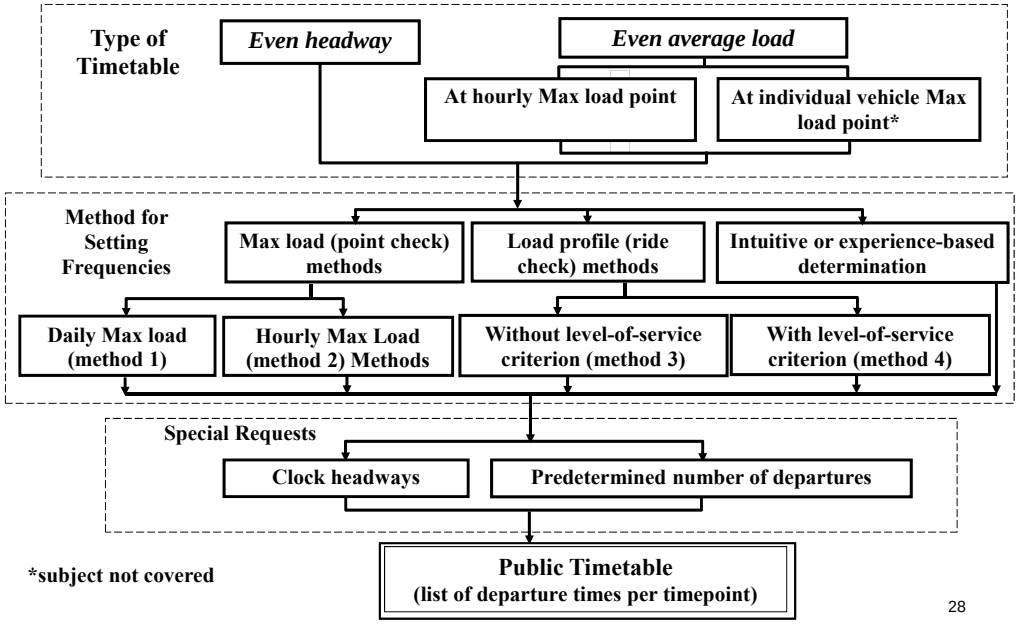
Alternative Timetables



*subject not covered

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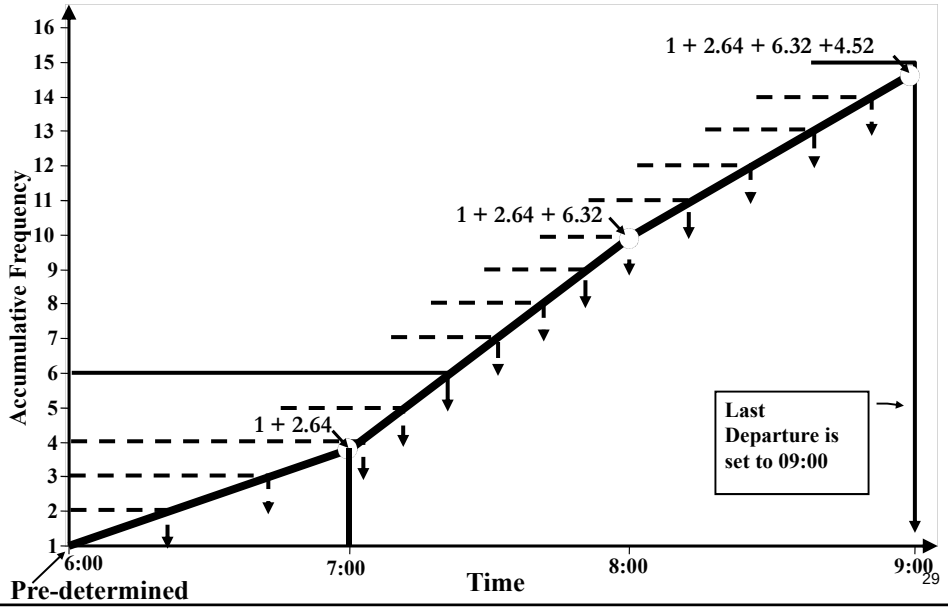
Determining Departure Times: Evenly Spaced Headway with Smoothing



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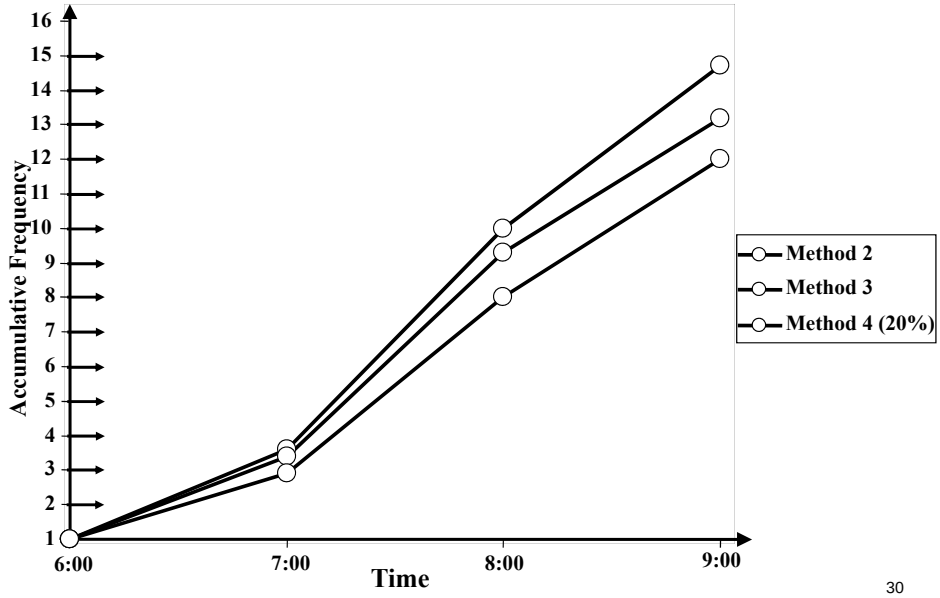
Frequency Curves of Three Methods



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How to Consider Passenger Loads?

India's Train Commuters…do they have a choice ?

Japan's Subway in peak hours

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COMPLEMENTRY DATA (Example Problem)

Time Period	Departure Time	Headway	# of Passengers Method 1	# of Passengers Method 2	Load Profile Passenger-Km (divided by length) Methods 3&4
06:00-06:59	06:00*	0			
	06:25	25	18	23	160 (16.0)
	06:45	20	59	67	557 (55.7)
07:00-07:59	07:05	20	52	56	484 (48.4)
	07:15	10	58	63	542 (54.2)
	07:25	10	84	90	669 (66.9)
	07:35	10	89	91	751 (75.1)
	07:45	10	65	78	634 (63.4)
	07:55	10	60	55	520 (52)
08:00-08:59	08:10	15	54	60	525 (52.5)
	08:25	15	84	89	727 (72.7)
	08:40	15	87	81	636 (63.6)
	08:55	15	60	84	510 (51)

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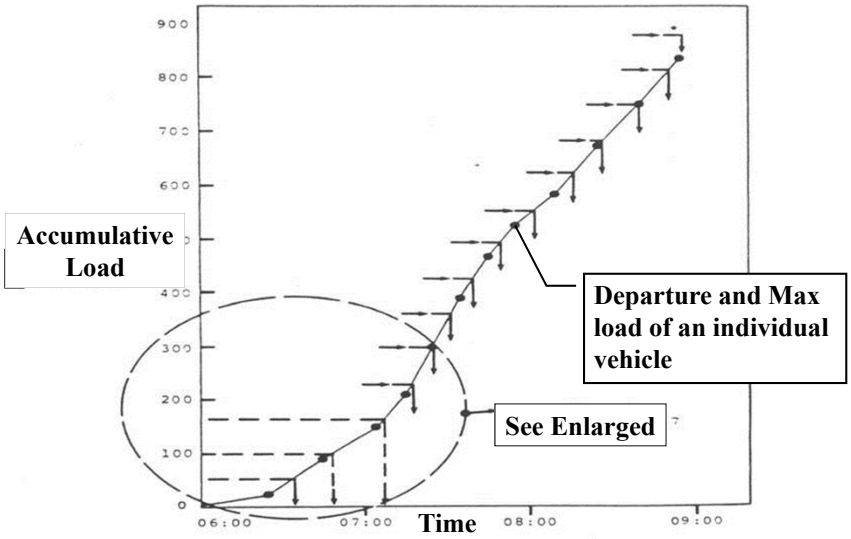
Balanced Loads Timetable (Method 2)



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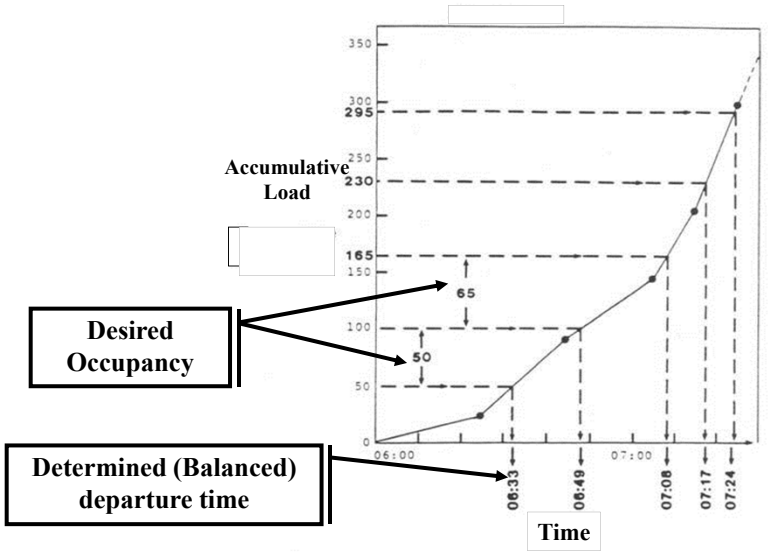
Enlarged part of the Cumulative load curve



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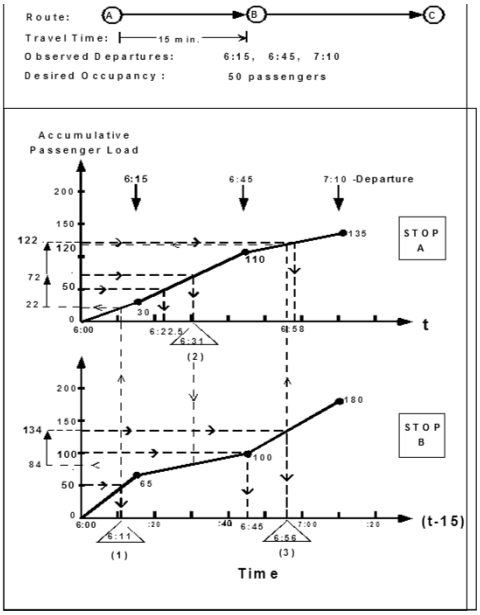
Even-load at individual-vehicle max-load point



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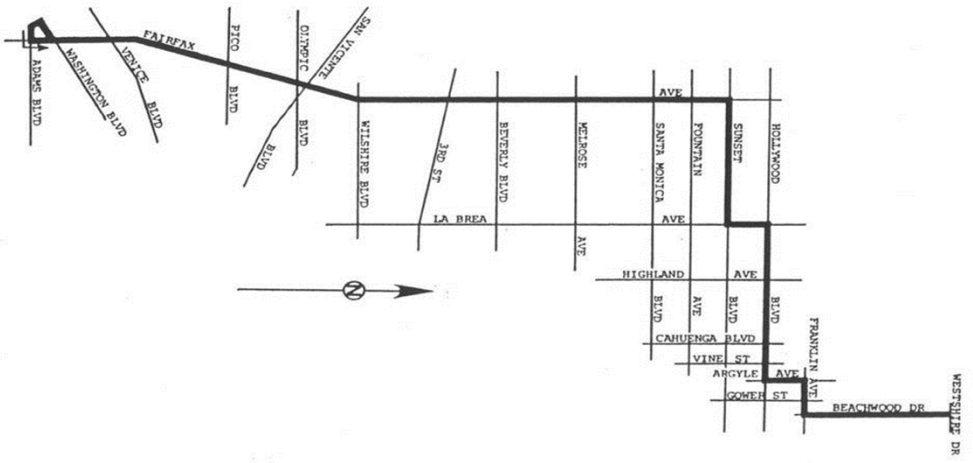
Real-Life Example (bus line 217 in LA)



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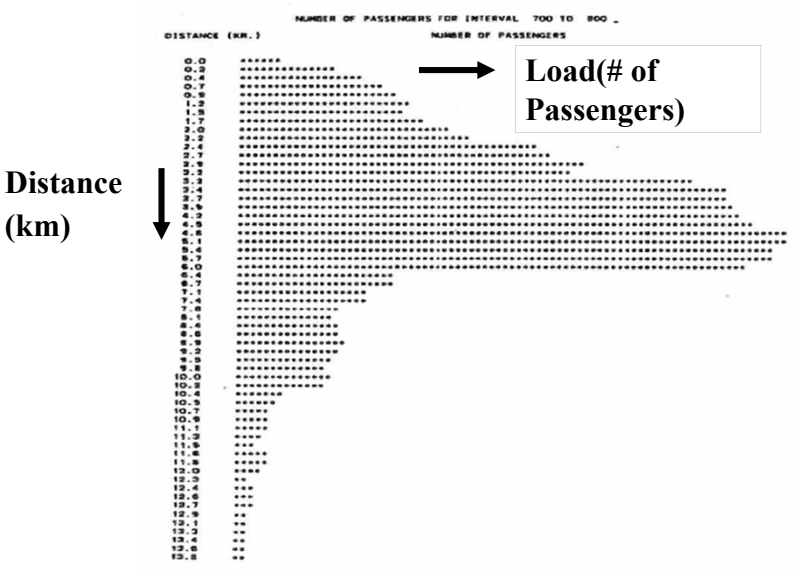
Line 217 Morning-Peak Load Profile



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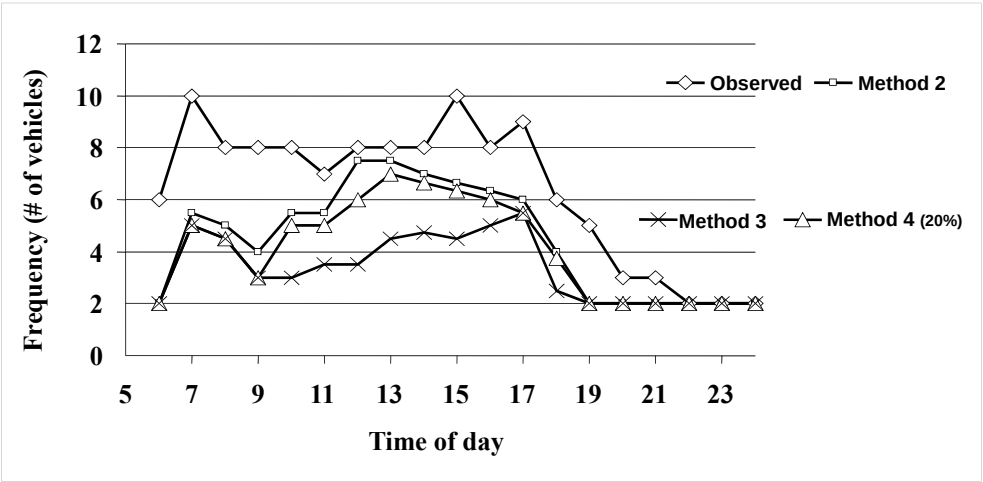
Line 217 (North)



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Computer Generated Timetable of line 217 at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)
METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (O)

MAX	4
MAX	6
MAX	9
MAX	9
MAX	9
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MAX	15

Min fleet size = largest number of buses departing in any time interval of length T

T= round trip time including layover and turn around time

Min single route required fleet size=15

TIMETABLE
****

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	44	13.54
2	6.30	45	14.02
3	7.00	46	14.10
4	7.11	47	14.18
5	7.21	48	14.26
6	7.32	49	14.34
7	7.42	50	14.42
8	7.53	51	14.50
9	8.04	52	14.58
10	8.15	53	15.07
11	8.27	54	15.15
12	8.38	55	15.24
13	8.49	56	15.32
14	9.01	57	15.41
15	9.16	58	15.49
16	9.31	59	15.58
17	9.45	60	16.06
18	10.00	61	16.15
19	10.10	62	16.24
20	10.21	63	16.33
21	10.31	64	16.42
22	10.42	65	16.50
23	10.52	66	16.59
24	11.02	67	17.10
25	11.13	68	17.21
26	11.23	69	17.33
27	11.33	70	17.44
28	11.44	71	17.55
29	11.54	72	18.09
30	12.03	73	18.26
31	12.11	74	18.42
32	12.19	75	18.59
33	12.27	76	19.28
34	12.35	77	19.58
35	12.43	78	20.23
36	12.51	79	20.58
37	12.59	80	21.29
38	13.07	81	21.59
39	13.15	82	22.29
40	13.22	83	22.59
41	13.30	84	23.29
42	13.38	85	24.00
43	13.46	86	0.30
		87	1.00

COMPARISON MEASURES
****

TOTAL NUMBER OF DEPARTURES: 87
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15

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Computer Generated Timetable of Line 217 across all Stops

THIS PROGRAM IS BASED ON THE FOLLOWING INPUT
****

TYPE OF HEADWAYS BALANCED (2)

TYPE OF TIMETABLE:ONE METHOD (1)
METHOD NUMBER 4 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS NO (O)

TIMETABLE
****

DEP NUM	BEACHWOO WESTSHIR	GOWER FRANKLIN	HOLLYWOO VINE	LA BREA SUNSET	FAIRFAX STA MONI	FAIRFAX BEVERLY	FAIRFAX OLYMPIC	ADAMS WASHINGT
1	5.27	5.41	5.44	5.50	5.56	6.00	6.05	6.11
2	6.15	6.19	6.22	6.28	6.34	6.38	6.44	6.50
3	6.33	6.38	6.41	6.47	6.55	7.00	7.06	7.13
4	6.48	6.53	6.56	7.03	7.10	7.15	7.21	7.28
5	7.03	7.08	7.11	7.17	7.25	7.30	7.36	7.43
6	7.14	7.19	7.22	7.29	7.37	7.42	7.48	7.55
7	7.23	7.28	7.31	7.38	7.46	7.51	7.57	8.04
8	7.33	7.38	7.41	7.49	7.58	8.03	8.09	8.17
9	7.44	7.49	7.52	8.00	8.09	8.14	8.20	8.28
10	7.56	8.01	8.04	8.12	8.21	8.26	8.32	8.40
11	8.08	8.13	8.16	8.24	8.33	8.38	8.44	8.52
12	8.23	8.28	8.31	8.39	8.48	8.53	8.59	9.07
13	8.37	8.42	8.45	8.53	9.02	9.07	9.13	9.21
14	8.48	8.53	8.56	9.04	9.13	9.18	9.24	9.32
15	8.59	9.04	9.07	9.15	9.24	9.29	9.35	9.43
16	9.11	9.16	9.19	9.27	9.36	9.41	9.47	9.55
17	9.22	9.27	9.30	9.38	9.47	9.52	9.58	10.06
18	9.30	9.35	9.38	9.46	9.55	10.00	10.07	10.15
19	9.41	9.45	9.48	9.56	10.05	10.11	10.18	10.26
20	9.48	9.53	9.56	10.04	10.13	10.18	10.25	10.33
21	10.00	10.05	10.08	10.16	10.25	10.31	10.37	10.48
22	10.09	10.14	10.17	10.25	10.34	10.40	10.46	10.55
23	10.22	10.27	10.30	10.38	10.47	10.52	10.59	11.07
24	10.30	10.35	10.38	10.46	10.55	11.01	11.08	11.17
25	10.43	10.48	10.51	10.59	11.08	11.14	11.21	11.30
26	10.52	10.57	11.00	11.08	11.17	11.23	11.30	11.39
27	11.04	11.09	11.12	11.20	11.29	11.35	11.42	11.51
28	11.16	11.21	11.24	11.32	11.41	11.47	11.54	12.03
29	11.27	11.32	11.35	11.43	11.52	11.58	12.05	12.14
30	11.38	11.43	11.46	11.54	12.03	12.09	12.16	12.27
31	11.55	12.00	12.03	12.11	12.20	12.26	12.33	12.44
32	12.04	12.09	12.12	12.20	12.29	12.35	12.42	12.53
33	12.16	12.21	12.24	12.32	12.41	12.47	12.54	13.06
34	12.27	12.32	12.35	12.43	12.52	12.58	13.05	13.16
35	12.37	12.43	12.46	12.54	13.03	13.09	13.16	13.25
36	12.44	12.49	12.52	13.01	13.10	13.16	13.23	13.32
37	12.52	12.57	13.00	13.08	13.17	13.23	13.30	13.39
38	13.00	13.05	13.08	13.16	13.25	13.31	13.38	13.47
39	13.18	13.23	13.26	13.34	13.43	13.49	13.56	14.05
40	13.29	13.34	13.37	13.47	13.57	14.03	14.11	14.20
41	13.35	13.40	13.43	13.53	14.03	14.09	14.17	14.26
42	13.42	13.47	13.50	14.00	14.10	14.16	14.24	14.33
43	13.50	13.55	13.58	14.08	14.18	14.24	14.32	14.41
44	14.02	14.07	14.10	14.20	14.30	14.36	14.44	14.53
45	14.14	14.19	14.22	14.32	14.42	14.48	14.56	15.05
46	14.26	14.31	14.34	14.44	14.54	15.00	15.08	15.17
47	14.30	14.35	14.38	14.48	14.58	15.04	15.12	15.21
48	14.36	14.41	14.44	14.54	15.04	15.10	15.18	15.27
49	14.44	14.49	14.52	15.02	15.12	15.18	15.26	15.35
50	14.55	15.00	15.03	15.13	15.23	15.29	15.37	15.46
51	15.06	15.11	15.14	15.24	15.34	15.40	15.48	15.57
52	15.14	15.19	15.22	15.32	15.42	15.48	15.56	16.05
53	15.25	15.30	15.33	15.43	15.53	15.59	16.07	16.16
54	15.41	15.46	15.49	15.59	16.09	16.15	16.23	16.32
55	15.55	16.00	16.03	16.13	16.23	16.29	16.37	16.46
56	16.15	16.20	16.23	16.33	16.43	16.49	16.57	17.06
57	16.35	16.40	16.43	16.53	17.03	17.09	17.17	17.26
58	16.55	17.00	17.03	17.13	17.23	17.29	17.37	17.46
59	17.23	17.28	17.31	17.41	17.51	17.57	18.05	18.14
60	17.52	17.56	17.59	18.07	18.17	18.22	18.29	18.38
61	18.24	18.28	18.31	18.39	18.49	18.54	19.01	19.10
62	18.52	18.57	19.00	19.08	19.16	19.21	19.27	19.36
63	19.29	19.34	19.37	19.45	19.53	19.58	20.04	20.13
64	19.55	20.00	20.03	20.11	20.18	20.23	20.29	20.37
65	20.28	20.33	20.36	20.44	20.51	20.56	21.02	21.10
66	21.05	21.10	21.13	21.21	21.28	21.33	21.39	21.47
67	21.30	21.35	21.38	21.46	21.53	21.58	22.04	22.12
68	21.57	22.02	22.05	22.13	22.20	22.25	22.31	22.39
69	22.32	22.37	22.40	22.48	22.55	23.00	23.06	23.14
70	22.52	22.57	23.00	23.08	23.15	23.20	23.26	23.34
71	23.31	23.36	23.39	23.47	23.54	23.59	0.05	0.13
72	0.52	0.57	0.00	0.08	0.15	0.20	0.26	0.34
73	0.30	0.35	0.38	0.46	0.53	0.58	1.04	1.12

COMPARISON MEASURES
****

TOTAL NUMBER OF DEPARTURES 73
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 14

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Vehicle Scheduling

You cannot depend on your eyes when your imagination is out of focus (Mark Twain)

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STUDY MOTIVATION

EGGED: The Israel National Bus Carrier (4000 Buses)
DAN: Tel Aviv Carrier (1400 Buses)
activities on a DAILY basis (EGGED):

Type	No. of trips	No. of veh-km
Service	36,000	775,000
Dead heading	14,500	91,000
Special routine	4,000	92,000
Special others	500	70,000
Total	55,000	1,028,000

Average daily passengers:

2,440,000
(1,600,000 + 840,000)
EGGED DAN

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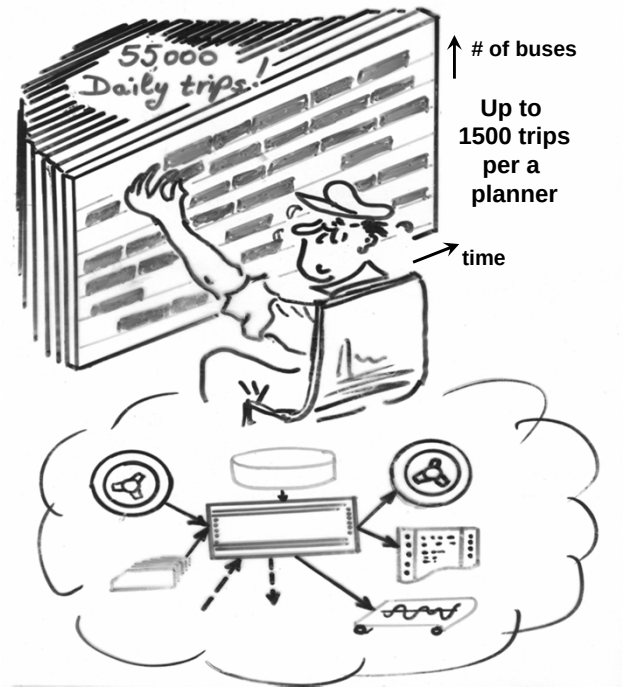

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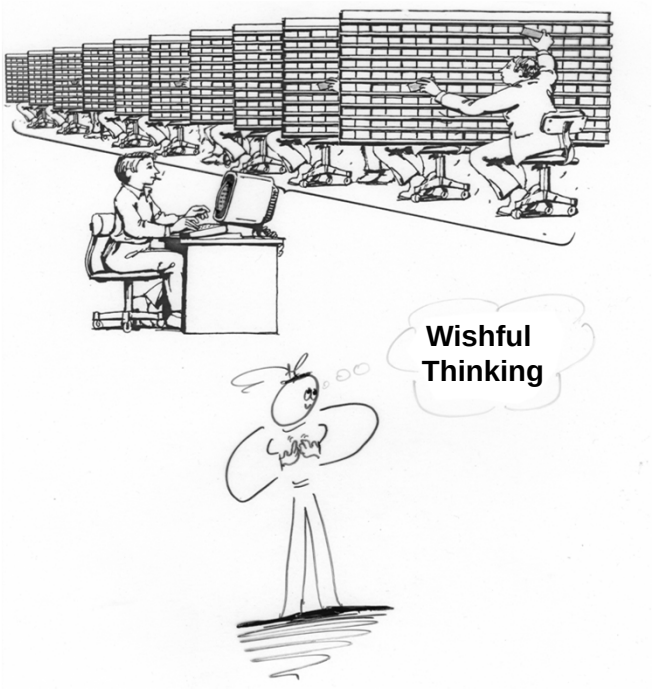

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Developing Optimal and Fully Computerized Algorithm

Fully computerized algorithm:

(a) Chaining bus trips in a sequential order: Depots→bus routes alternating with idle time and dead-heading trips →depots (formulated as a one-zero integer programming problem and is converted to a large-scale assignment problem)

(b) Assigning buses from depots to the bus schedules generated in (a) (formulated as a "transportation problem")

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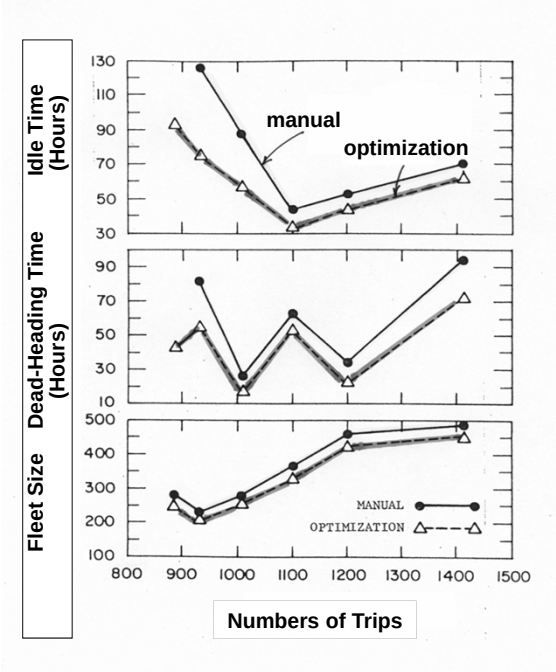

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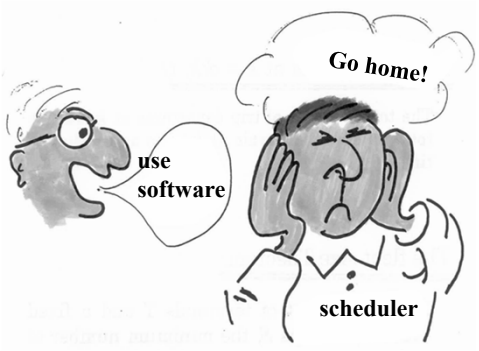
Major limitations

Cannot consider:

(1) the integration of more than 2500 trips.
(2) the need for bus refueling.
(3) the need for driver's meals.
(4) availability of adequate bus type for each trip.
(5) some drivers' constraints.
(6) different scheduling policies for each group of lines.



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Deficit Function at $k = d(k, t)$:

The total number of trip departures at *k* less the total number of arrivals at *k*-up to and including time *t*

The fleet size Theorem

For a given set of terminals T and a fixed schedule of trips *S*, the minimum number of vehicles required to service all trips in *S* is:

$$N(s) = \sum_{k \in T} D(k) = \sum_{k} \max d(k,t)$$

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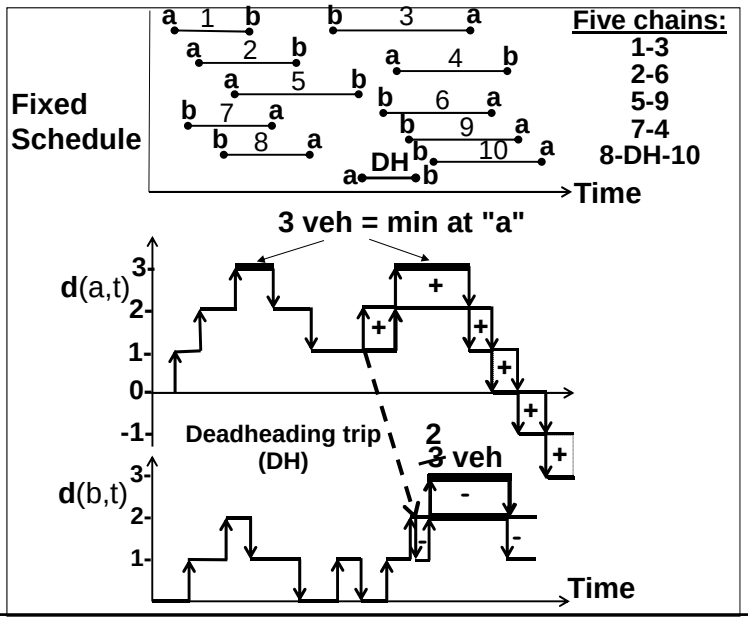
DEFICIT FUNCTION THEORY

(+1→every departure, -1→every arrival)



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Lower Bound

- When no reduction in the number of vehicles can be further made (in the algorithm)
- How much the transit management can expect to reduce the fleet size?

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Constructing Lower Bound on the Fleet Size

$$G(S) = \max\ g(t,S),\ t \in [T_1, T_2],$$

where $$g(t,S) = \sum_{k \in T} d(k,t,S)$$

$G(S)$ describes, at each point of time, the No of vehicles simultaneously in operation (service)

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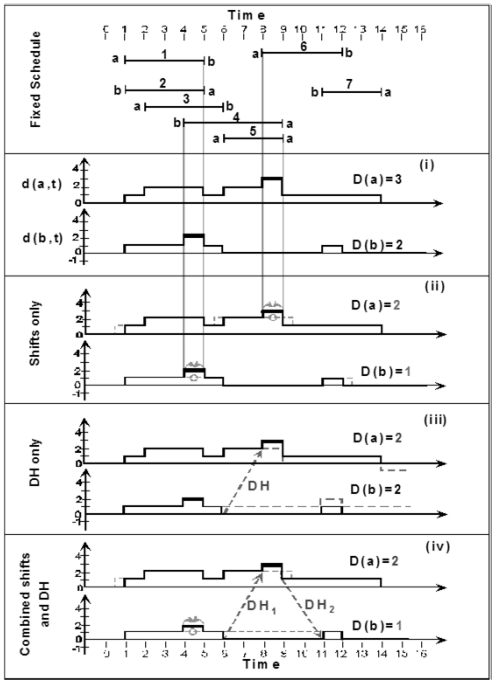
Shifting consideration of departure times within given tolerances



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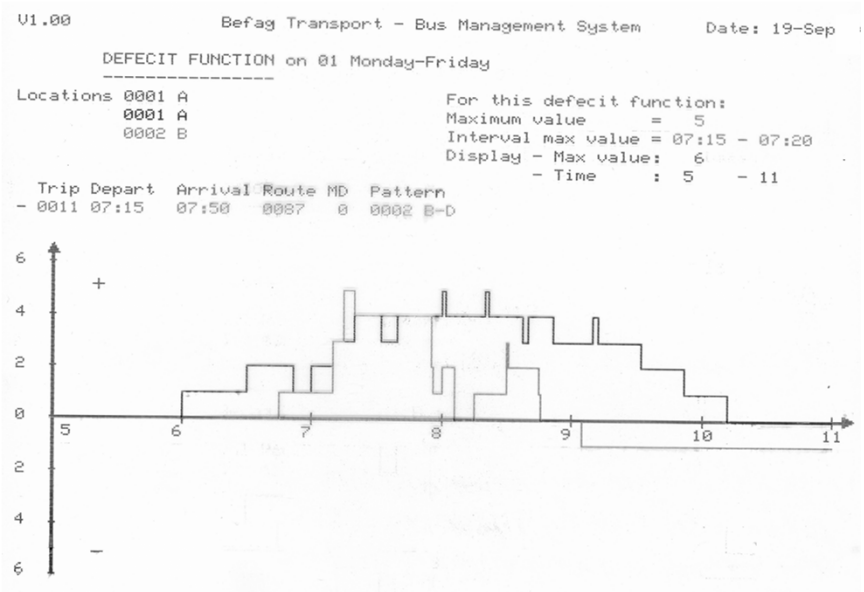
Implementation



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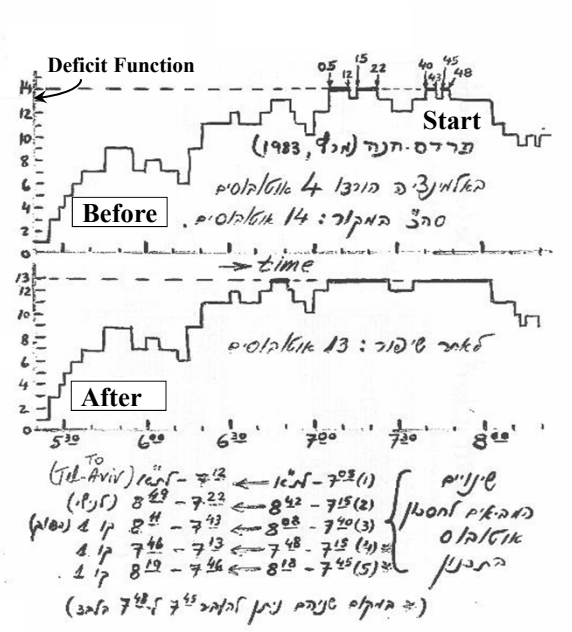
Real Life Experience



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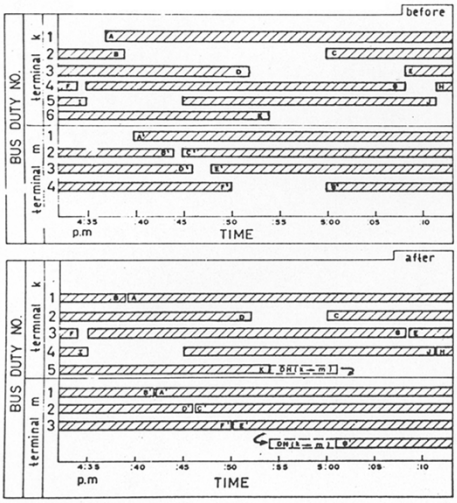
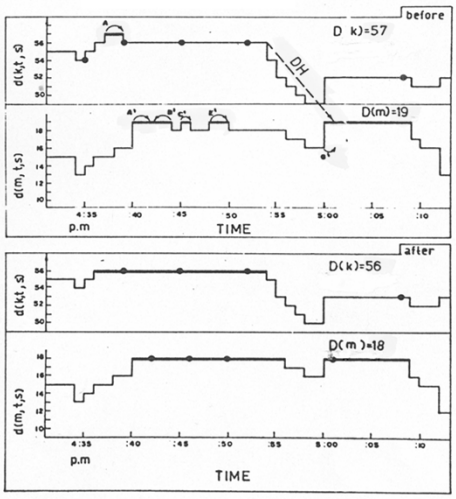
Gantt Chart



Deficit Function



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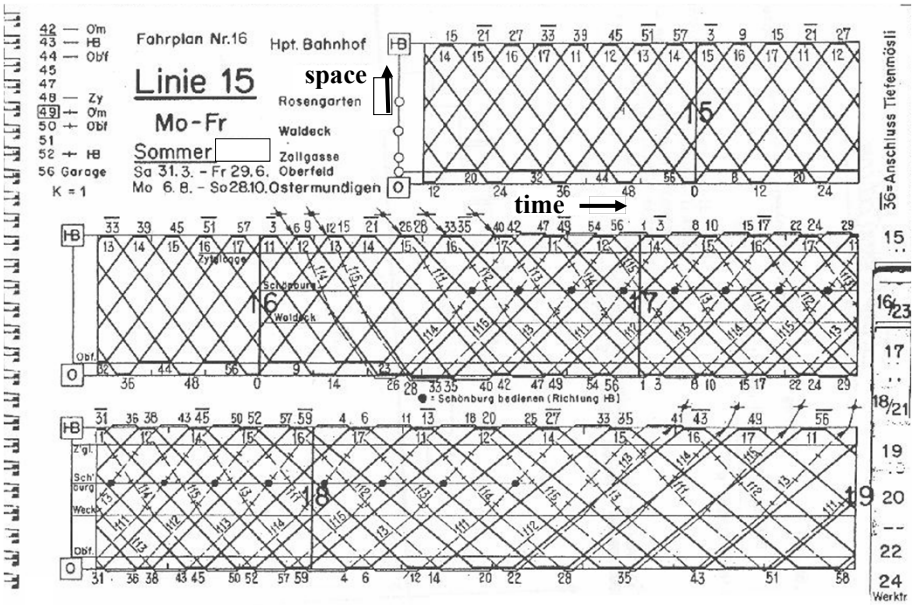
Common Practice



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Applications

1. Design of new transit network or redesign an existing one
2. Design of efficient short-turns
3. Design of operational transit parking spaces
4. Vehicle scheduling with different vehicles types
5. Crew scheduling

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Not all buses are treated same

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Easy to schedule – Chinese fast rail

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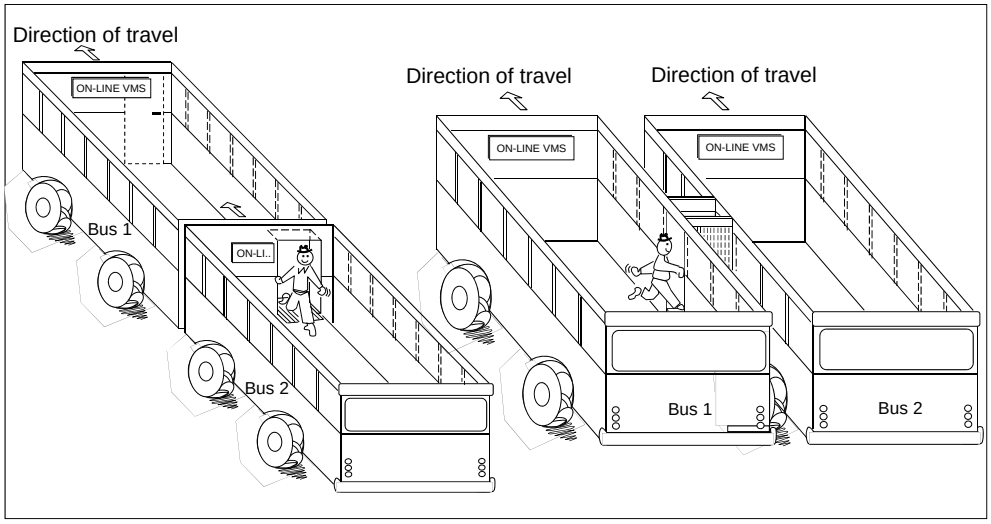
Future linkage to transit scheduling – current study on coordination and transfers



Longitudinal Transfer

Lateral Transfer

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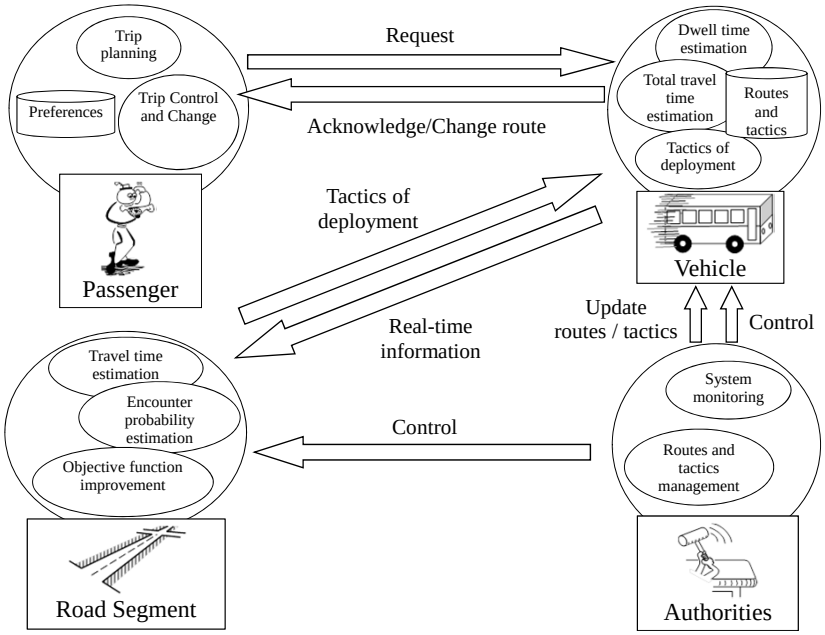
Creating Online Coordination using Agents' activities



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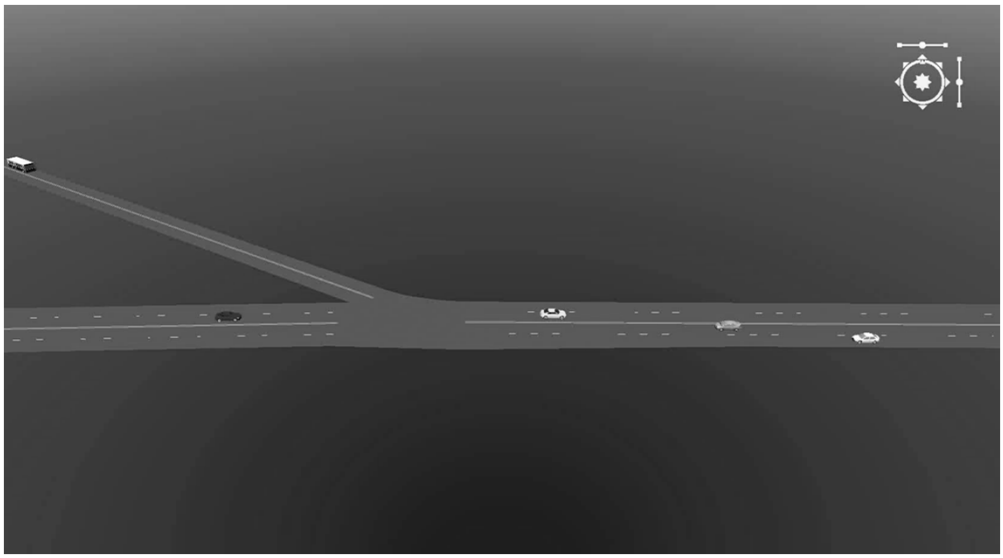
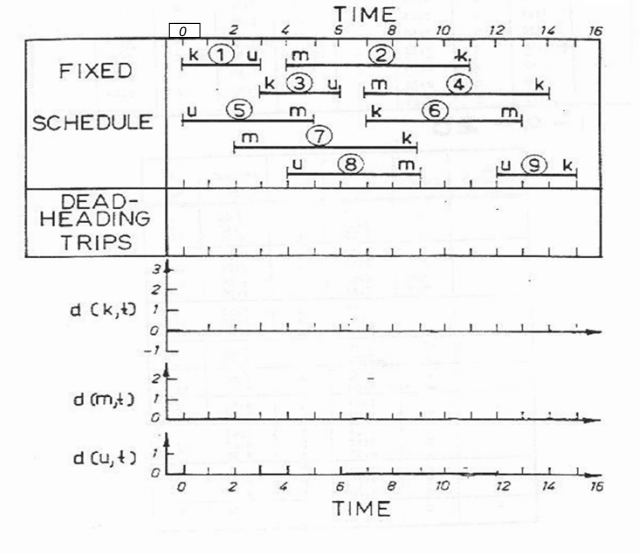
Visual synchronization by TransModeler



Exercise

Deadhead Time=DH $DH_{mu}=DH_{um}=1$

$DH_{ku}=DH_{uk}=DH_{km}=DH_{mk}=2$



1. **Construct all 3 deficit functions**
2. **Insert DH trips (minimize their time)**
3. **Find the minimum fleet size**

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Tutorial: Scheduled Service Management

The 20th ISTTT at Noordwijk, The Netherlands

July 16, 2013

End of Presentation

Thank-you!

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