Vehicle Scheduling

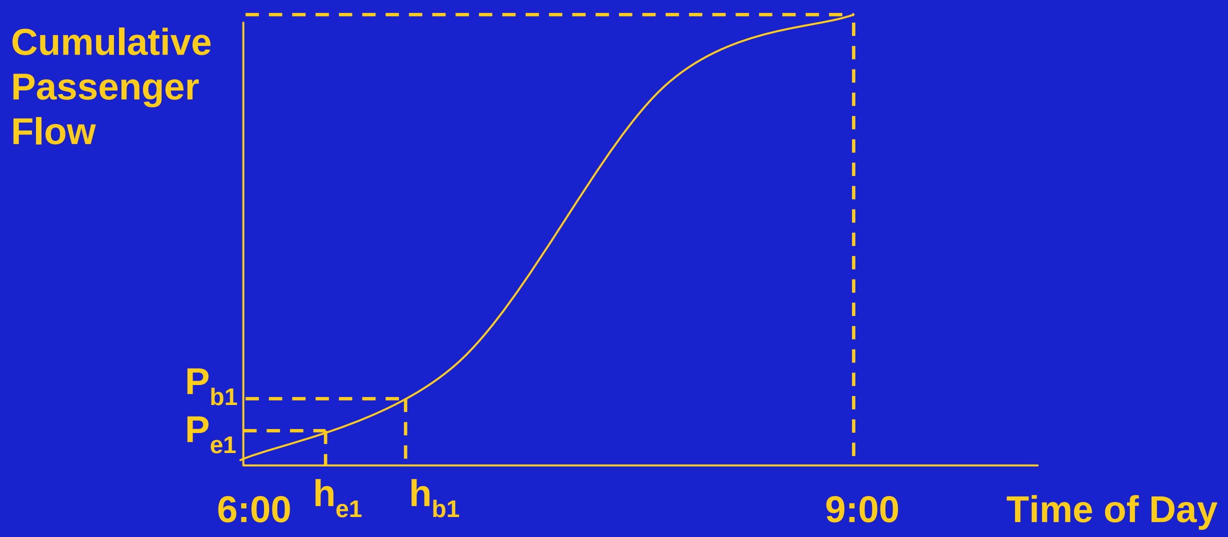
Outline

1. Timetable Development
2. Fleet Size
3. Vehicle Scheduling

Timetable Development

Can translate frequency into timetable by specifying headways as:

- **equal -- appropriate if demand is uniformly distributed across period**
- **balanced load -- appropriate if there is substantial variation in demand over period**
- **clockface or not -- do headways repeat every hour**



Timetable Development

If we have N departures in peak period:

- **equal headway solution:**

$$H = \frac{Peak\ Period}{N}$$

- **balanced load solution:**

$$\boldsymbol{Pass\ Load / Departure = \frac{Total\ Passenger\ Flow}{N}}$$

Fleet Size Requirement

Salzborn's Fleet Size Theorem:

Given:

l(k,t,s)* = # of departures from terminal *k* by time *t* following schedule *s

a(k,t,s)* = # of arrivals at terminal *k* by time *t* following schedule *s

and:

d(k,t,s)* = *l(k,t,s)* - *a(k,t,s)*, deficit function at terminal *k* at time *t* following schedule *s

.

Fleet Size Requirement

Salzborn's Fleet Size Theorem:

Then:

N(s), **the minimum size fleet to serve schedule *s*, is given by:**

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

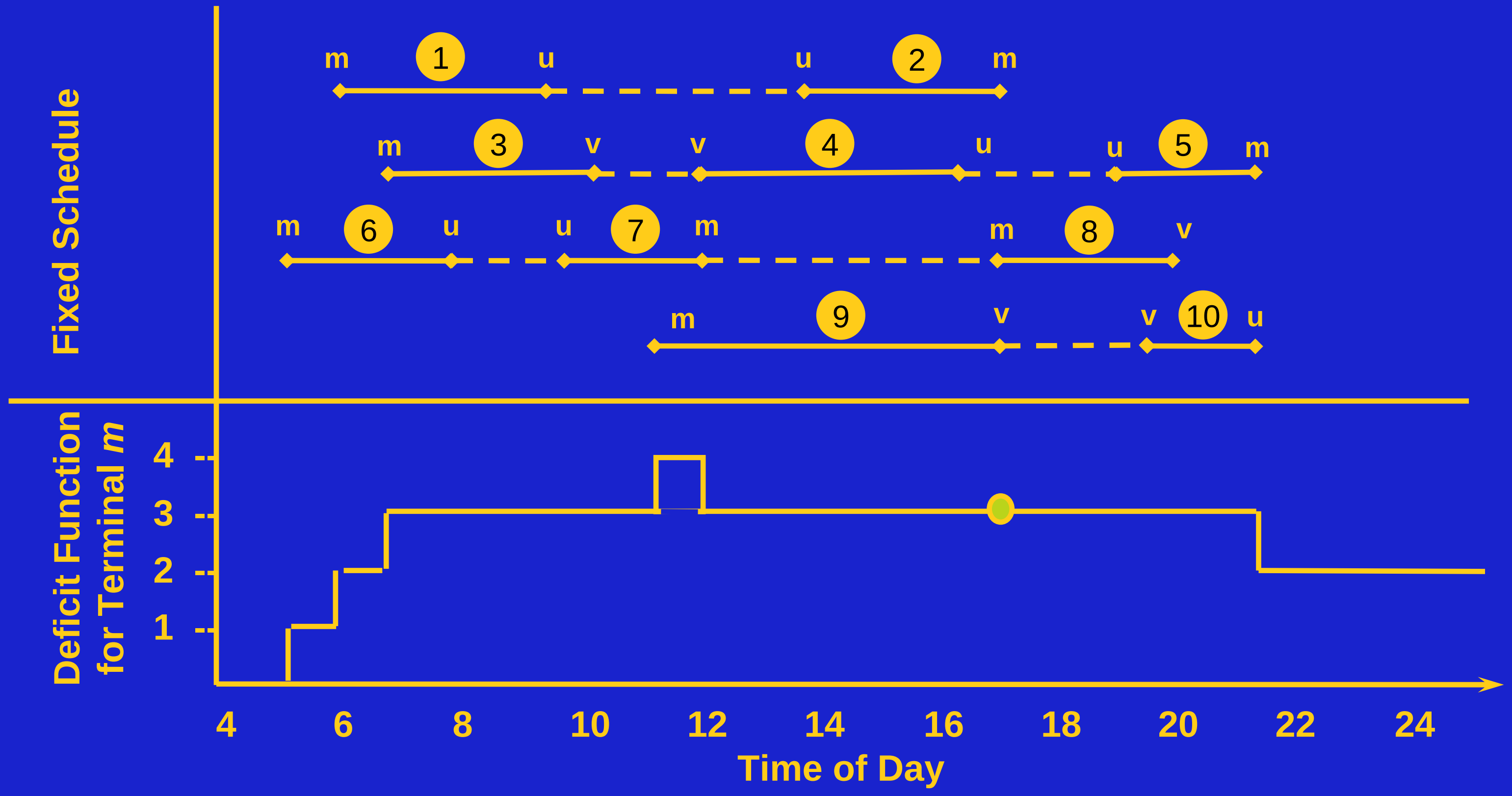
for *T* terminals

Also, *N(s)* ≥ Max # of trips in simultaneous operation.

Fleet Size Required

The deficit function, or minimum required fleet size, may be reduced by:

- shifting departure and/or arrival times
- adding deadhead trips between terminals



Vehicle Scheduling Problem

Input:

- -- A set of vehicle revenue trips to be operated, each characterized by:
  - -- starting point and time
  - -- ending point and time
- -- Possible <u>layover arcs</u> between the end of a trip and the start of a (later) trip at the same location
- -- Possible <u>deadhead arcs</u> connecting:
  - -- depot(s) to trip starting points
  - -- trip ending points to depot(s)
  - -- trip ending points to trips starting at a different point

Vehicle Scheduling Problem

Observations:

-- there are many feasible but unattractive deadhead and layover arcs, generate only plausible non-revenue arcs

-- layover time affects service reliability, set minimum layover (recovery) time

Vehicle Scheduling Problem (continued)

Objective:

-- Define vehicle blocks (sequences of revenue and non-revenue activities for each vehicle) covering all trips so as to:

- -- minimize fleet size (i.e. minimize #crews)
- -- minimize non-revenue time (i.e. minimize extra crew time)

Observation:

-- these are proxies for cost, but a large portion of cost will depend on crew duties which are unknown at this stage of solution.

Vehicle Scheduling Problem (continued)

Constraints:

-- Minimum vehicle block length

-- Maximum vehicle block length

Variations:

-- each vehicle restricted to a single line vs. interlining permitted

-- single depot vs multi-depot

-- vehicle fleet size constrained at depot level

-- routes (trips) assigned to specific depot

-- multiple vehicle types

Example: Single Route AB

Results of earlier planning and scheduling analysis:

	AM Peak Period (6-9 AM)	Base Period (after 9 AM)
Headways	20 min	30 min
Scheduled trip time (A⇒B or B⇒A)	40 min	35 min
Minimum layover time	10 min	10 min

Dominant direction of travel in AM is A⇒B

Timetable and Vehicle Block Development

Depart A	Arrive B
6:00	6:40
6:20	7:00
6:40	7:20
7:00	7:40
7:20	8:00
7:40	8:20
8:00	8:40
8:20	9:00
8:40	9:20
9:00	9:35
9:30	10:05
10:00	10:25
10:30	11:05
11:00	11:35

Timetable and Vehicle Block Development

Depart A	Arrive B	Depart B	Arrive A
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8:40	9:20		
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9:30	10:05	10:15	10:50
10:00	10:25	10:45	11:20
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Timetable and Vehicle Block Development

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Timetable and Vehicle Block Development

Veh #	Depart A	Arrive B	Depart B	Arrive A
1 x	>6:00	6:40	6:50	7:30--->
2x	6:20	7:00	7:10	7:50
	6:40	7:20	7:30	8:10
	7:00	7:40	7:50	8:30
	7:20	8:00	8:10	8:50
1	7:40	8:20	8:30	9:10
2	8:00	8:40	8:50	9:30 --> y
	8:20	9:00	9:15	9:50
	8:40	9:20		
	9:00	9:35	9:45	10:20
1	9:30	10:05	10:15	10:50
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3x	6:40	7:20	7:30	8:10
	7:00	7:40	7:50	8:30
	7:20	8:00	8:10	8:50
1	7:40	8:20	8:30	9:10
2	8:00	8:40	8:50	9:30 -->y
3	8:20	9:00	9:15	9:50
	8:40	9:20		
	9:00	9:35	9:45	10:20
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3x	6:40	7:20	7:30	8:10
4x	7:00	7:40	7:50	8:30
	7:20	8:00	8:10	8:50
1	7:40	8:20	8:30	9:10
2	8:00	8:40	8:50	9:30 -->y
3	8:20	9:00	9:15	9:50
4	8:40	9:20--> y		
	9:00	9:35	9:45	10:20
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3x	6:40	7:20	7:30	8:10
4x	7:00	7:40	7:50	8:30
5x	7:20	8:00	8:10	8:50
1	7:40	8:20	8:30	9:10
2	8:00	8:40	8:50	9:30-->y
3	8:20	9:00	9:15	9:50
4	8:40	9:20 -->y		
5	9:00	9:35	9:45	10:20
1	9:30	10:05	10:15	10:50
3	10:00	10:25	10:45	11:20
5	10:30	11:05	11:15	11:50
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Example: Vehicle Blocks

Block 1: Depot - A (6:00) - B (6:50) - A (7:40) - B (8:30) - A (9:30) - B (10:15) - A (11:00) - B (11:45) - . . .

Block 2: Depot - A (6:20) - B (7:10) - A (8:00) - B (8:50) - Depot

Block 3: Depot - A (6:40) - B (7:30) - A (8:20) - B (9:15) - A (10:00) - B (10:45) - . . .

Block 4: Depot - A (7:00) - B (7:50) - A (8:40) - Depot

Block 5: Depot - A (7:20) - B (8:10) - A (9:00) - B (9:45) - A (10:30) - B (11:15) - ...

Vehicle Scheduling Model Approaches

Heuristic approaches:

1. Define compatible trips at same terminal *k* such that trips *i* and *j* are compatible iff :

$$t_{s_j} - t_{e_i} > M_k$$

$$t_{s_j} - t_{e_i} < 2 D_k$$

where t_{s_j} = starting time for trip *j*

t_{e_i} = ending time for trip *i*

M_k = minimum recovery/layover time at terminal *k*

D_k = deadhead time from terminal *k* to depot

Vehicle Scheduling Model Approaches

2. Apply Restricted First-in-First-out rules at each terminal

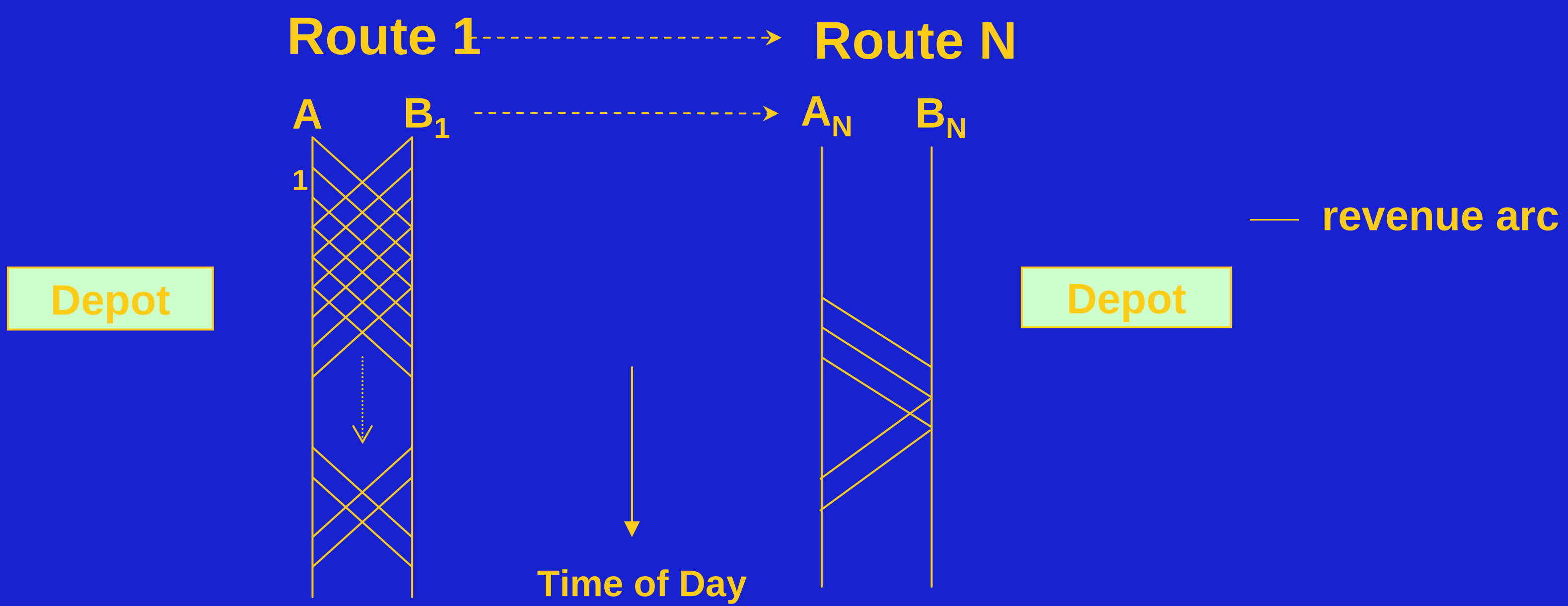
   (a) Start with (next) earliest arrival at terminal; if none, go to step (d)

   (b) Link to earliest compatible trip departure; if none, return vehicle to depot and return to step (a)

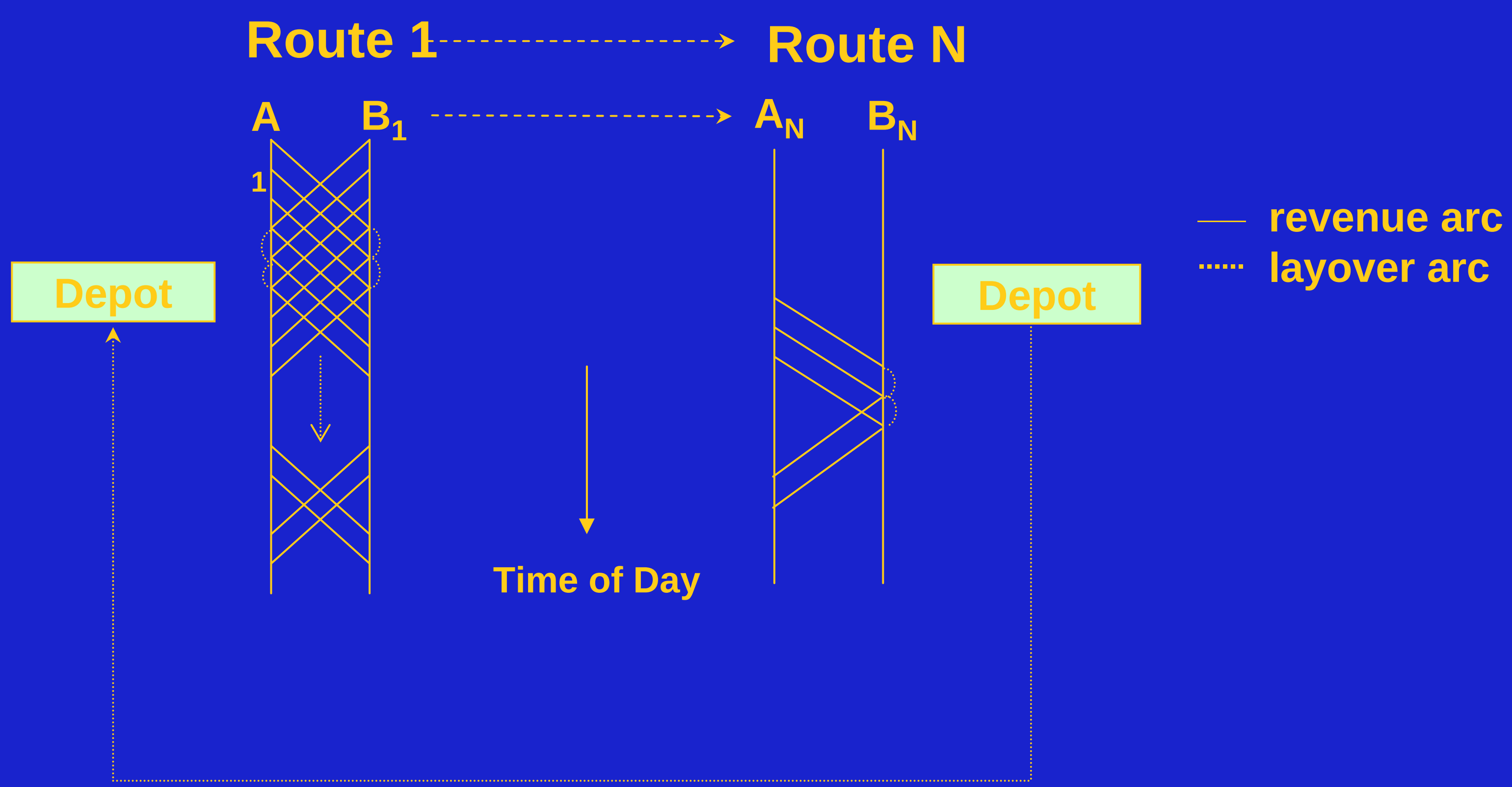
   (c) Check vehicle block length against constraint: if constraining, return vehicle to depot and return to step (a); otherwise return to step (b) with new trip arrival time

   (d) Serve all remaining unlinked departures from depot

Time-Space Network Representation



Time-Space Network Representation



Time-Space Network Representation