Transit Vehicle Scheduling: Problem Description

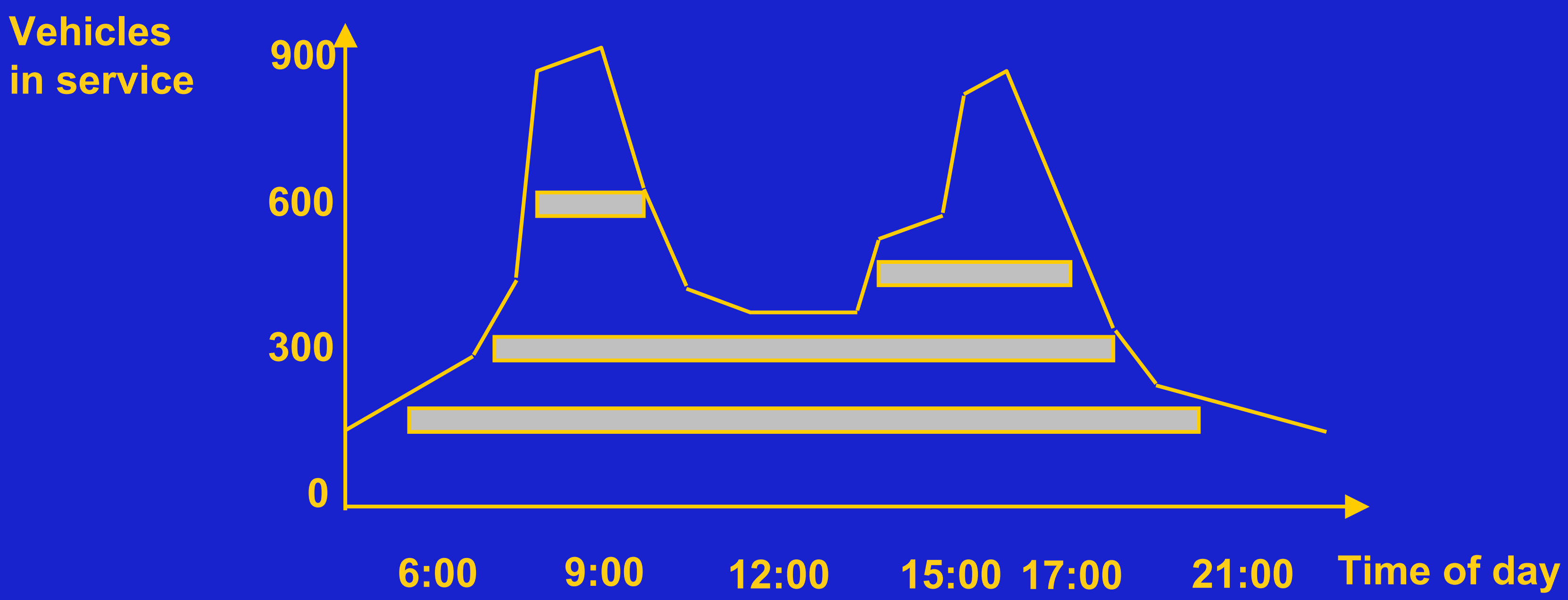
Outline

- Problem Characteristics
- Service Planning Hierarchy (revisited)
- Vehicle Scheduling

Problem Characteristics

- Consolidated Operations (vs. Direct Operations)
- Passengers (vs freight) being moved
- Urban vs. intercity (short vs. long trip lengths)
- Relatively high service frequency (several trips per hour vs one trip per day)
- High temporal variation in demand within day
- Feasible speeds vary by time of day if vehicles affected by traffic congestion
- Operations/service plan is stable over a period of months
- Different type of competition
- May be a public agency or a private company
- Crew costs are significant fraction of total costs
- Routes have many nodes

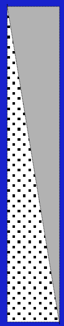
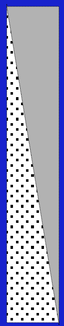
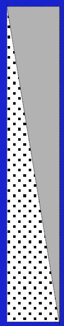
Temporal Variation in Vehicle Requirements and Vehicle Blocks



Service Planning Hierarchy

Input	Function	Output
Demand characteristics Infrastructure Resources Policies (e.g. coverage)	Network and Route Design	Set of routes
Demand characteristics Resources Policies (e.g. headways and pass loads)	Frequency Setting	Service Frequency by route, day, and time period
Route travel times Demand characteristics Resources Policies (e.g. reliability)	Timetable Development	Departure/Arrival times for individual trips on each route (per stop)
Route travel times Resources Policies (e.g. reliability)	Vehicle Scheduling	Revenue and Non-revenue Activities by Vehicle
Work rules and pay provisions Resources Policies	Crew Scheduling	Crew duties

Service Planning Hierarchy

	Infrequent Decisions	Service and Lost Considerations both significant	Incremental Analysis Methods Dominate
Network Design Frequency Setting Timetable Development Vehicle Scheduling Crew Scheduling			
	Frequent Decisions	Cost Considerations Dominate	Computer Dominates Optimization-Based Methods

Vehicle Scheduling Problem

Input:

- The timetable: a set of vehicle revenue trips to be operated, each characterized by:
  - -- starting point and time
  - -- ending point and time
- Possible <u>layover/recovery 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 to trip starting points
  - -- trip ending points to depot
  - -- 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

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
6:00	6:40	6:50	7:30
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7:00	7:40	7:50	8:30
7:20	8:00	8:10	8:50
7:40	8:20	8:30	9:10
8:00	8:40	8:50	9:30
8:20	9:00	9:15	9:50
8:40	9:20		
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Timetable and Vehicle Block Development

Veh #	Depart A	Arrive B	Depart B	Arrive A
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	6:40	7:20	7:30	8:10
	7:00	7:40	7:50	8:30
	7:20	8:00	8:10	8:50
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x = from depot

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	8:00	8:40	8:50	9:30
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	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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3	x-->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
1	9:30	10:05	10:15	10:50
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3	x-->6:40	7:20	7:30	8:10
4	x-->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		
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4	x-->7:00	7:40	7:50	8:30
5	x-->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		
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x = from depot

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) Order arrivals and departures at the terminal chronologically

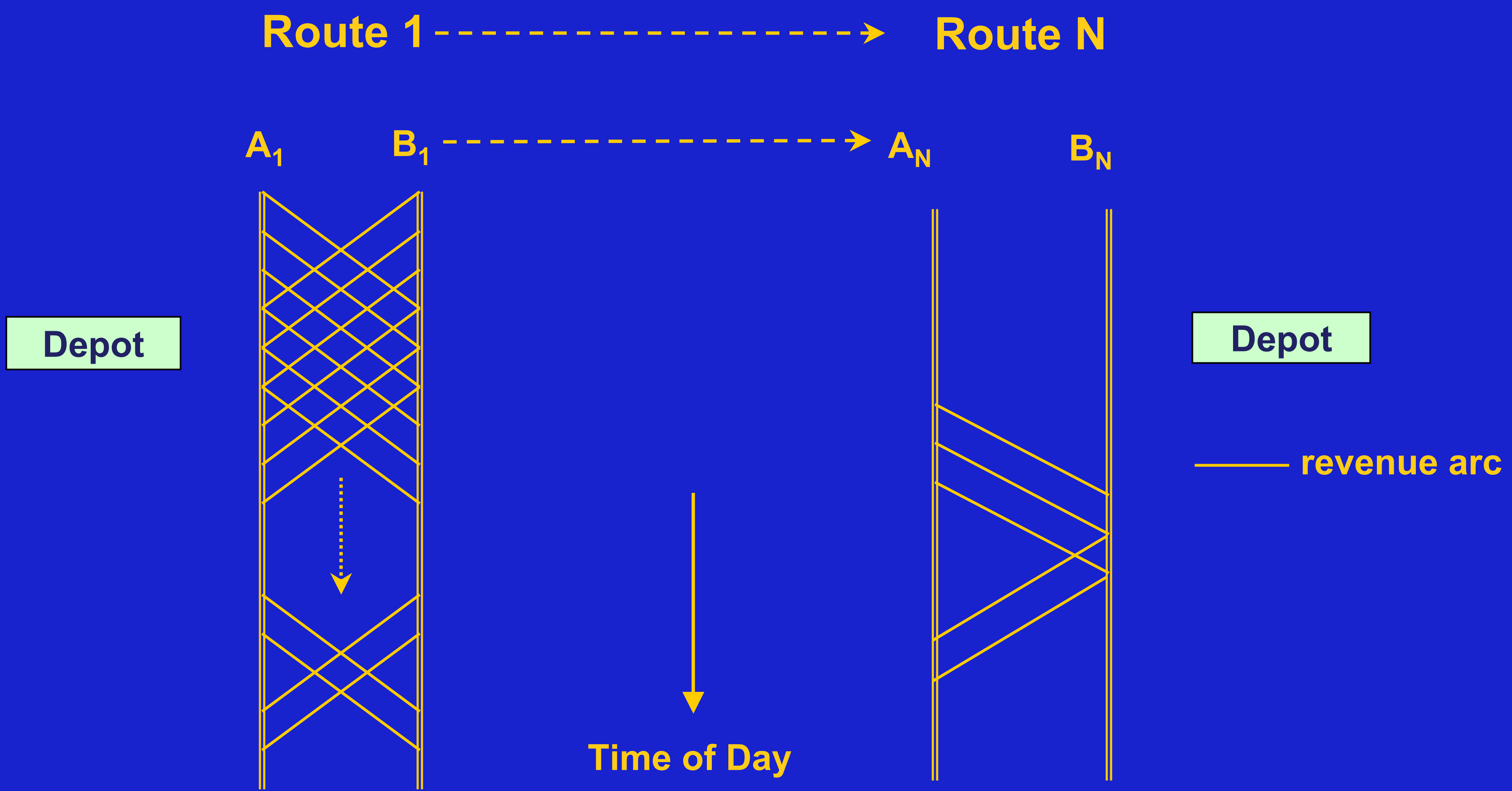
   (b) Start with (next) earliest arrival at terminal; if none, go to step (e)

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

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

   (e) Serve all remaining unlinked departures from depot

Time-Space Network Representation



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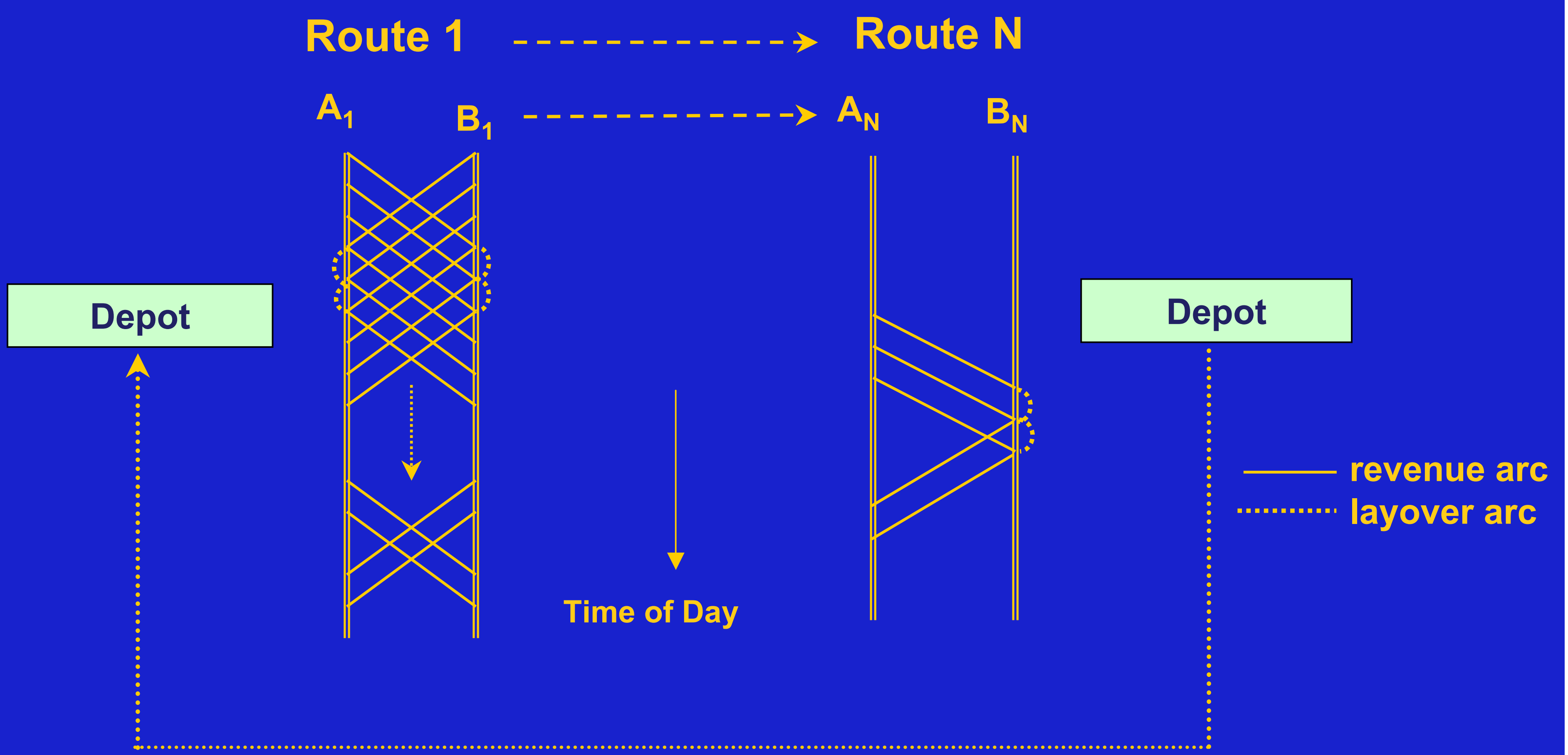
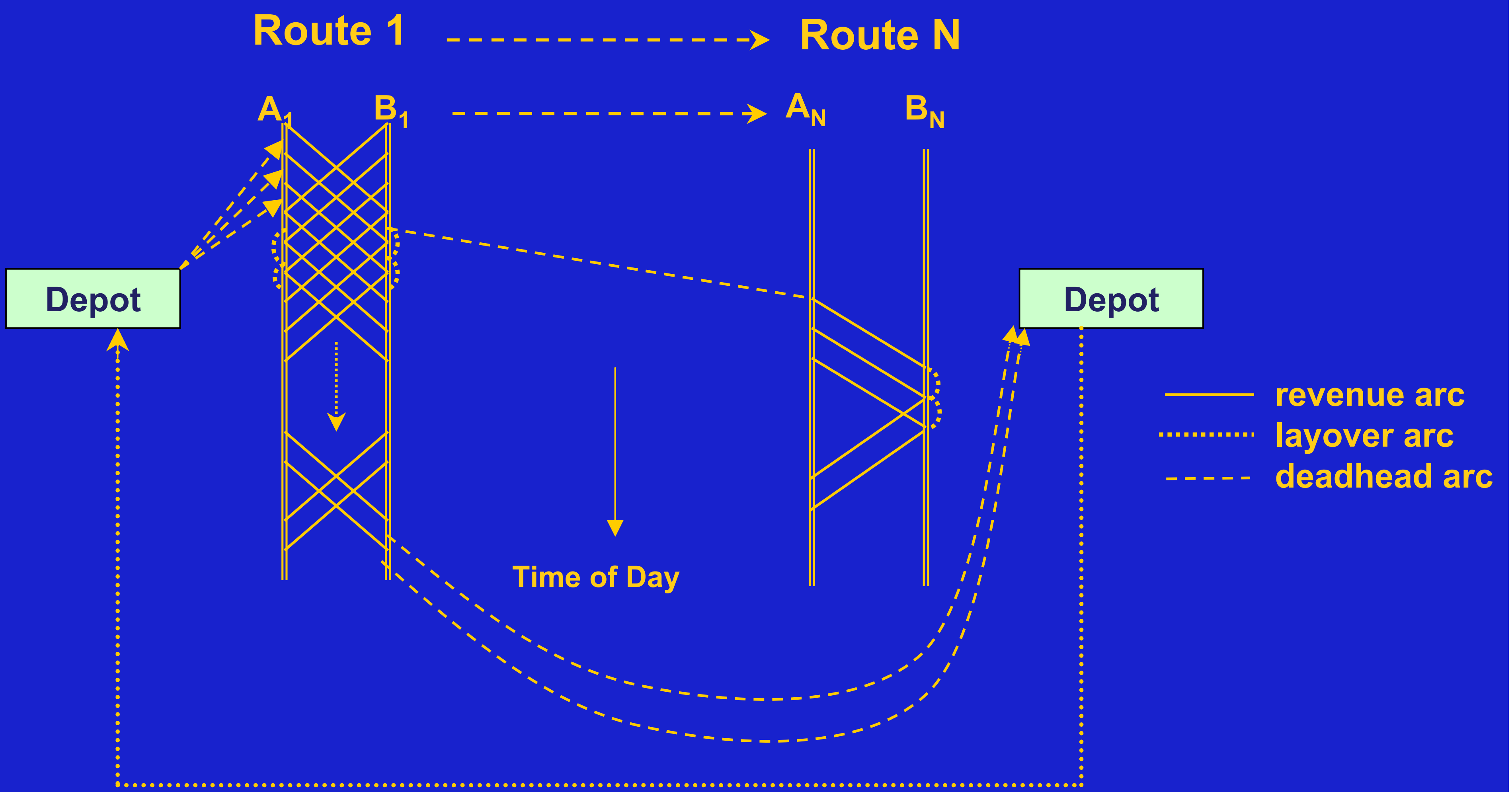
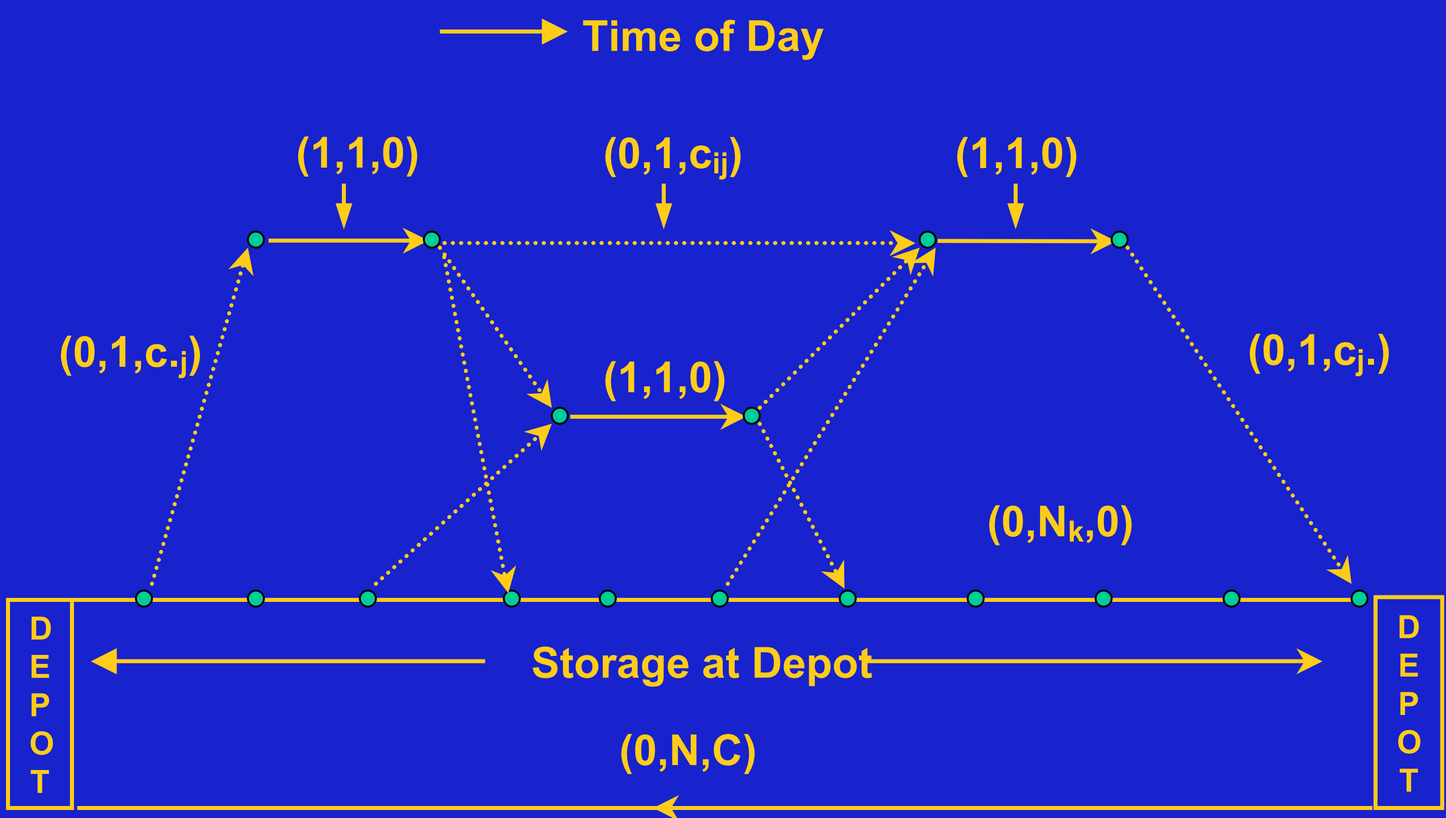


Time-Space Network Representation



Time Space Network Representation Detail



(l_{ij}, u_{ij}, c_{ij}) (minimum flow, maximum flow, cost per unit of flow)

correspond to revenue trips

deadhead trip to or from the depot or between routes, or layovers between revenue trips on same route

Minimum Cost Network Flow Formulation

$$\textit{Minimize} \sum_{(i,j)\in A} c_{ij} x_{ij}$$

s.t.

$$\sum_{\{j:(i,j)\in A\}} x_{ij} - \sum_{\{j:(j,i)\in A\}} x_{ji} = 0 \qquad \forall i \in N \text{ ....(1)}$$

$$x_{ij} \geq l_{ij}, \qquad \forall (i,j) \in A \text{..............(2)}$$

$$x_{ij} \leq u_{ij}, \qquad \forall (i,j) \in A \text{..............(3)}$$

$$x_{ij} \in Z^{+}, \qquad \forall (i,j) \in A \text{.............(4)}$$