A Combined Blocking, Makeup and Scheduling Model

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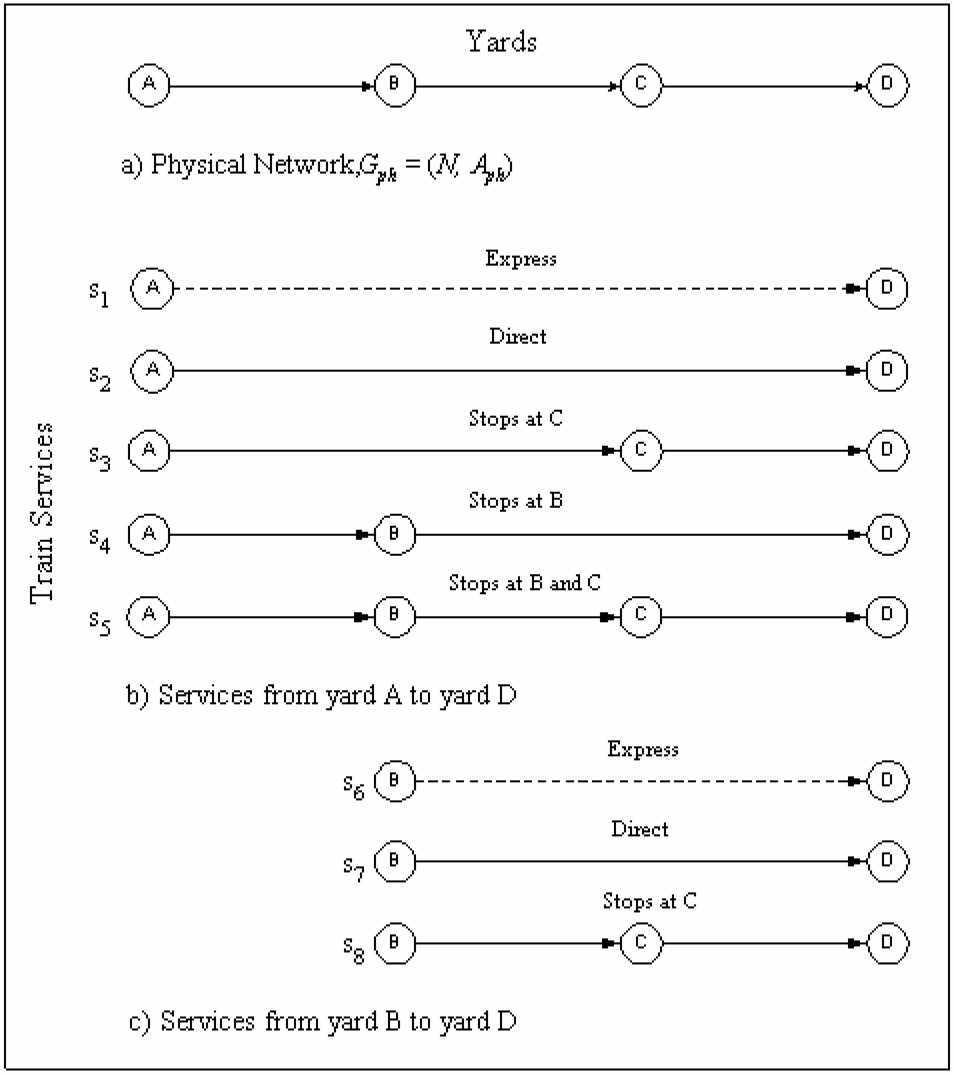
Contents

- **The objective of this optimization model is to determine train routing, makeup, and scheduling simultaneously. This compound model is constructed to answer the following important railroad operating questions:**
  (1) On what routes should trains run, at what speed priority and at what frequencies?
  (2) Which pairs of terminals are to be provided with direct train connections?
  (3) For each freight class, what train sequence should be used and what operations should be performed on the cars at each intermediary stop?
  (4) How are cars physically grouped within trains?
  (5) What time do trains run?

Contents

- The Service Network Design
  - **The Static Service Network Design**
  - **The Dynamic Service Network Design**

The Static Service Network Design



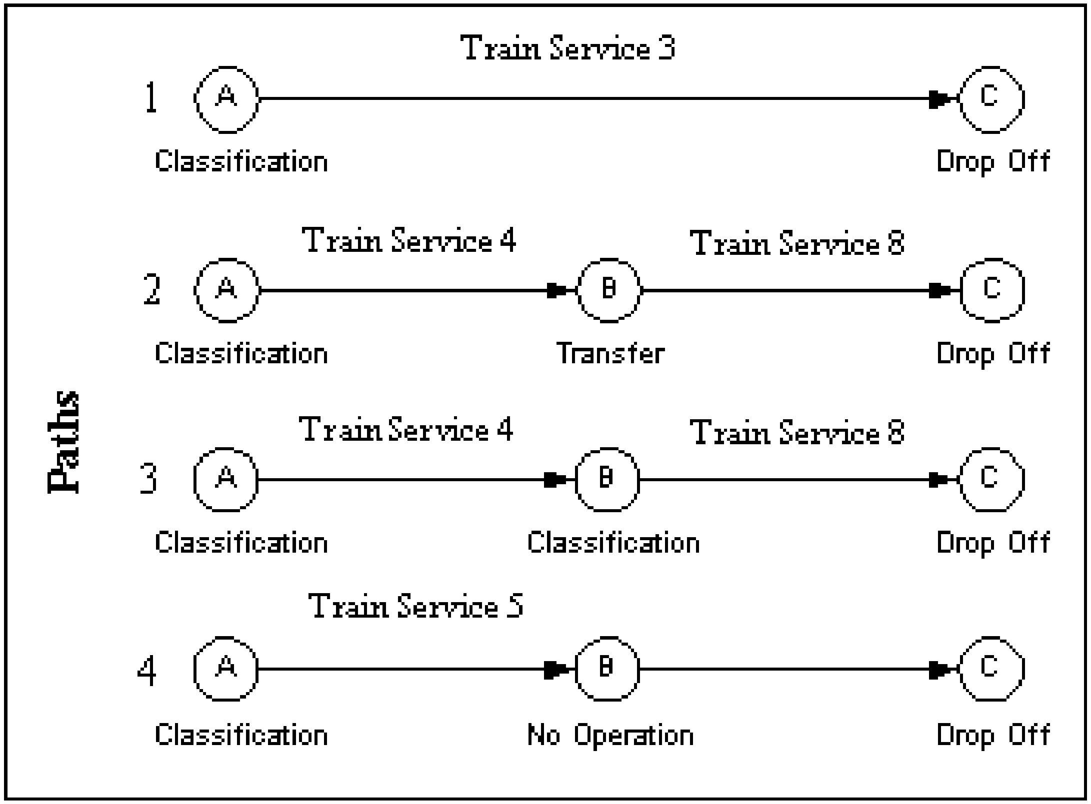
Physical Network and Some Train Services on Static Service Network

The Static Service Network Design

On static service network, a service is characterized by:

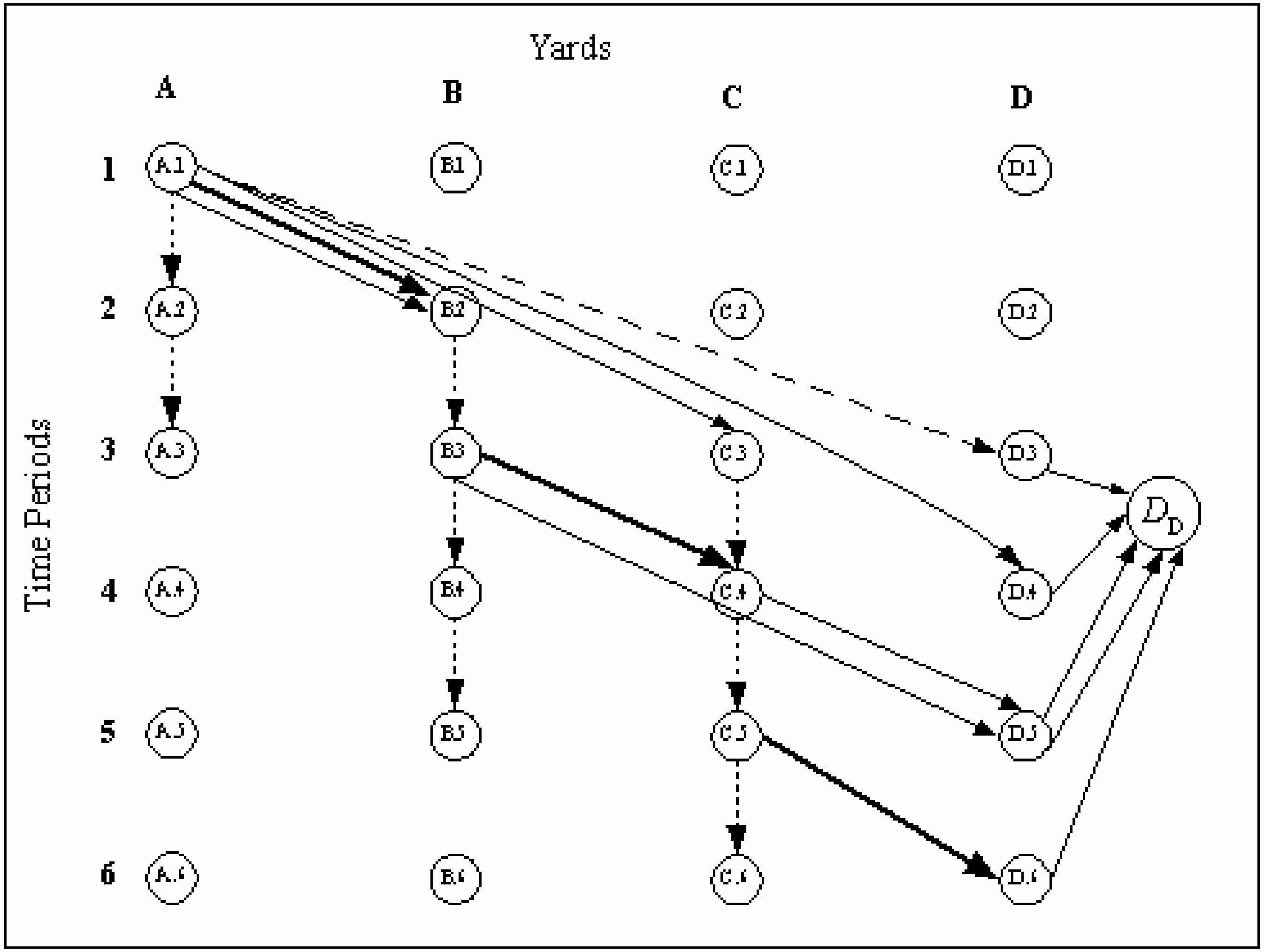
- An origin,
- A destination,
- A set of service links from origin to destination,
- A set of intermediate stops,
- A specification of the type of service in terms of speed and priority.

The Static Service Network Design



Four Paths for the Traffic from Yard A to Yard C

The Dynamic Service Network Design



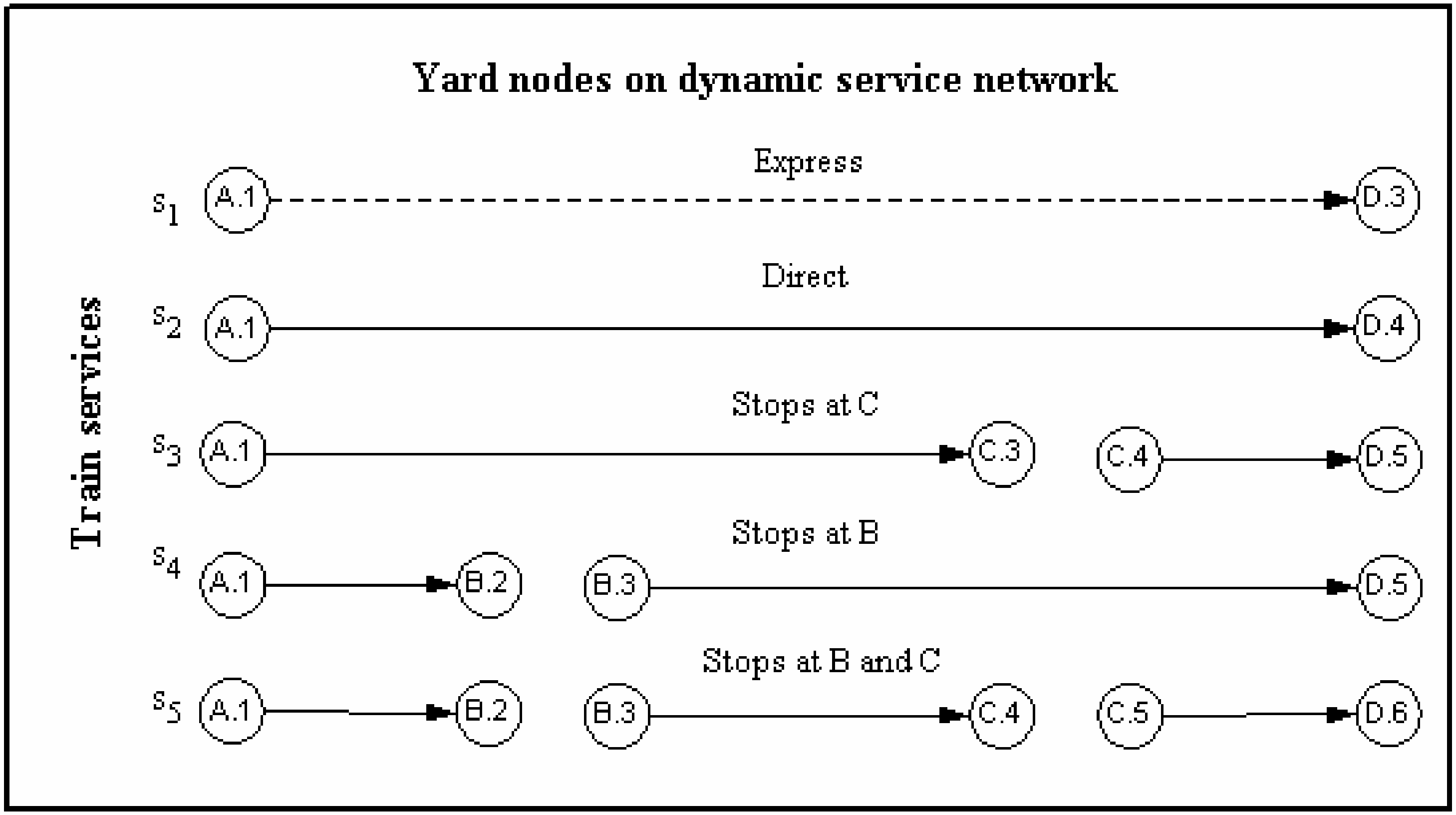
The Dynamic Service Network Design

The Dynamic Service Network Design

In the dynamic network each service has all the specification of a service in static service network plus:

- A departure time from its origin,
- Arrival time and departure times in intermediate stops, and
- Arrival time at the destination.

The Dynamic Service Network Design



Service Legs of Some Train Services from Yard A to Yard D
On Dynamic Network Design

Characteristics of Proposed Models

- **Formulation Structure:** Deterministic Dynamic Service Network Design (similar to fixed-charge, Capacitated, Multicommodity Network Design (*CMND*) formulation)
- **Planning horizon:** Operational and Tactical
- **Program horizon:** Day
- **Time period:** Hour
- **Train running time:** Fixed
- **Switching operation time:** Fixed

Characteristics of Proposed Models

- Objective: Minimizing Operating and Time Costs
- Costs:
  - **Fixed cost of a train,** (mainly crew costs)
  - **Intermediate yard costs,** (for switching operation)
  - **Car-time cost,** (Time Cost)
  - **Cost of additional horsepower per car,** (for faster trains)
  - **Penalty costs,** (to penalize delivery before and/or after a specified due date)

Formulation 1: Arc-node Based Model

Notation

Indices:

i : index for nodes, $i \in (I,\ D)$

j : index for track sections between consecutive yards, $j \in J$

k : index for demands, $k \in K$

l : index for links, $l \in L$

n : index for yards (terminals), $n \in N$

s : index for train services, $s \in S$

t : index for time periods, $t = 0, 1, 2, \ldots, T$

Formulation 1: Arc-node Based Model

Sets:

I : the set of yard nodes

D : the set of super nodes

N : the set of yards (terminals)

J : the set of track sections

K : the set of demands

L : the set of links, $L=\{ L^s , L^h , L^p \}$

L^s : the set of service links

L^h : the set of inventory links

L^p : the set of penalty (super) links

L_i^+ : the set of links incident to node $i \in (I, D)$

L_i^- : the set of links emanating from node $i \in (I, D)$

Formulation 1: Arc-node Based Model

Parameters:

f_s : the fixed cost of running train $s \in S$

c_l^k : the unit cost of moving demand $k \in K$ on link $l \in L$

u_{sl} : the total capacity of train service $s \in S$ on service link $l \in \Pi_s$

b_i^k : the net flow of demand $k \in K$, at node $i \in (I, D)$

Decision Variables:

y_s : binary variable, 1 if providing train service $s \in S$, 0 otherwise

x_l^k : the flow on link $l \in L$ of demand $k \in K$

Arc-node Based Model

$$\text{minimize } Z = \sum_{s \in S} f_s y_s + \sum_{k \in K} \sum_{l \in L} c_l^k x_l^k \qquad (1)$$

subject to

$$\sum_{l \in L_i^+} x_l^k - \sum_{l \in L_i^-} x_l^k = b_i^k \qquad \text{for all } i \in (I, D),\ k \in K \qquad (2)$$

$$\sum_{k \in K} x_l^k \le u_{sl} y_s \qquad \text{for all } s \in S,\ l \in \Pi_s \qquad (3)$$

$$y_s \in \Omega \qquad \text{for all } s \in S \qquad (4)$$

$$y_s \in \{0, 1\} \qquad \text{for all } k \in K \qquad (5)$$

$$x_l^k \ge 0 \text{ and integer} \qquad \text{for all } k \in K,\ l \in L \qquad (6)$$

Arc-node Based Model

Link Capacity Constraints

No more than a specified number of trains may be on a link over some period time

$$\sum_{s \in S_{jt}^{c}} y_s \leq \varphi_{jt} \qquad \text{for all } j \in J,\ t$$

Yard Capacity Constraints

limit the number of trains, which can be serviced (break up or make up operations) at each yard for each time period

$$\sum_{s \in S_{nt}^{d}} y_s \leq \beta_{nt} \qquad \text{for all } n \in N,\ t$$

limit the number of train stocks, which each yard can have

$$\sum_{s \in S_{nt}^{e}} y_s \leq \theta_{nt} \qquad \text{for all } n \in N,\ t$$

Arc-node Based Model

$$\text{minimize } Z = \sum_{s \in S} f_s y_s + \sum_{k \in K} \sum_{l \in L} c_l^k x_l^k \qquad (1)$$

subject to

$$\sum_{l \in L_i^+} x_l^k - \sum_{l \in L_i^-} x_l^k = b_i^k \qquad \text{for all } i \in (I, D), k \in K \qquad (2)$$

$$\sum_{k \in K} x_l^k \leq u_{sl} y_s \qquad \text{for all } s \in S, l \in \Pi_s \qquad (3)$$

$$y_s \in \Omega \qquad \text{for all } s \in S \qquad (4)$$

$$y_s \in \{0, 1\} \qquad \text{for all } k \in K \qquad (5)$$

$$x_l^k \geq 0 \text{ and integer} \qquad \text{for all } k \in K, l \in L \qquad (6)$$

Formulation 2: Path-based Model

Notation

Parameters

w_p^k : the unit cost of demand $k \in K$ on path $p \in P^k$

δ_{sl}^{pk} : 1 if link $l \in \Pi_s$ of service $s \in S$ is used by path $p \in P^k$ of demand $k \in K$, 0 otherwise

Decision Variables

h_p^k : the flow of demand $k \in K$, on path $p \in P^k$

Path-based Model

$$\text{minimize } Z = \sum_{s\in S} f_s y_s + \sum_{k\in K} \sum_{p\in P^k} w_p^k h_p^k \qquad (1)$$

subject to

$$\sum_{p\in P^k} h_p^k = b^k \qquad \text{for all } k\in K \qquad (2)$$

$$\sum_{k\in K} \sum_{p\in P^k} h_p^k \delta_{sl}^{pk} \le u_{sl} y_s \qquad \text{for all } s\in S,\ l\in \Pi_s \qquad (3)$$

$$y_s \in \Omega \qquad \text{for all } s\in S \qquad (4)$$

$$y_s \in \{0, 1\} \qquad \text{for all } k\in K \qquad (5)$$

$$h_p^k \ge 0 \text{ and integer} \qquad \text{for all } k\in K,\ p\in p^k \qquad (6)$$

Comparisons of Models

- Advantages of path-based formulation:
  - **Route costs can be easily incorporated in path model but not in arc model**
  - **Certain classes of constraints that are difficult, if not impossible, to write for arc model are easily defined in path formulation**
  - **The number of constraints in path model is greatly reduced comparing to the number in arc model**
- Disadvantage of path-based formulation:
  - **The increase in the number of decision variables**

Algorithmic Ideas (continue)

Formulation when all the design trains y_s ($s \in S$) are open. (Similar to a capacitated multicommodity minimum cost network flow (MCNF) problem in path flow variables)

minimize Z = $\sum_{k \in K} \sum_{p \in P^k} w_p^k h_p^k$

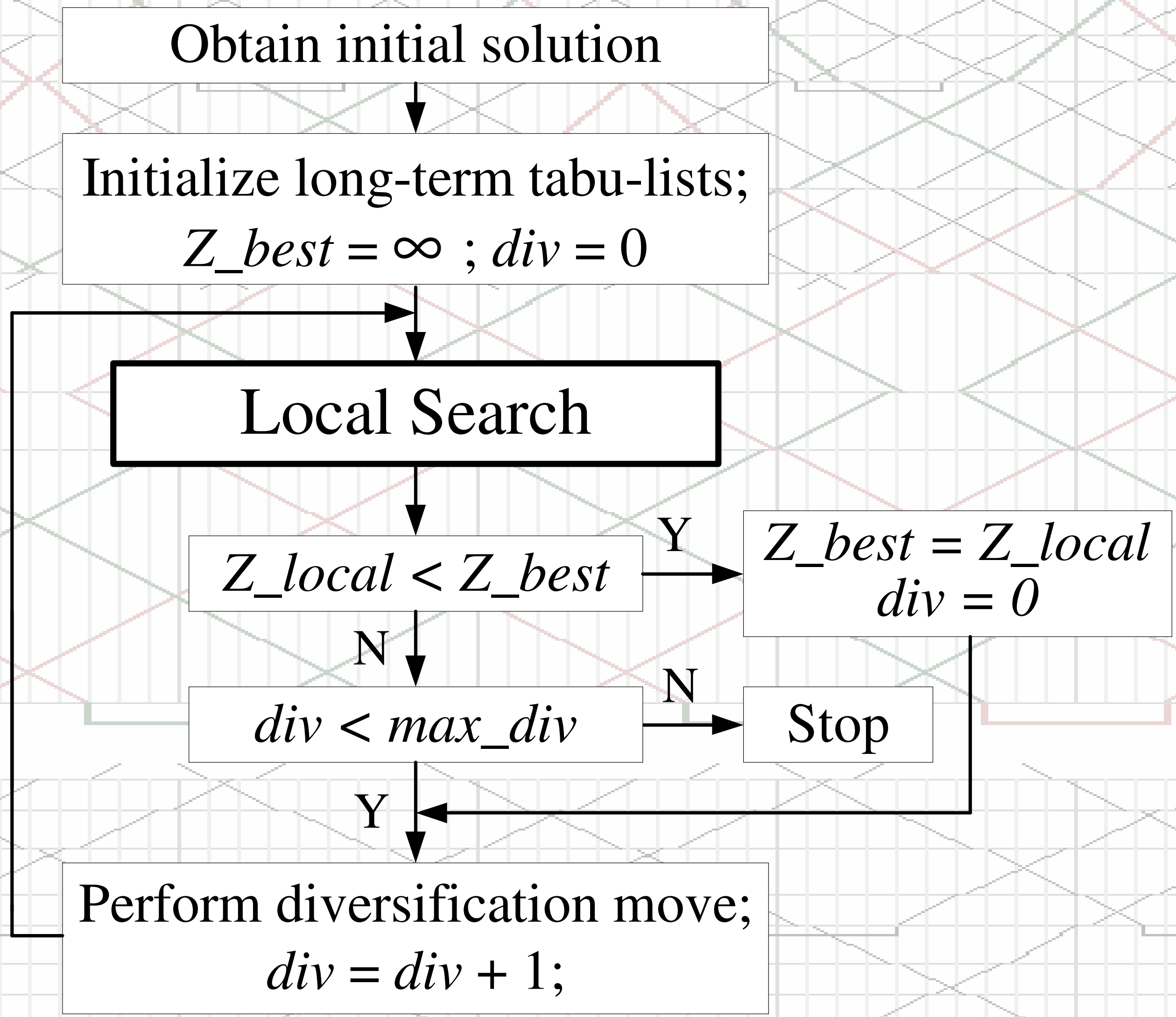
subject to

$\sum_{p \in P^k} h_p^k = b^k$ for all $k \in K$

$\sum_{k \in K} \sum_{p \in P^k} h_p^k \delta_{sl}^{pk} \leq u_{sl}$ for all $s \in S$, $l \in \Pi_s$

$h_p^k \geq 0$ and integer for all $k \in K$, $p \in P^k$

Proposed Tabu Search Method



Proposed Tabu Search Method

- ***Long-term frequency memory:*** **how many iterations a train has been in the basis**

- ***Long-term tabu list:*** **the trains and paths which are closed each diversification move**

Proposed Tabu Search Method

- ***div*: the number of consecutive unimproving diversification moves**

- ***max_div*: the maximum number of consecutive unimproving diversification moves**

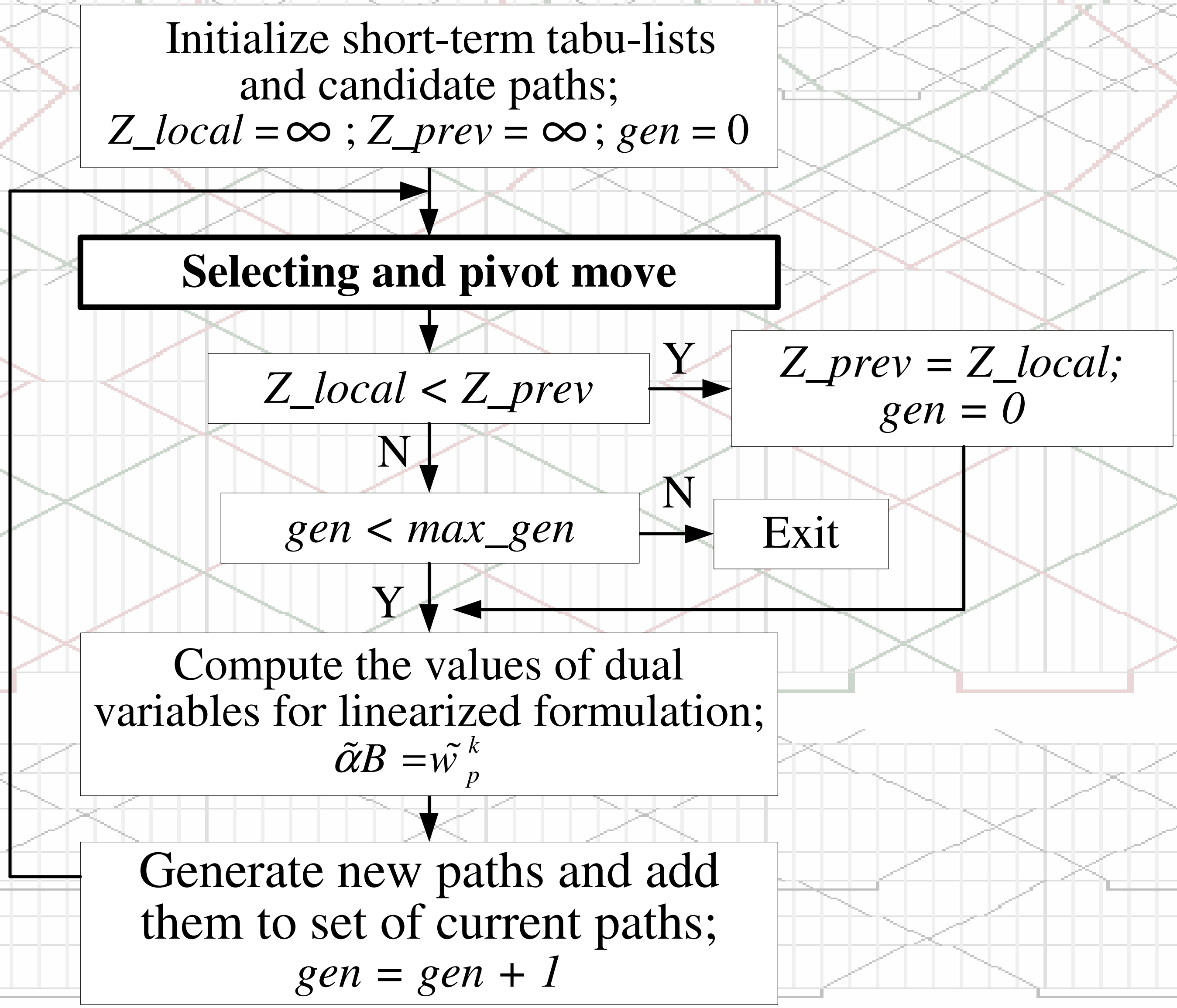
Proposed Tabu Search Method

- ***tabu_cycle:*** **the trains and paths which are closed at diversification move are tabu for *tabu_cycle* column generation cycles**

- ***sr_close*****: percentage of train services which are closed at each diversification**

Local Search – Column Generation

Cycle



Local Search – Column Generation

Cycle

- ***Short-term tabu list:*** **path variables that recently got out the basis**

- ***tabu_tenure*: the number of iteration which an exiting variable remain in short-term tabu list**

Local Search – Column Generation
Cycle

- *gen*: the number of consecutive unimproving column generation cycles
- *max_gen*: the maximum number of consecutive unimproving column generation cycles
- *pa_gen*: the number of paths generate for each commodity during the column generation cycle

Local Search – Column Generation

Cycle

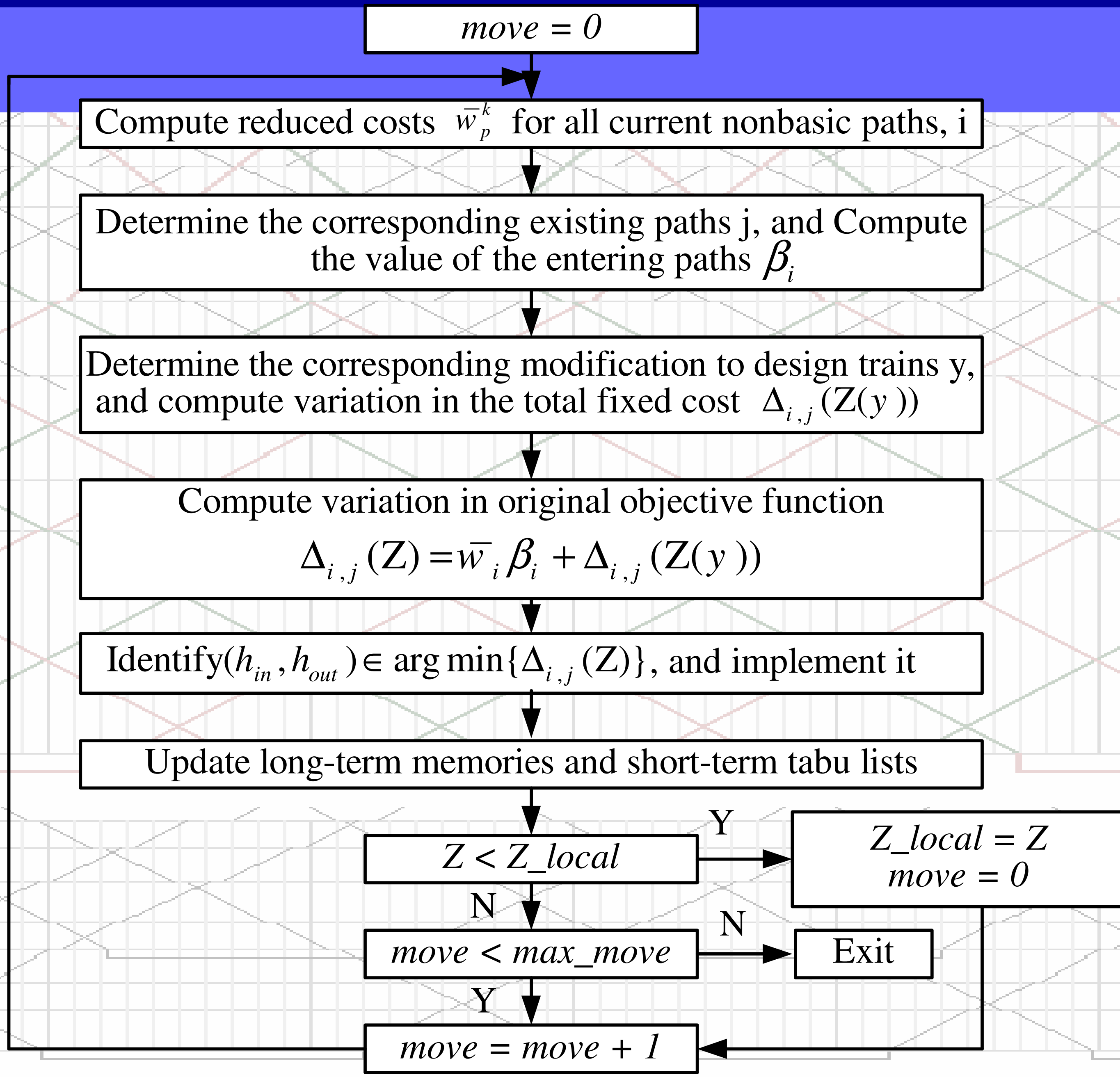
Linearized formulation:

$$z(\tilde{h}_p^k) = \sum_{k \in K} \sum_{p \in P^k} \tilde{w}_p^k h_p^k$$

where

$$\tilde{w}_p^k = w_p^k + \sum_{s \in S} \delta_{sl}^{pk} (f_s / u_s)$$

Selecting and Pivot Moves



Selecting and Pivot Moves

- ***move***: **the number of consecutive unimproving revised simplex method moves**
- ***max_move***: **the maximum number of consecutive unimproving revised simplex method moves**

Input Data

- Network
- Freight Trains
- Demands

Input Data

- Network
  - Capacity of each track section for freight trains
  - Number of cars which can be stored at each yard
  - Number of trains which can be made up and broken up at each yard
  - Average cost of set off and pick up operation per car at each yard

Input Data

➢Freight Trains

- **Types of freight trains**
- **Origin and destination of freight trains**
- **Running time between yards**
- **Intermediate stops and operations (set off or pick up)**
- **Train capacity (number of cars)**
- **Fixed cost of running of the freight trains**
- **Number of locomotive and their cost for each train**
- **Variable cost per car**

Input Data

- Demands
  - **Origin and destinations of demands**
  - **Volume and type of each demand**
  - **Arrival time of each demand at the origin station**
  - **Maximum transport time for each demand (if there is**

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