Travel Time Estimation and Deadlock-free Routing of an AGV system

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Outline

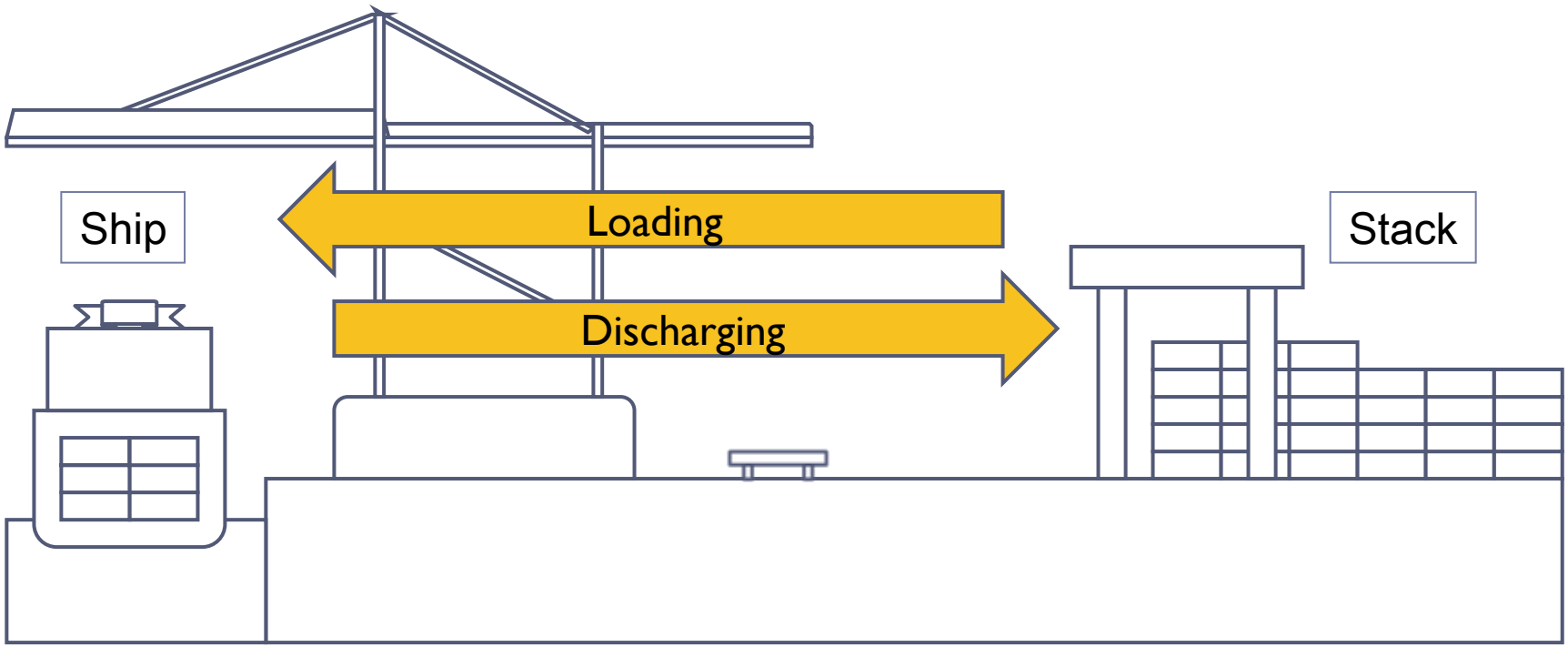
- Introduction
- AGV traffic control
  - Route creation
  - Travel scheduling
- Travel time estimation algorithm
  - Travel time estimation in accelerated motion
  - Travel time estimation considering interference
- Experimental results
- Conclusions

Introduction

- Automated container terminal
- AGV routing problem
- Previous research
- Motivations

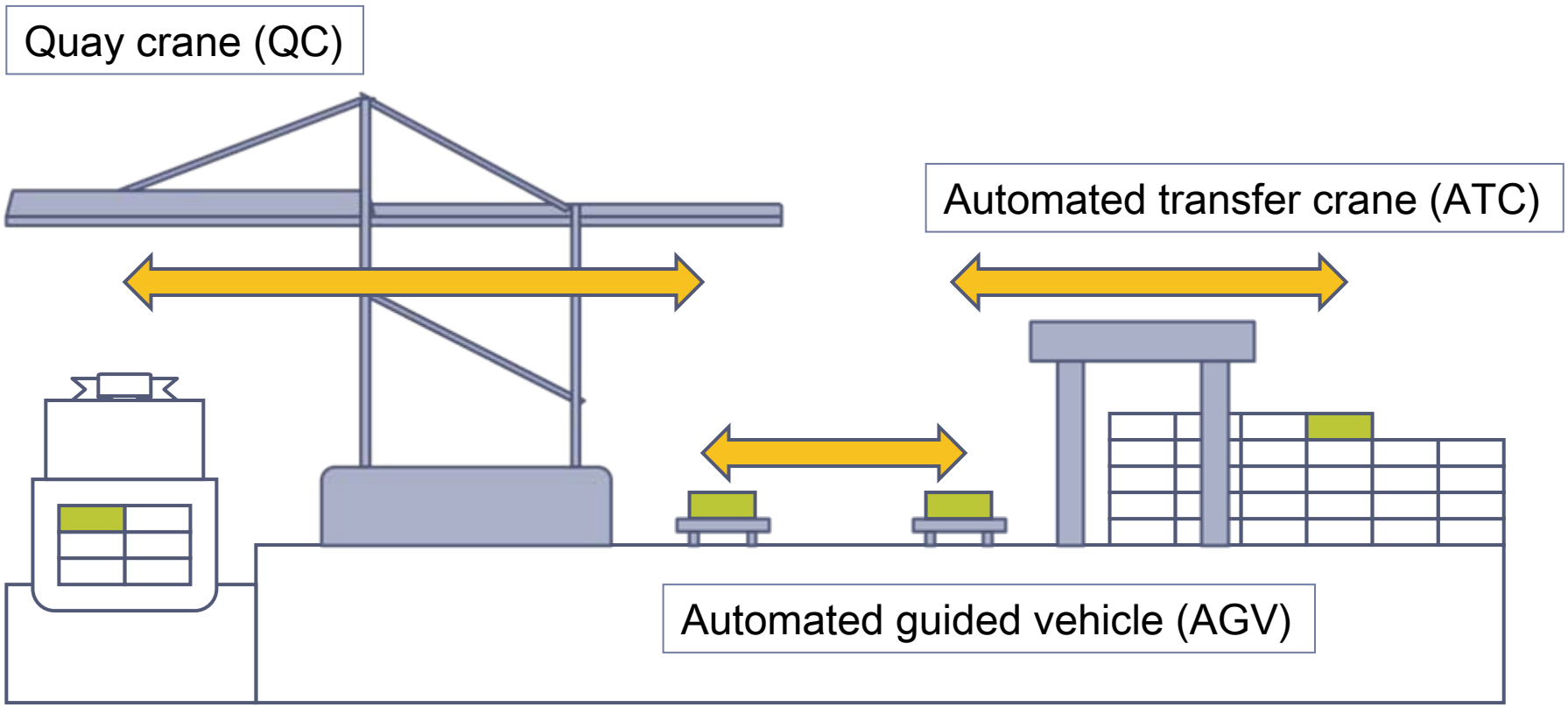
Automated Container Terminal

- Two main processes
  - Loading
  - Discharging



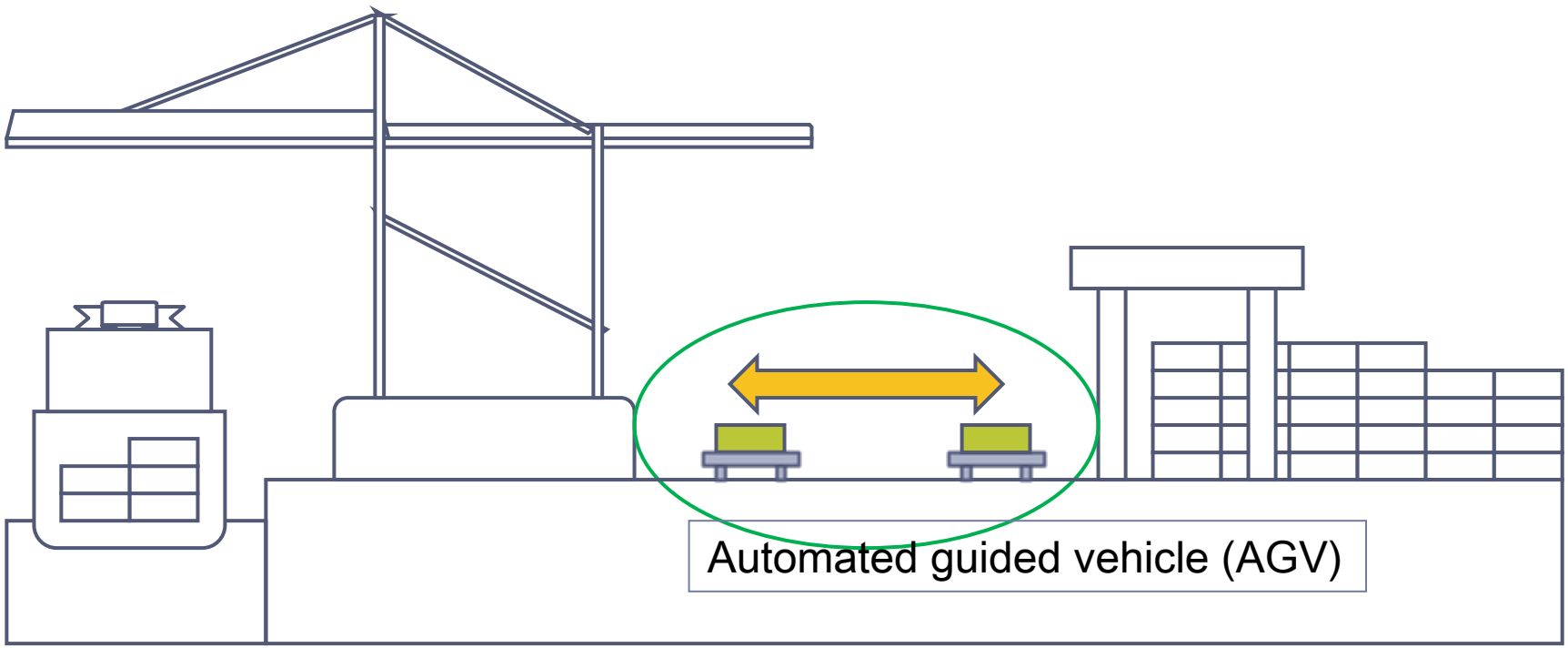
Automated Container Terminal

- Three types of equipments



Automated Container Terminal

- Efficient AGV operation is essential for a high productivity of a container terminal.



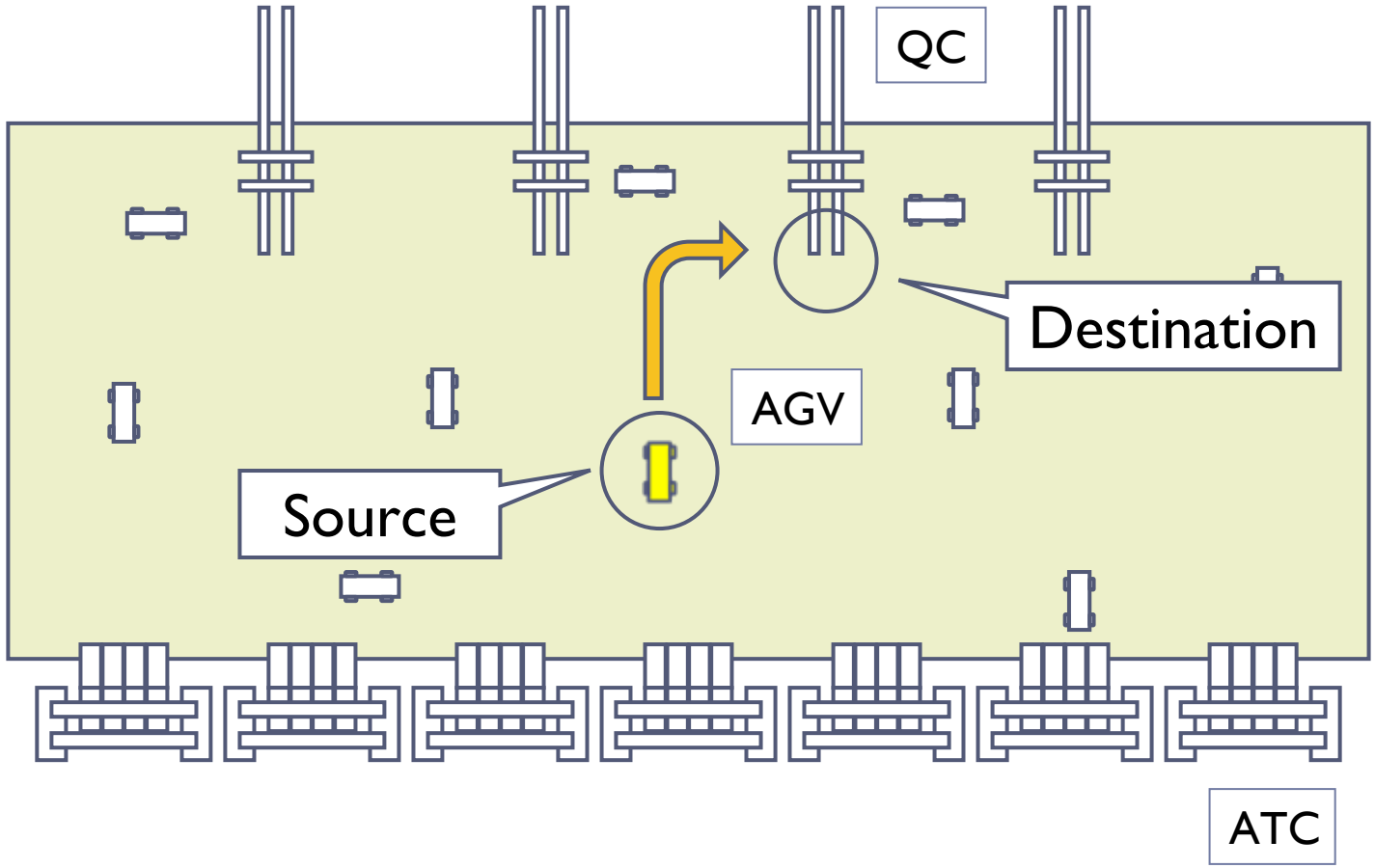
AGV Routing Problem

- Routing
  - The process of setting up a travel path to the destination

- Two main issues
  - Traffic control
    - Dealing with the collisions and conflicts.
  - Route selection
    - Find a good route

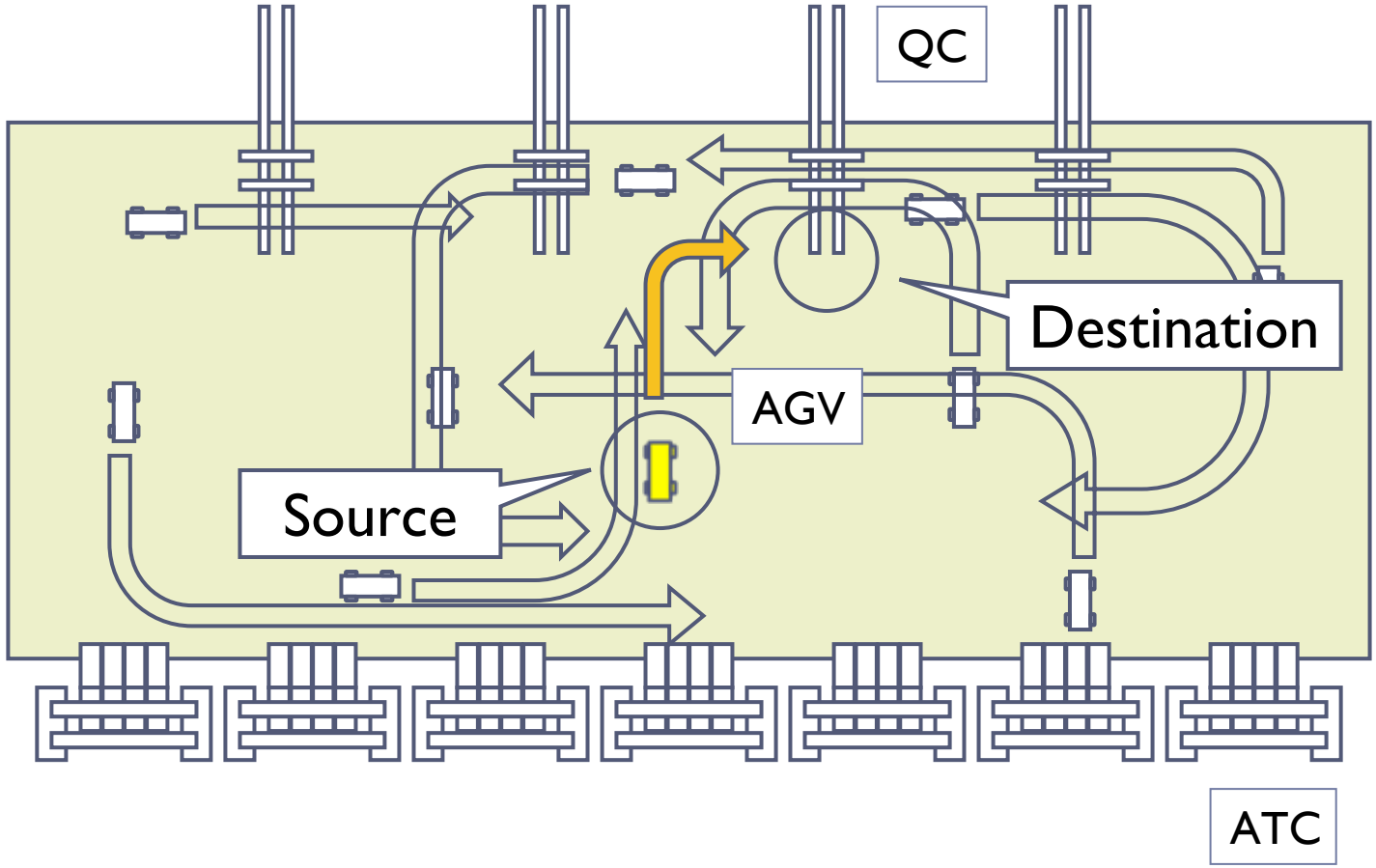
AGV Routing Problem

- Top view of an automated container terminal



AGV Routing Problem

- Considering other AGVs.



AGV Routing Problem

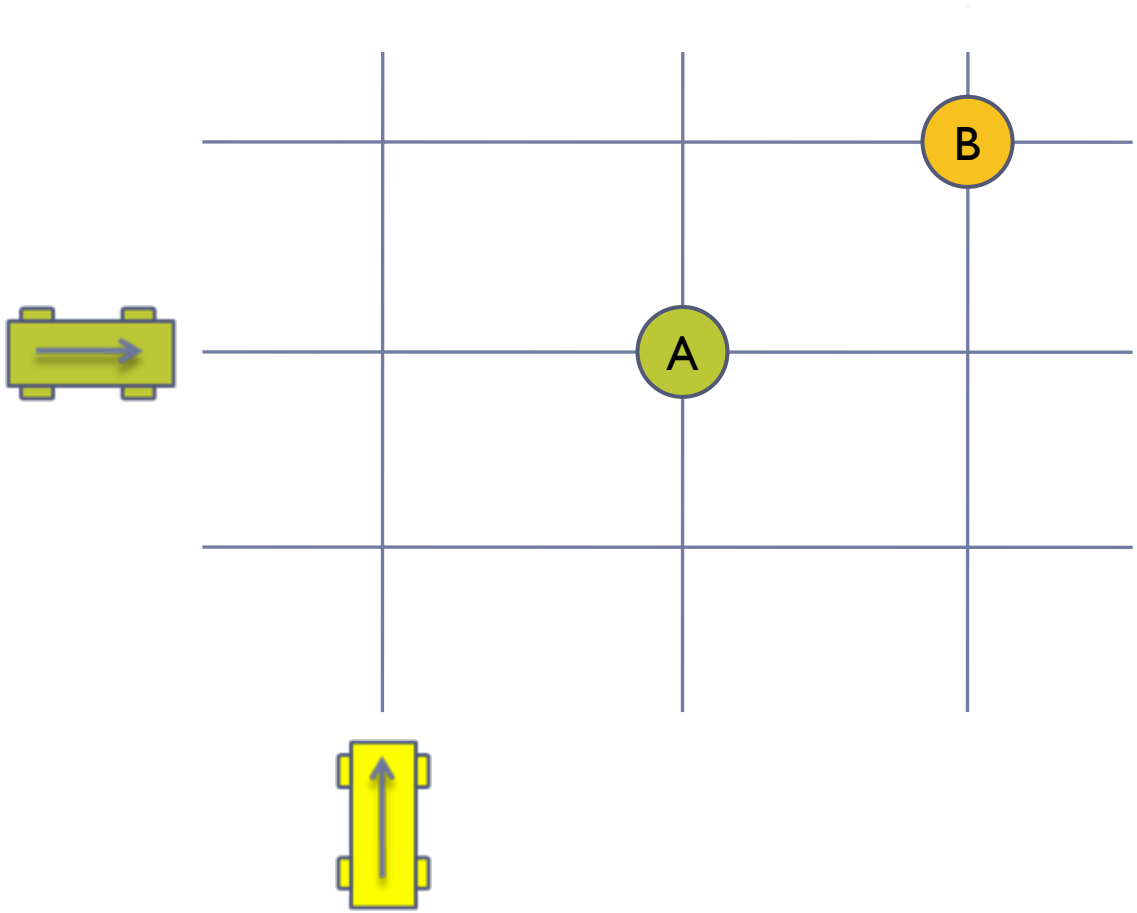
- Route selection
  - A route taking a minimum travel time.
  - Difficulty to calculate the exact travel time.
    - Accelerations
    - Interference due to other AGVs

Previous Research

- Zone control scheme
- Grid control scheme

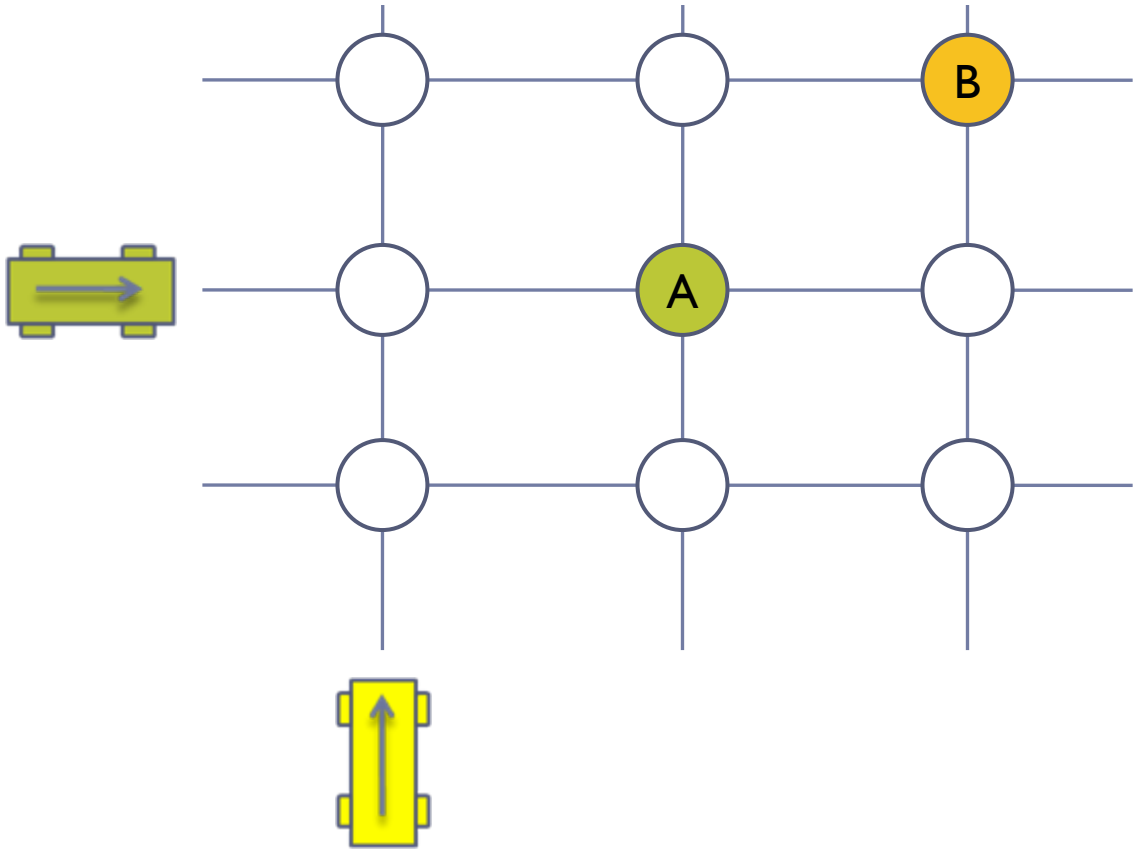
Zone Control Scheme

- Uses a fixed path layout.



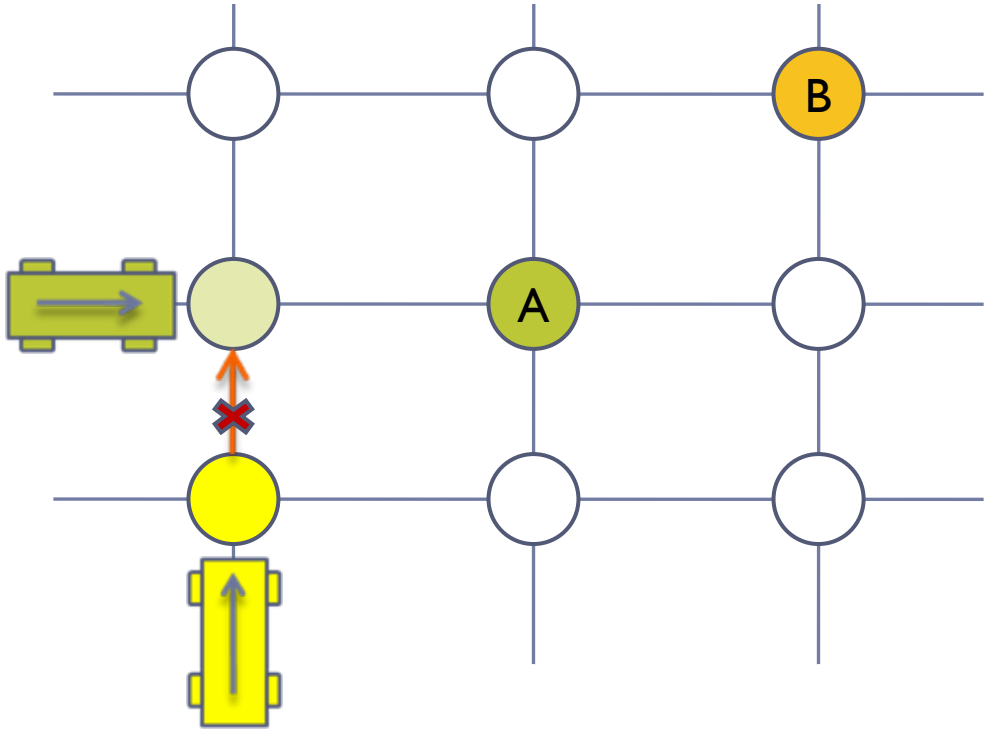
Zone Control Scheme

- Generates a graph by dividing guide paths into zones and linking them to each other.



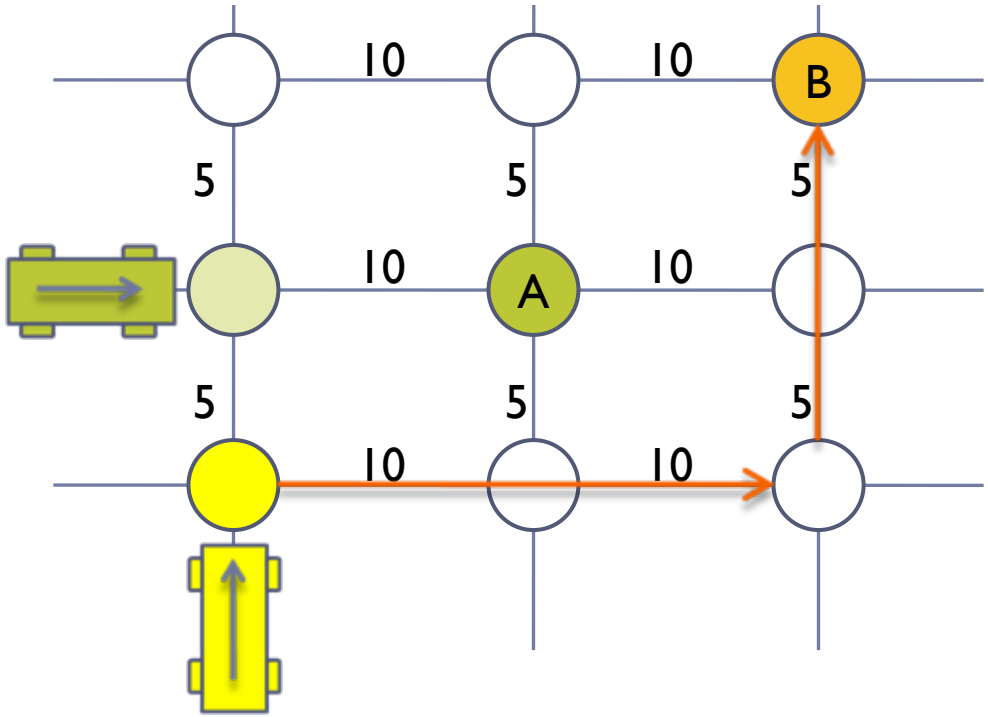
Zone Control Scheme

- To avoid collision, only one AGV is allowed to occupy a zone at a time



Zone Control Scheme

- Assumes path costs as constants.
  - Applies the shortest path algorithm

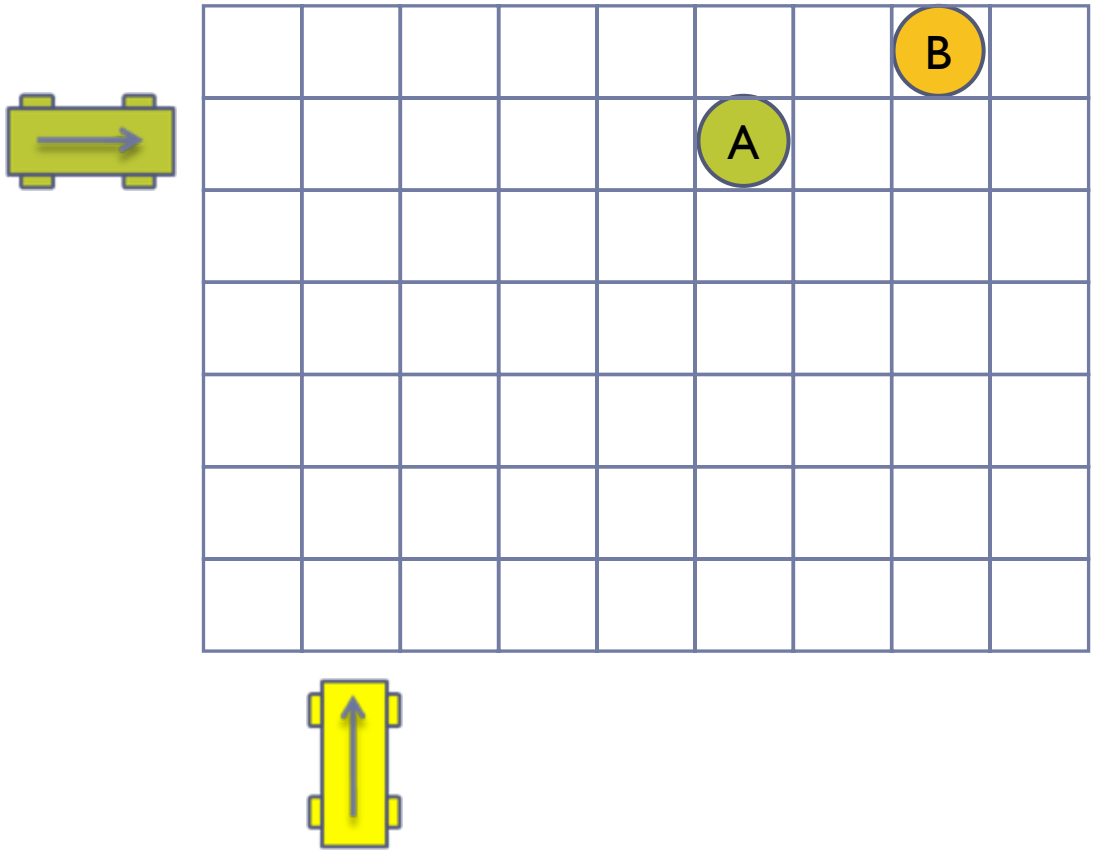


Zone Control Scheme

- Limitations
  - Has low degree of freedom to set a travel path.
  - Cannot take into account the acceleration.

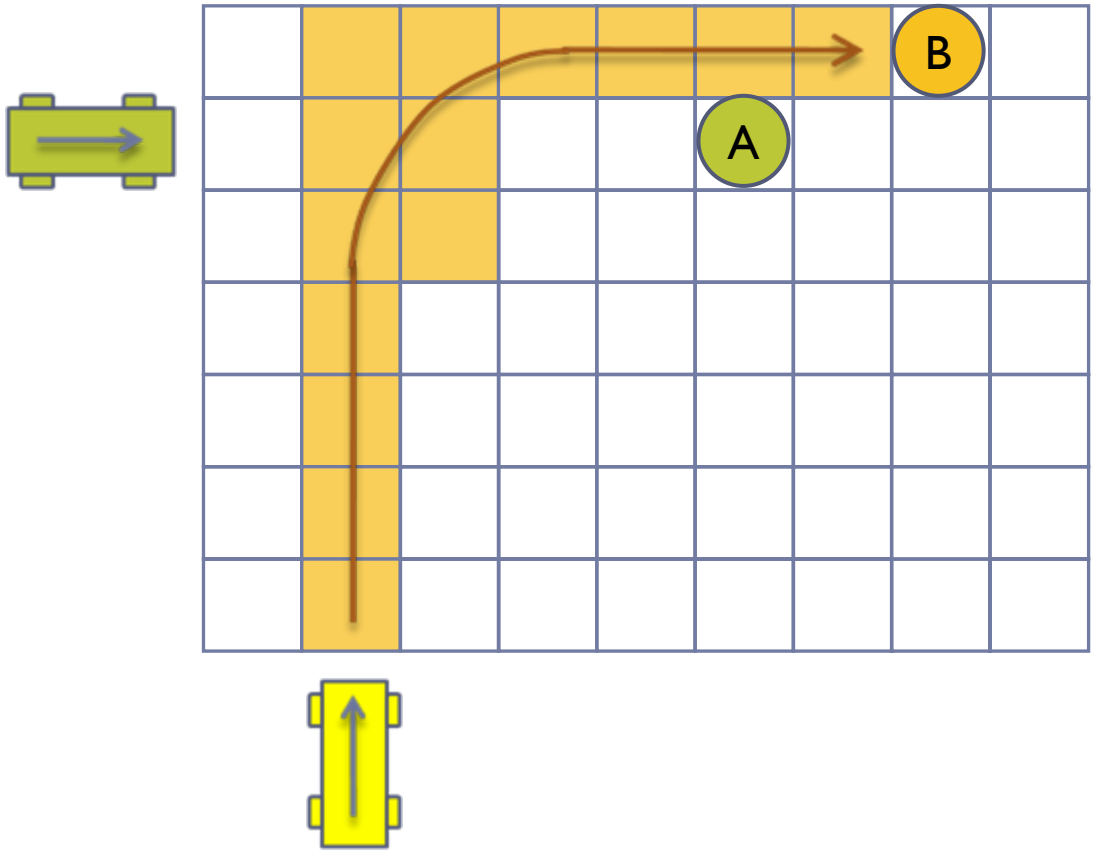
Grid Control Scheme

- Uses a grid path layout.



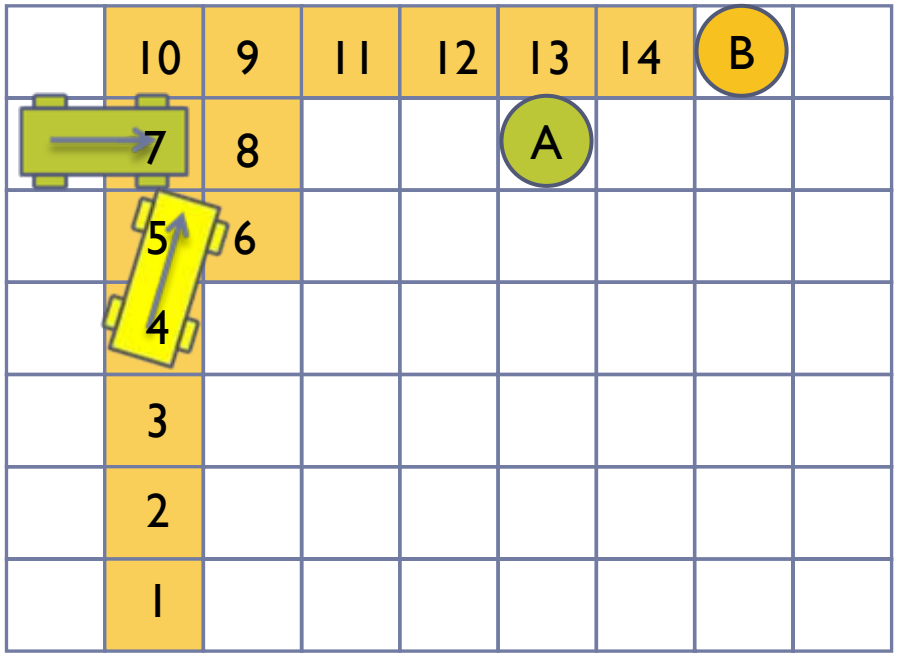
Grid Control Scheme

- More flexible travel path
  - Represented by a sequence of occupied grids.



Grid Control Scheme

- When an AGV turns, the sequence of occupied grids cannot follow the direction of motion



Motivations

- Create a flexible travel path of which the sequence of areas follows the motion of an AGV when making turns

- Estimate the travel time of an AGV considering accelerations and interferences

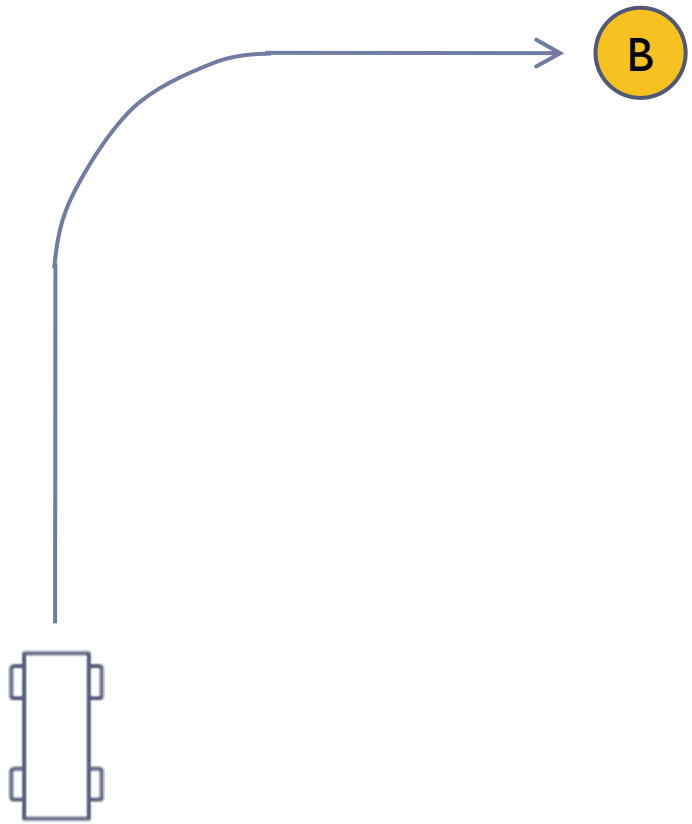
AGV Traffic Control

- Route creation
  - Generate unit areas along the trajectory of AGVs
  - Set up a route with a sequence of unit areas

- Travel scheduling
  - Occupation Area Reservation (OAR) table
  - Deadlock-free routing algorithm with OAR table

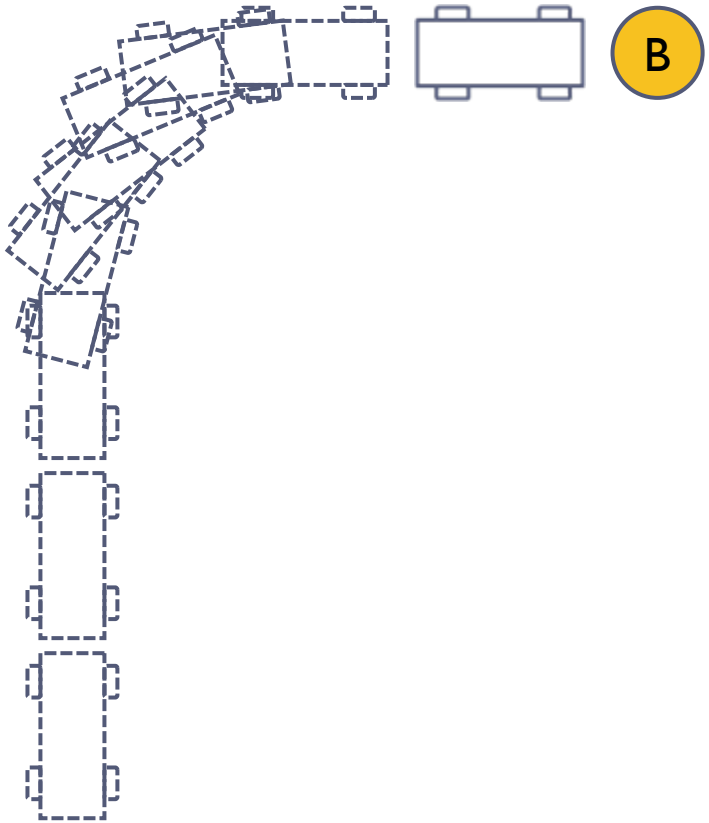
Route Creation

- An actual trace of the AGV



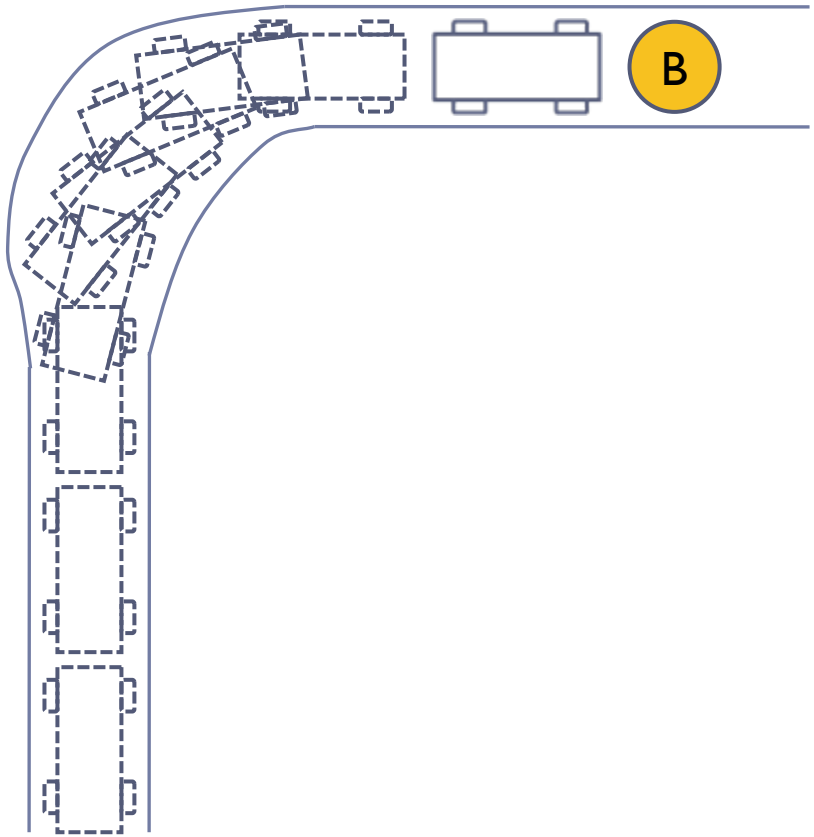
Route Creation

- Area occupied by the AGV



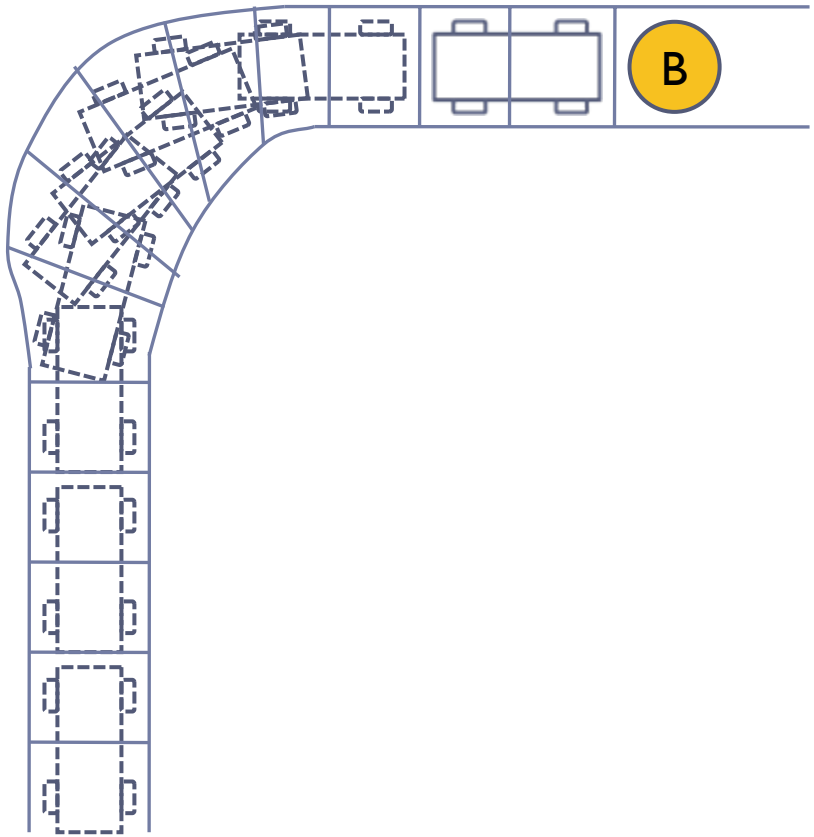
Route Creation

- The contour of the occupied areas



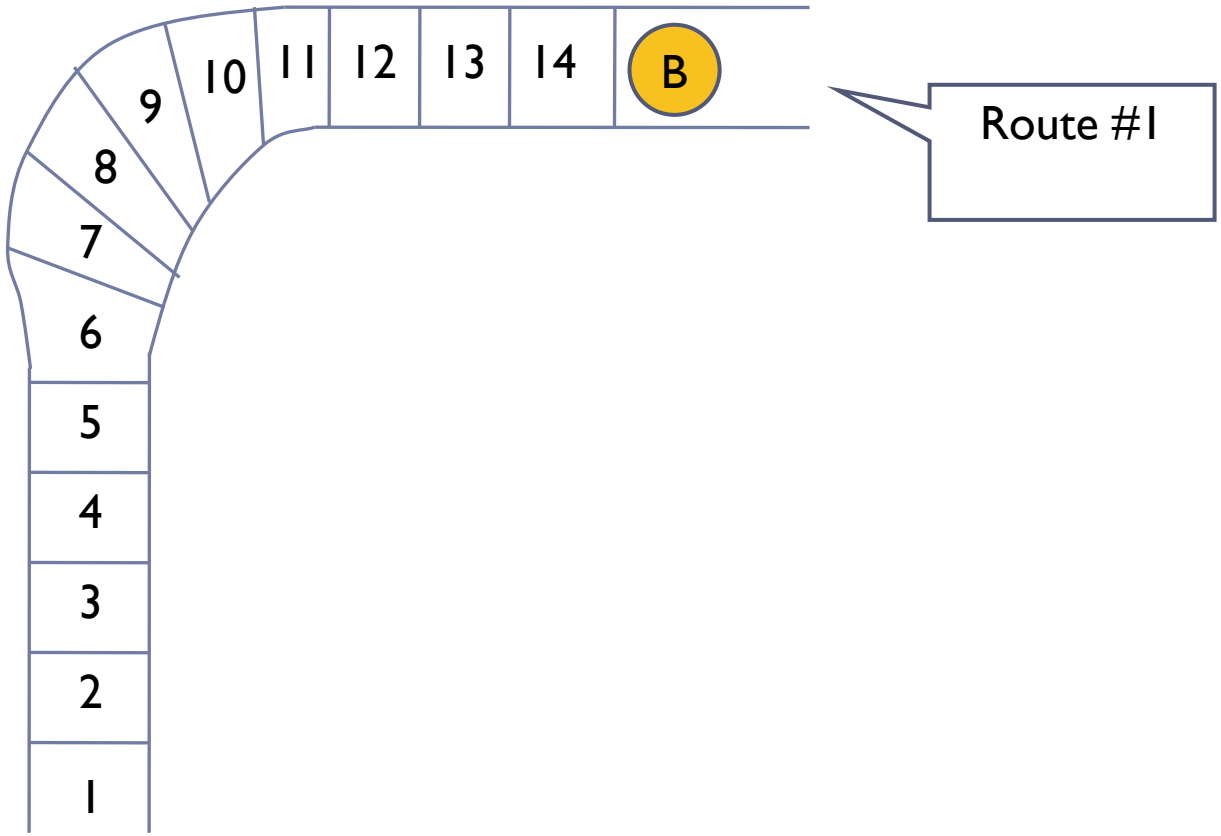
Route Creation

- Splitting the occupied area



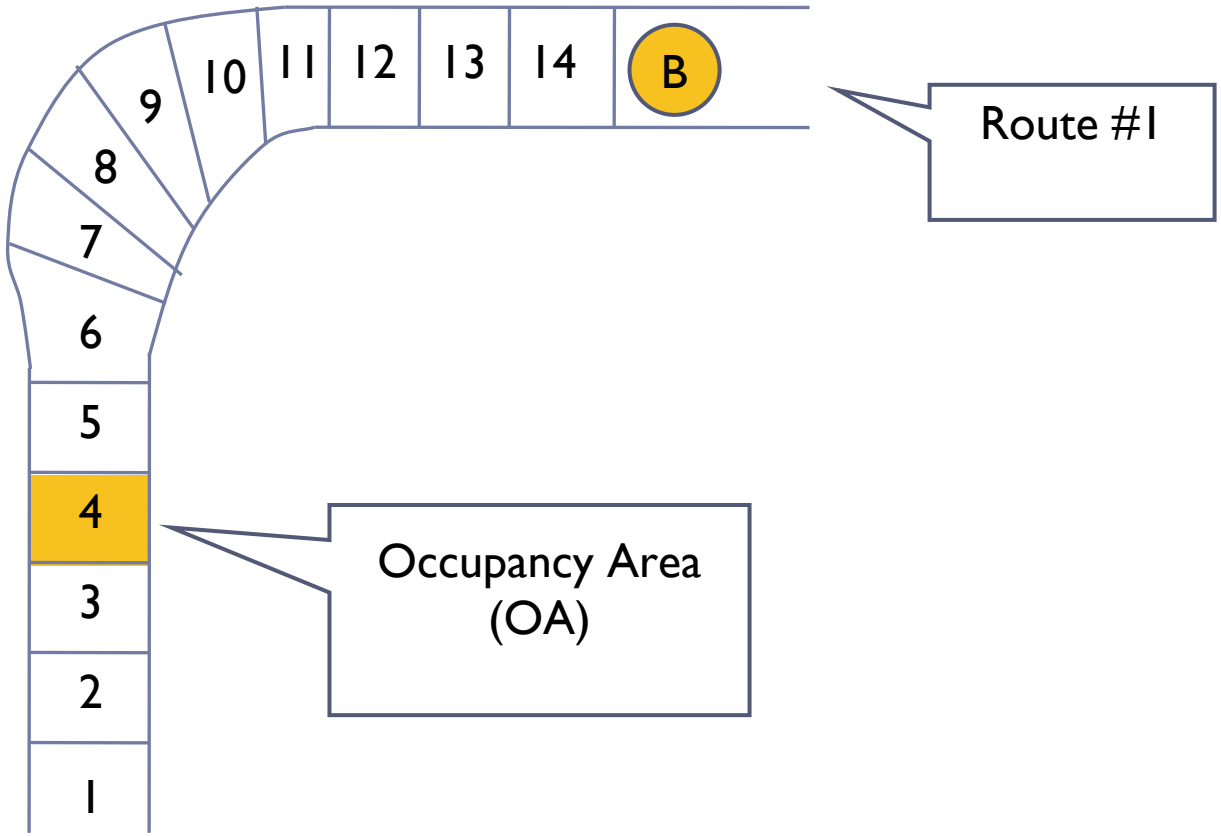
Route Creation

- Define a route as a sequence of unit areas.



Route Creation

- Occupancy Area (OA)



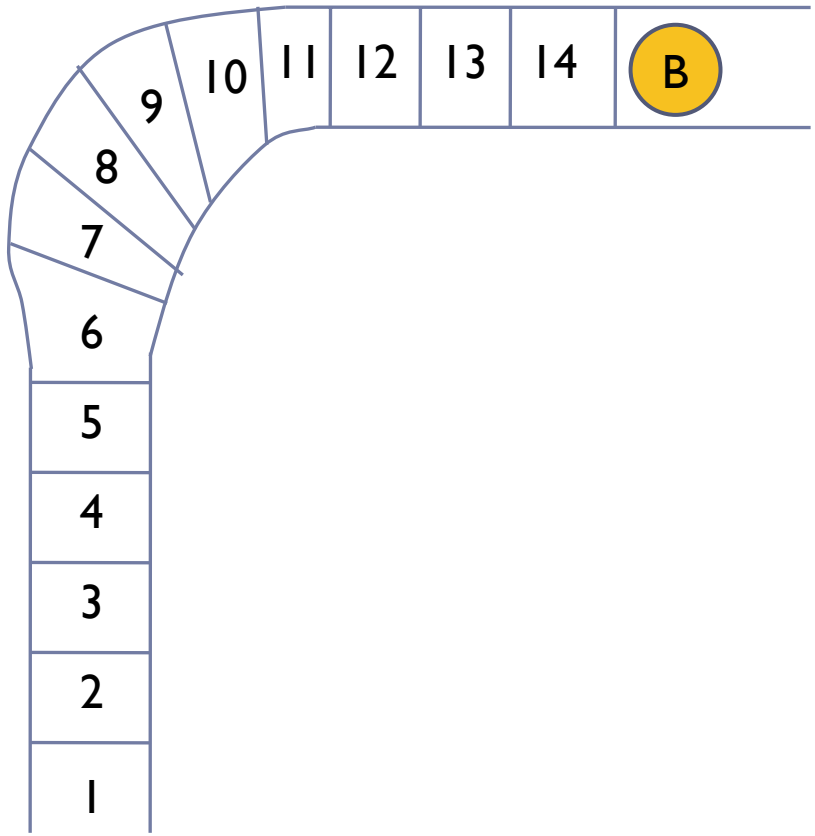
AGV Traffic Control

- Route creation
  - Generate unit areas along the trajectory of AGVs
  - Set up a route with a sequence of unit areas

- Travel scheduling
  - Occupation Area Reservation (OAR) table
  - Deadlock-free routing algorithm with OAR table

Travel Scheduling

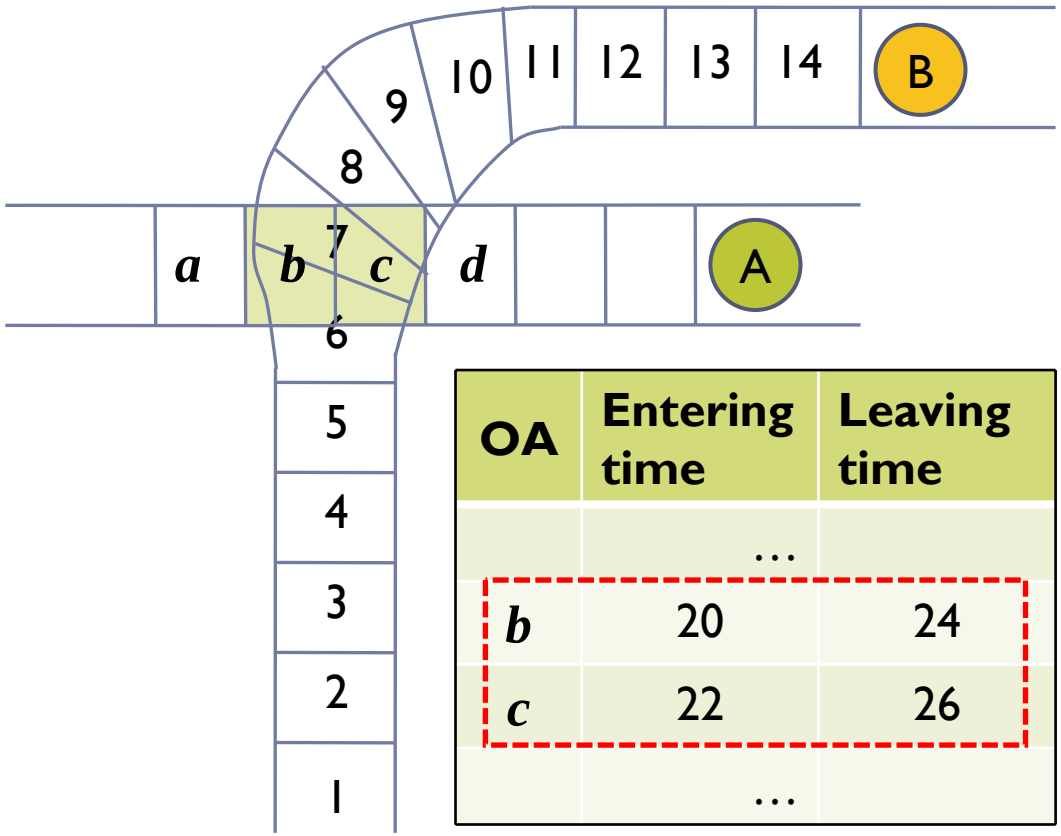
- Occupation Area Reservation table (OAR table)
  - Records the entering and leaving time of each OA



OA	Entering time	Leaving time
1	10	14
2	12	16
3	14	18
4	16	
5	18	
6		
	…	
13		
14		

Travel Scheduling

- To avoid collisions, check the OAR table of other routes overlapped.

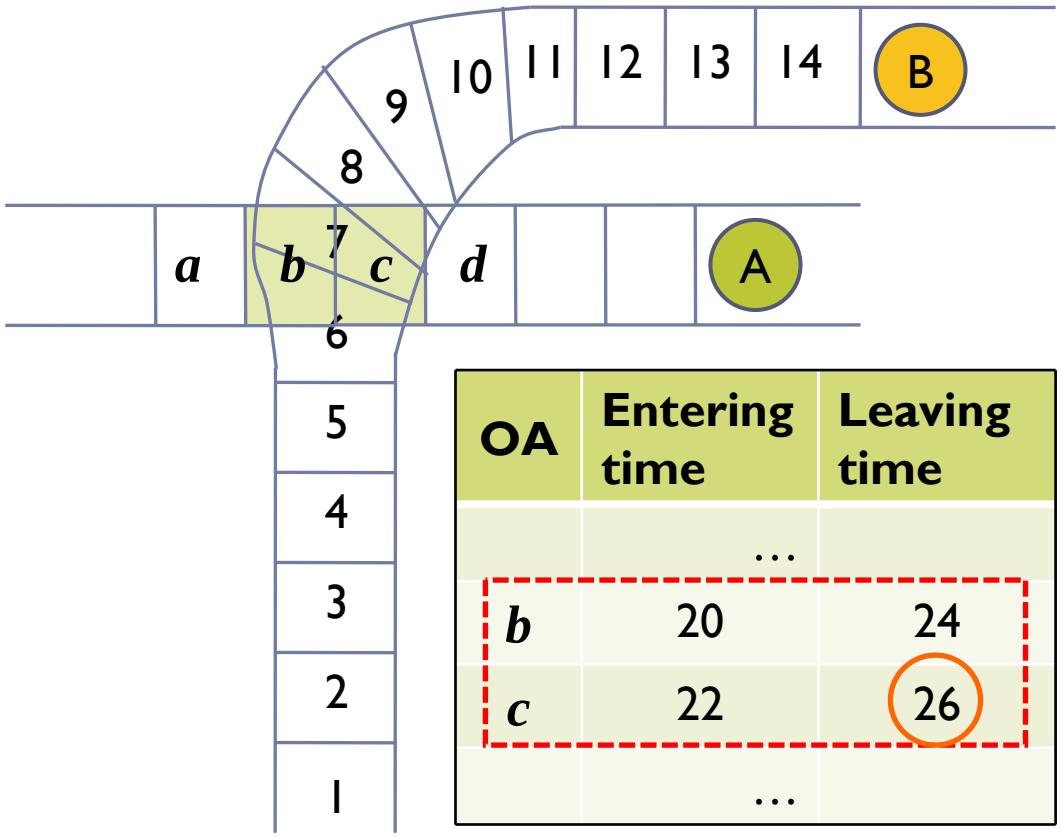


OA	Entering time	Leaving time
	…	
b	20	24
c	22	26
	…	

OA	Entering time	Leaving time
1	10	14
2	12	16
3	14	18
4	16	
5	18	
6		
	…	
13		
14		

Travel Scheduling

- The AGV can reserve the OA labeled ‘6’ after the OA labeled ‘c’ is released.

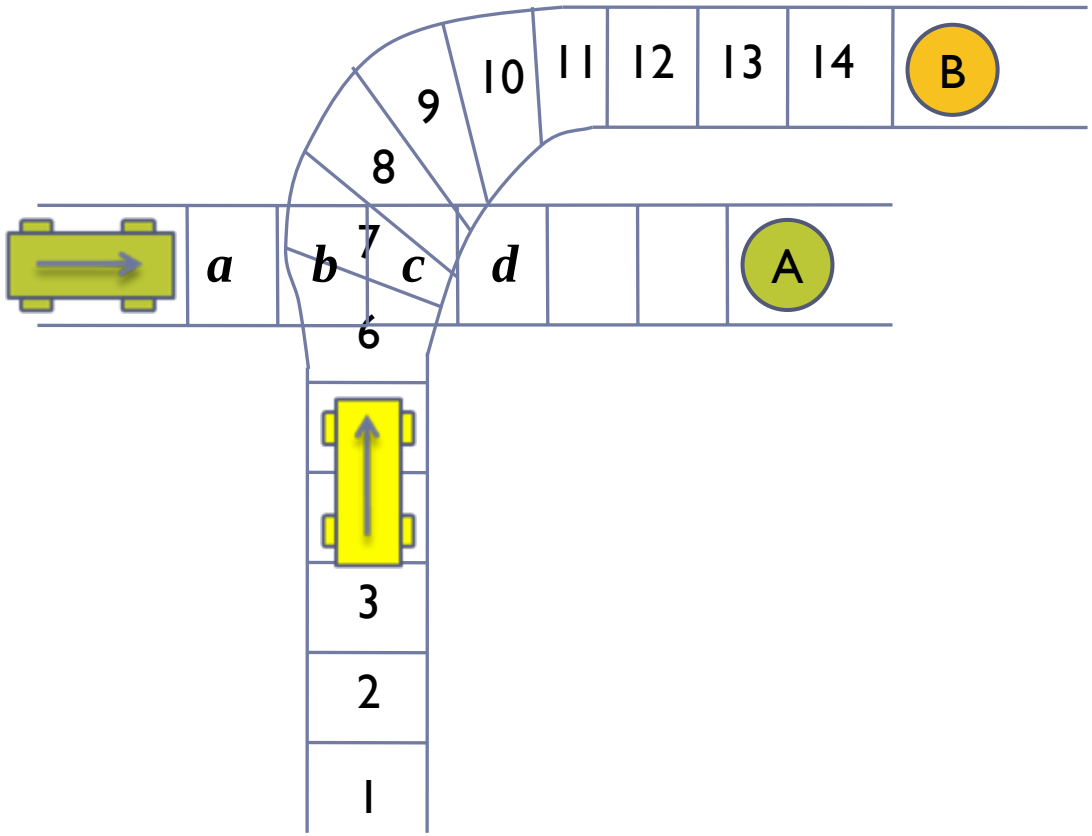


OA	Entering time	Leaving time
	…	
b	20	24
c	22	26
	…	

OA	Entering time	Leaving time
1	10	14
2	12	16
3	14	18
4	16	26
5	18	28
6	26	30
	…	
13		
14		

Travel Scheduling

- The travel of AGVs follows the OAR table.



Travel Scheduling

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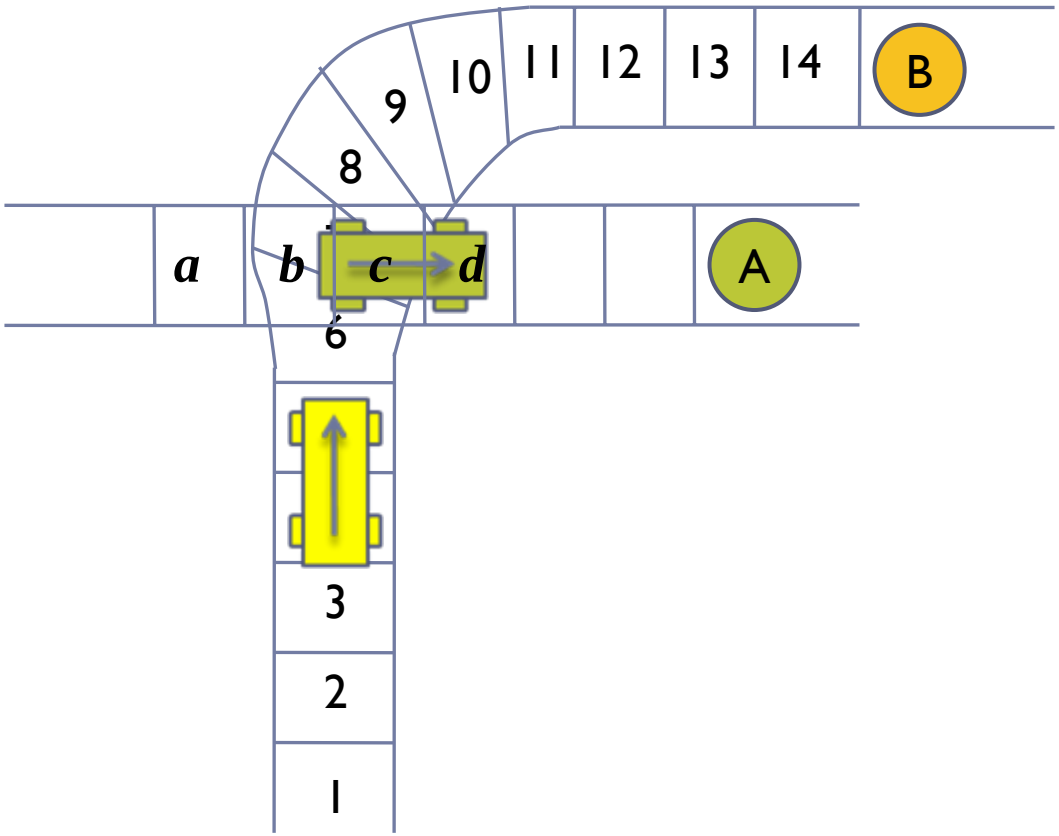

Travel Scheduling

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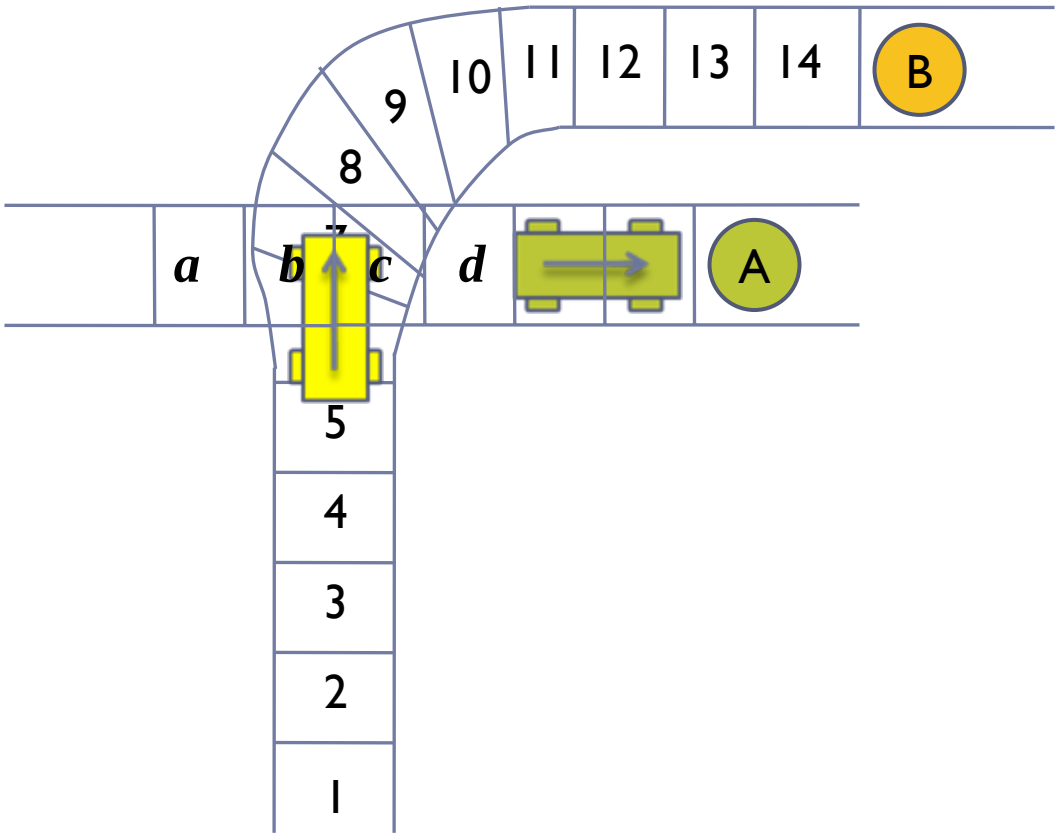
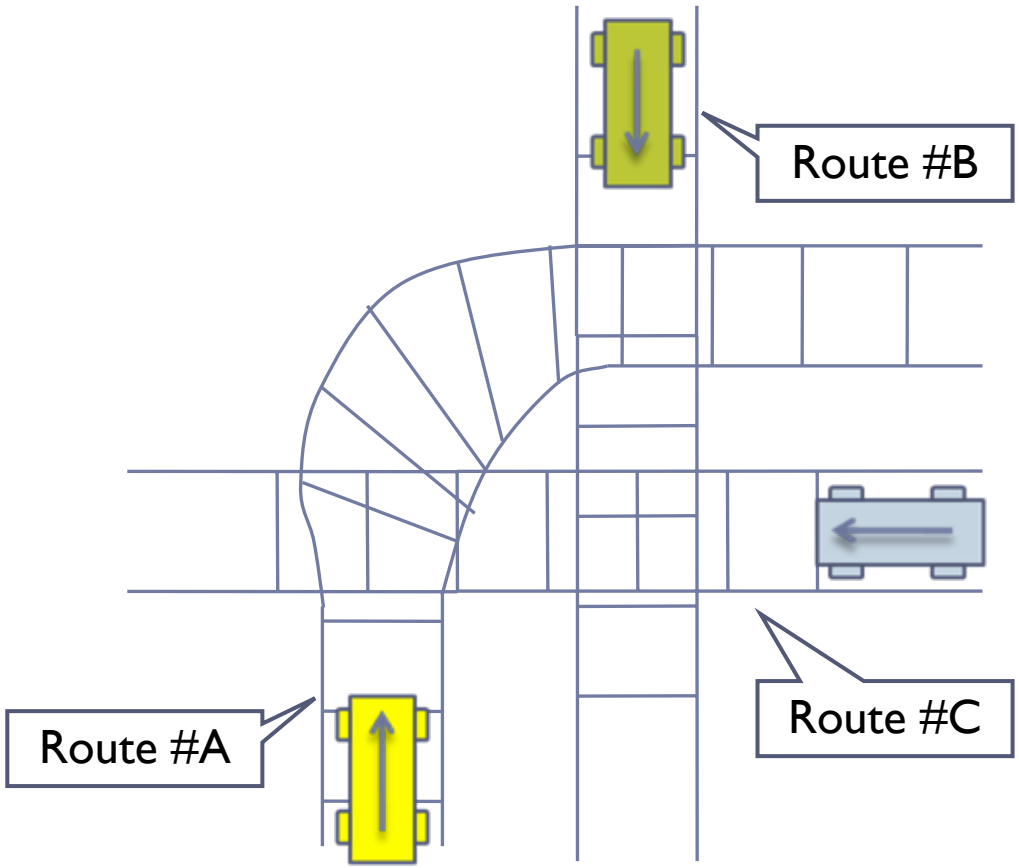


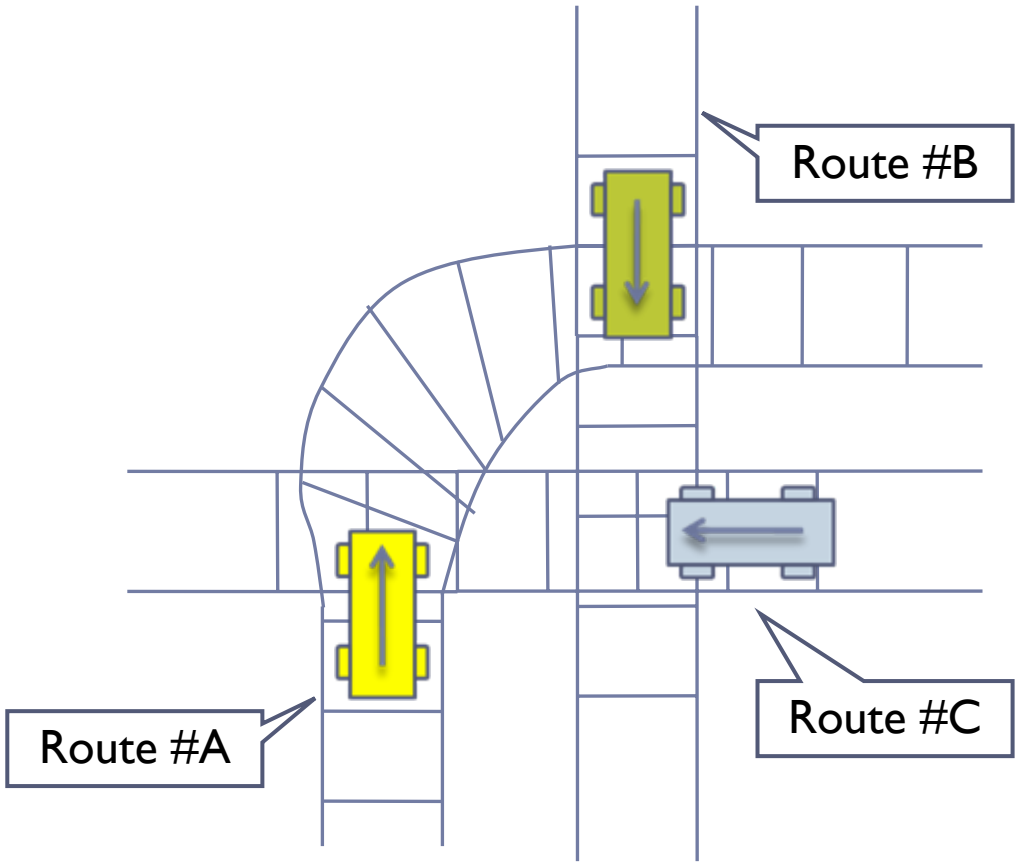
Travel Scheduling

- Deadlock



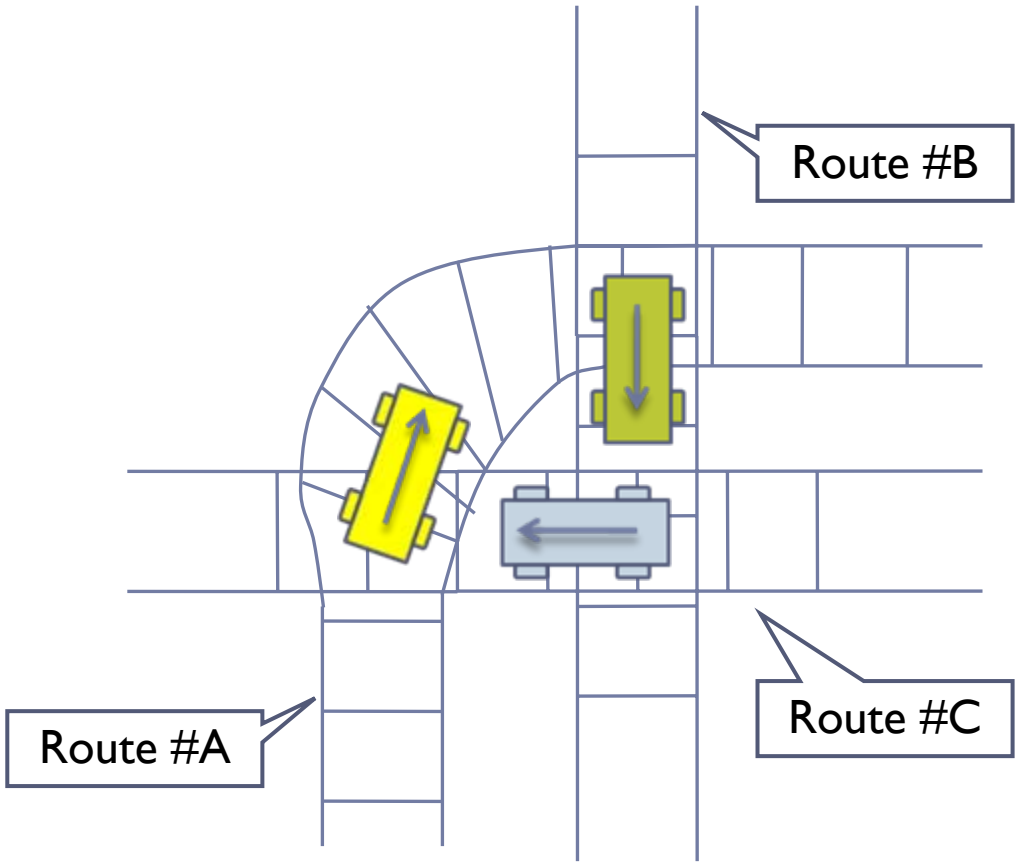
Travel Scheduling

- Deadlock



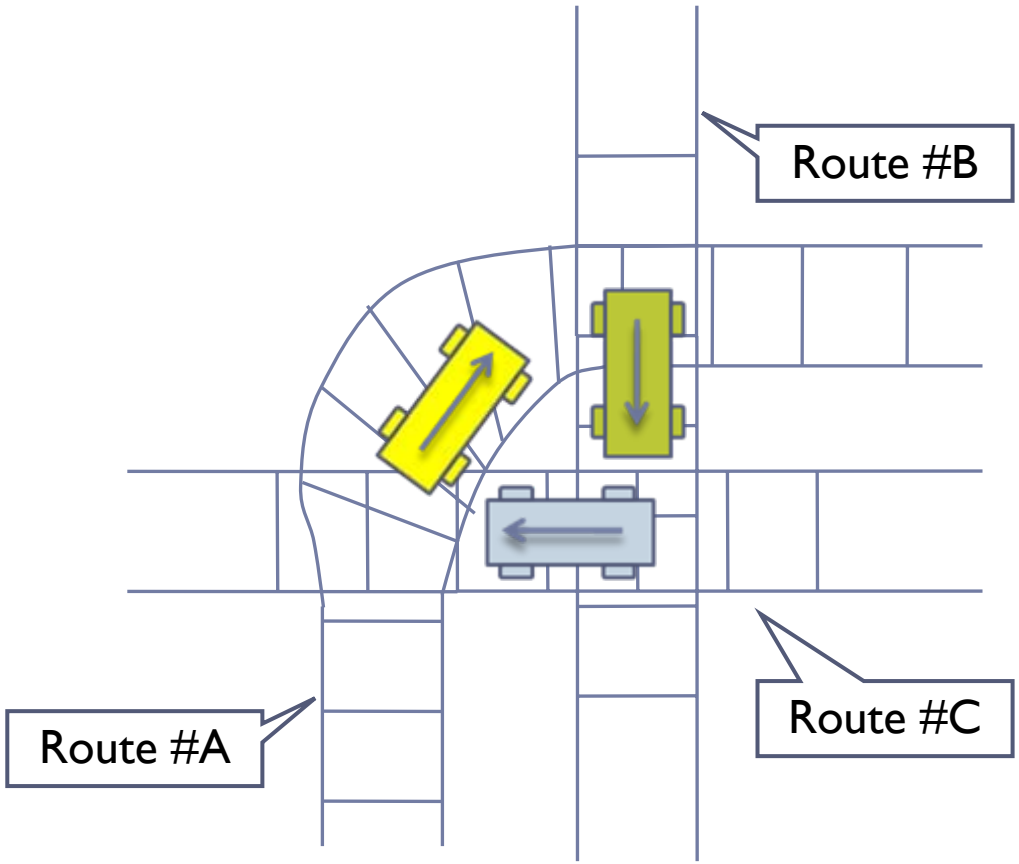
Travel Scheduling

- Deadlock



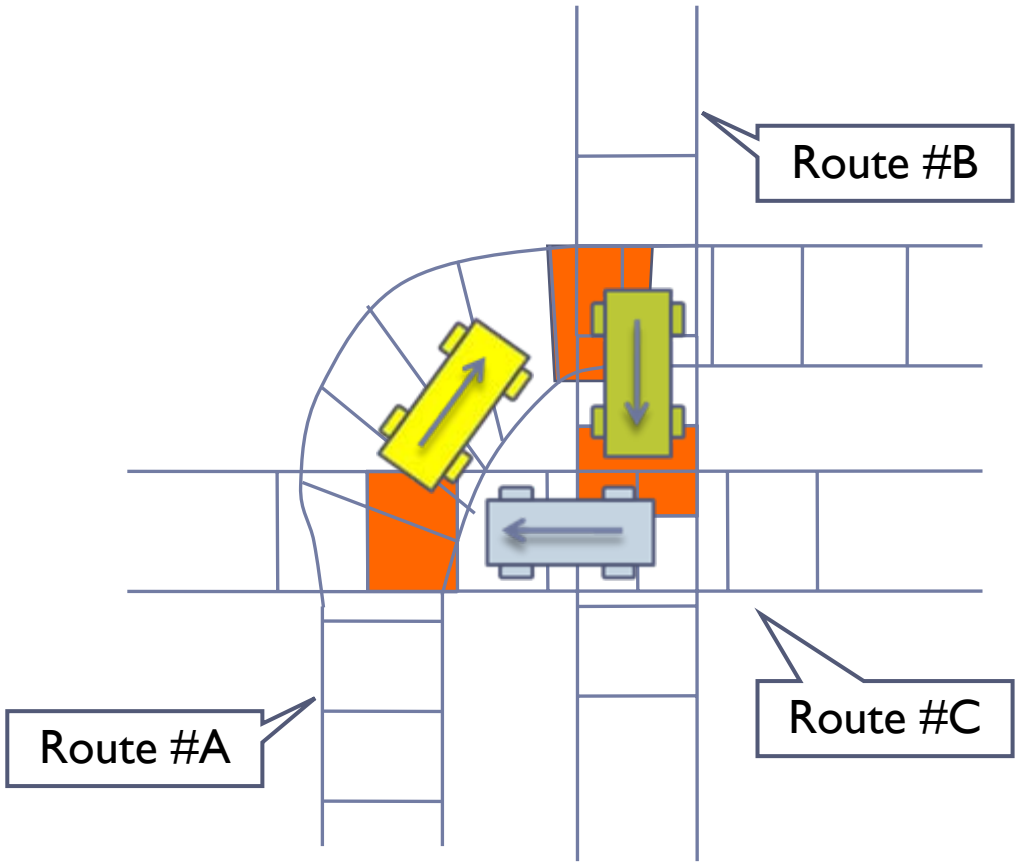
Travel Scheduling

- Deadlock



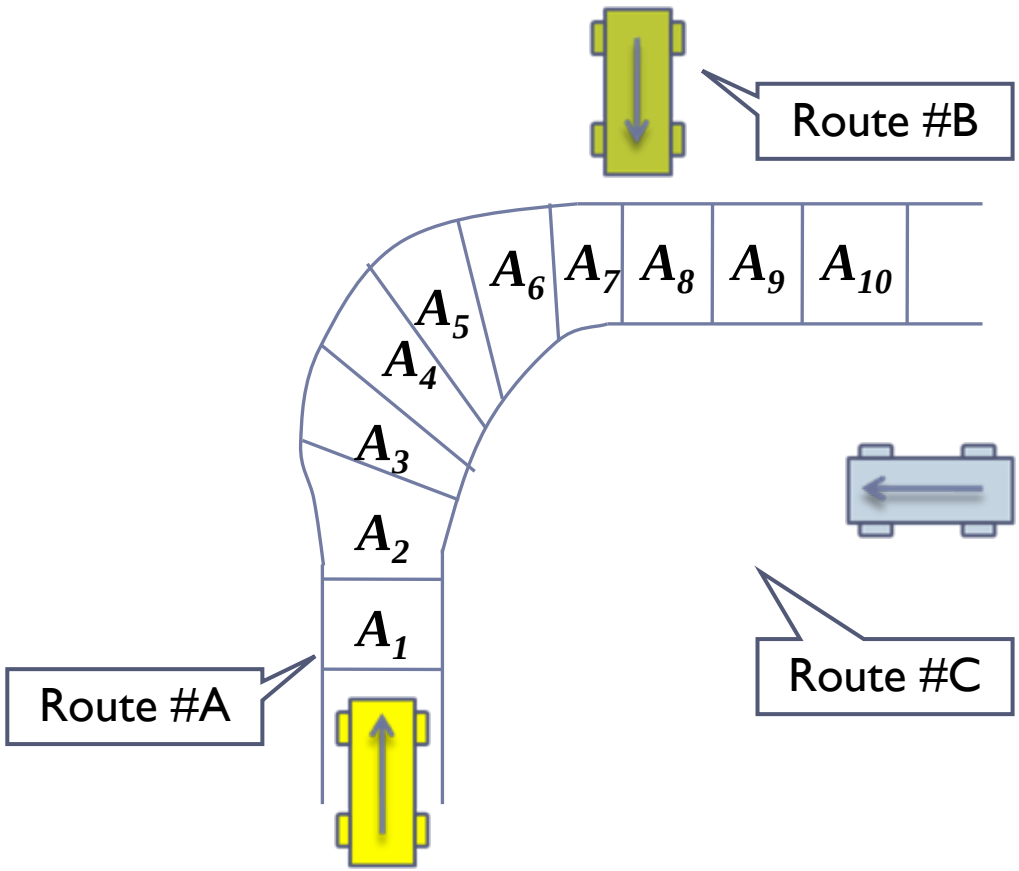
Travel Scheduling

- Deadlock



Travel Scheduling

- Deadlock prevention



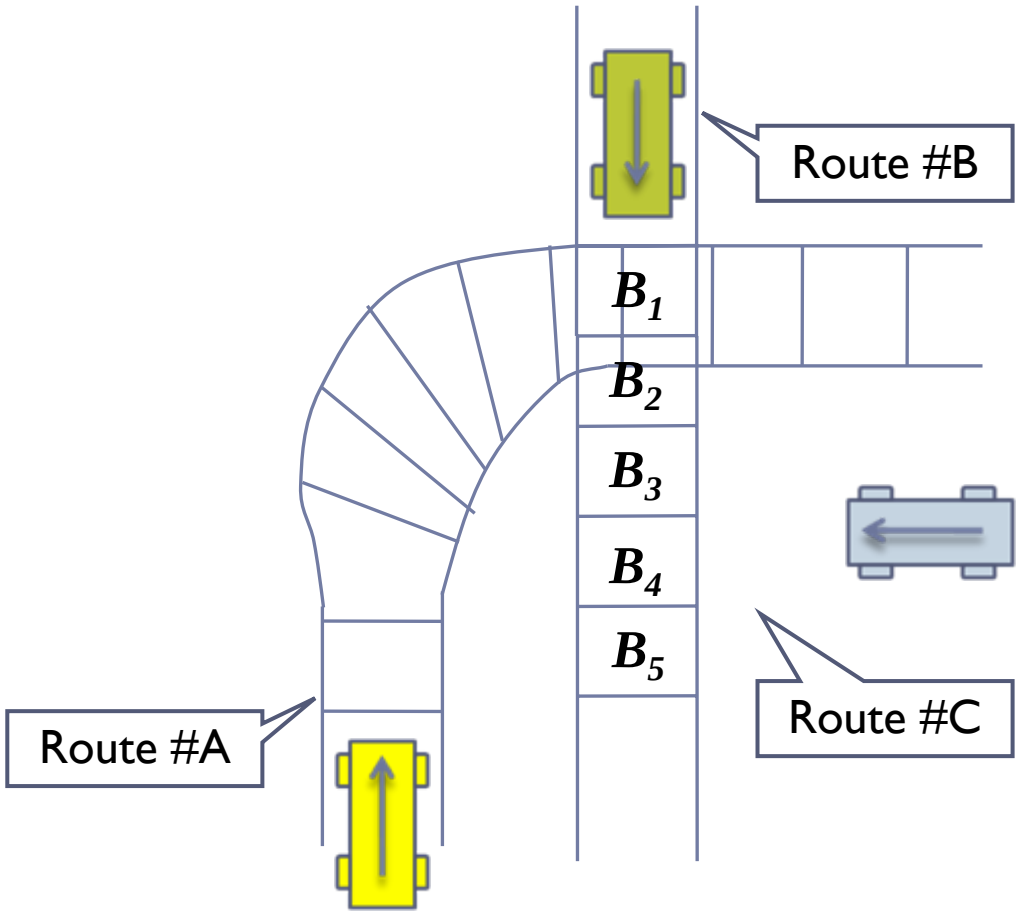
OA	Entering time	Leaving time
A_2	2	6
A_7	12	16

OA	Entering time	Leaving time
B_3		
B_4		

OA	Entering time	Leaving time
C_2		
C_5		

Travel Scheduling

- Deadlock Prevention



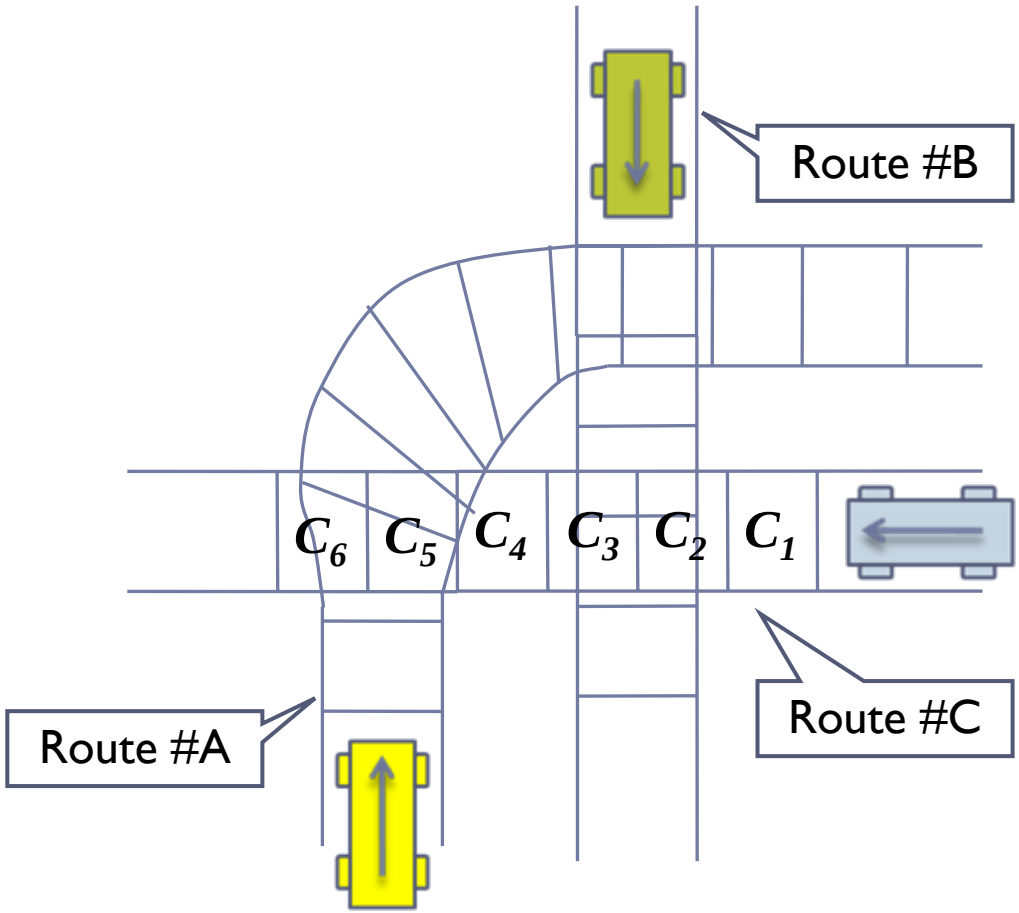
OA	Entering time	Leaving time
A_2	2	6
A_7	12	16

OA	Entering time	Leaving time
B_3	5	9
B_4	7	11

OA	Entering time	Leaving time
C_2		
C_5		

Travel Scheduling

- Deadlock prevention



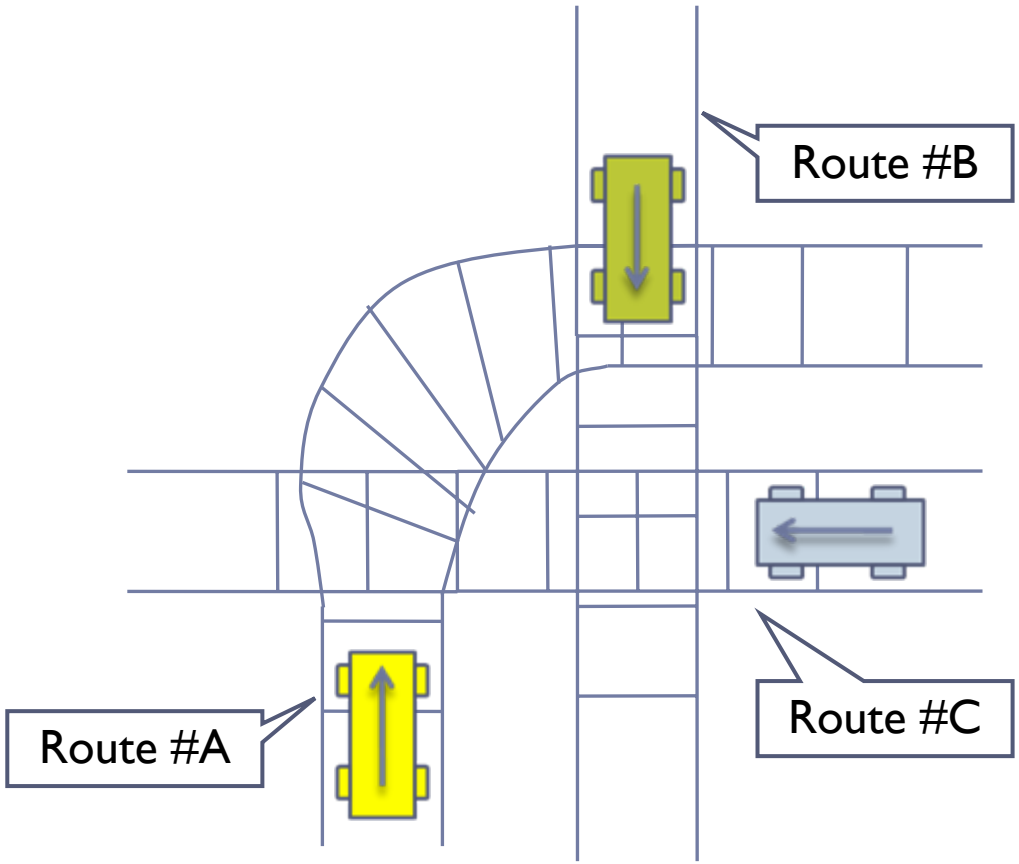
OA	Entering time	Leaving time
A_2	2	6
A_7	12	16

OA	Entering time	Leaving time
B_3	5	9
B_4	7	11

OA	Entering time	Leaving time
C_1	2	19
C_2	17	21

Travel Scheduling

- Deadlock prevention



OA	Entering time	Leaving time
A_1	0	4
A_2	2	6

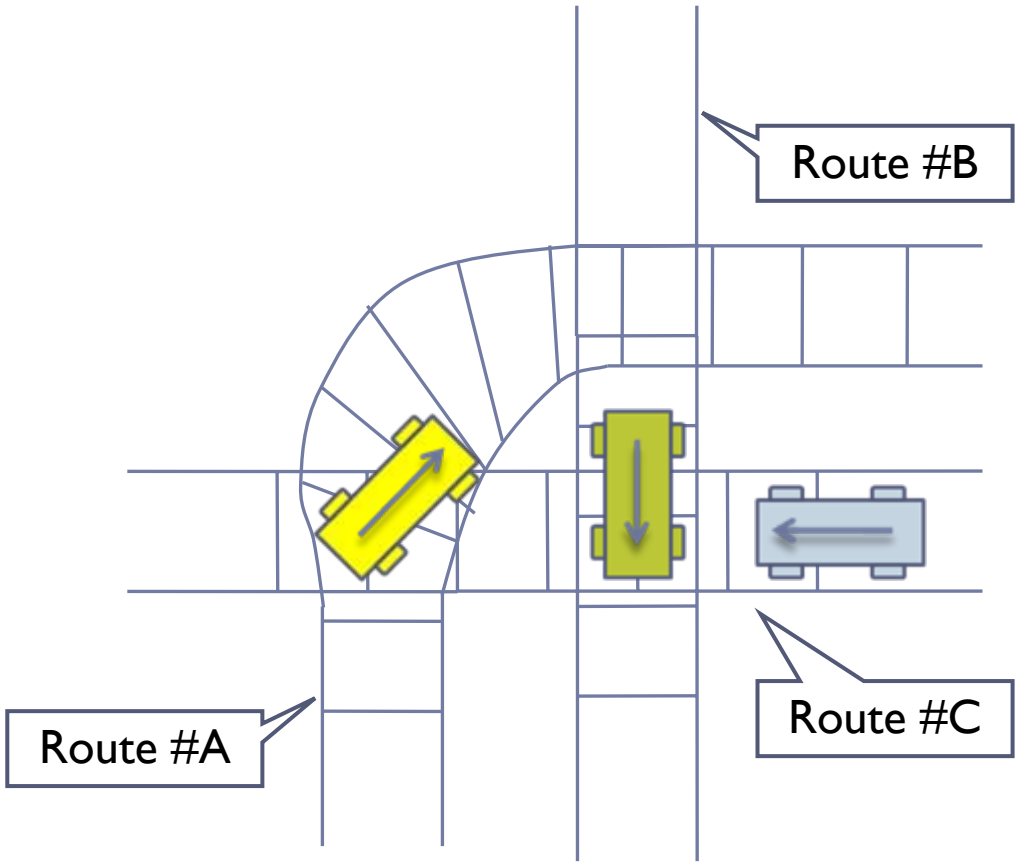
OA	Entering time	Leaving time
B_1	1	5
B_2	3	7

OA	Entering time	Leaving time
C_1	2	13
C_2	11	15

WAITING

Travel Scheduling

- Deadlock prevention



OA	Entering time	Leaving time
A_3	4	8
A_4	6	10

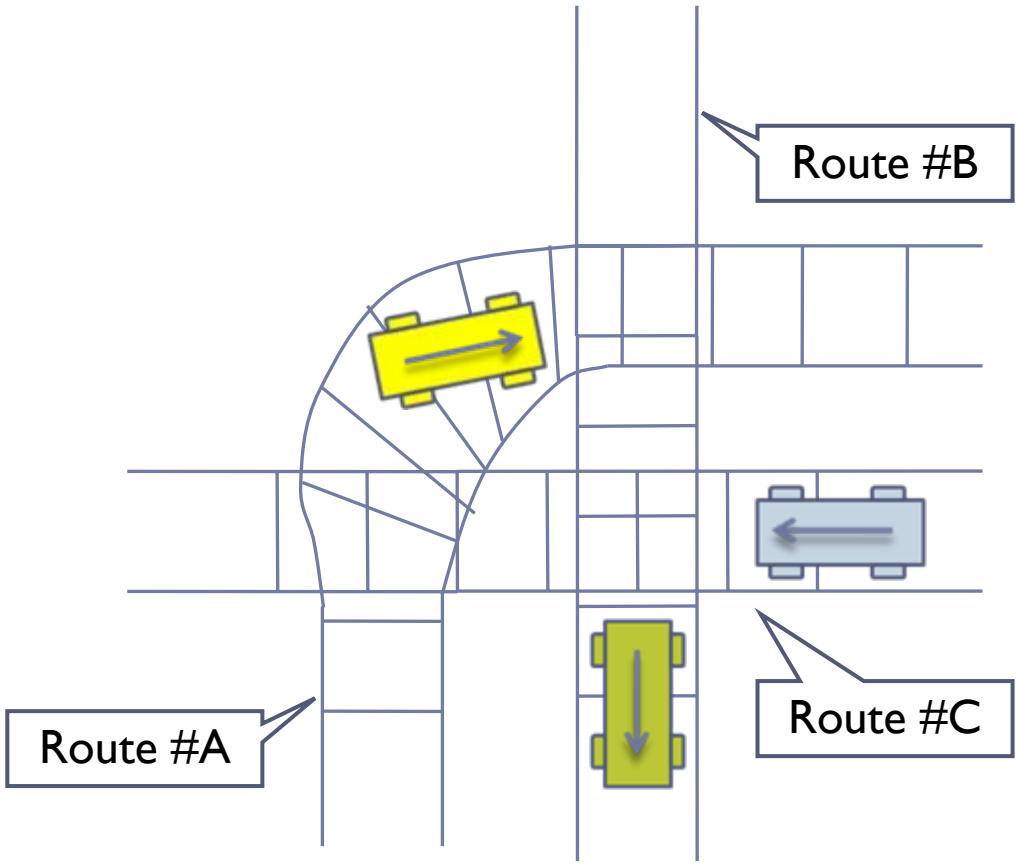
OA	Entering time	Leaving time
B_3	5	9
B_4	7	11

OA	Entering time	Leaving time
C_1	2	13
C_2	11	15

WAITING

Travel Scheduling

- Deadlock prevention



OA	Entering time	Leaving time
A_5	8	12
A_6	10	14

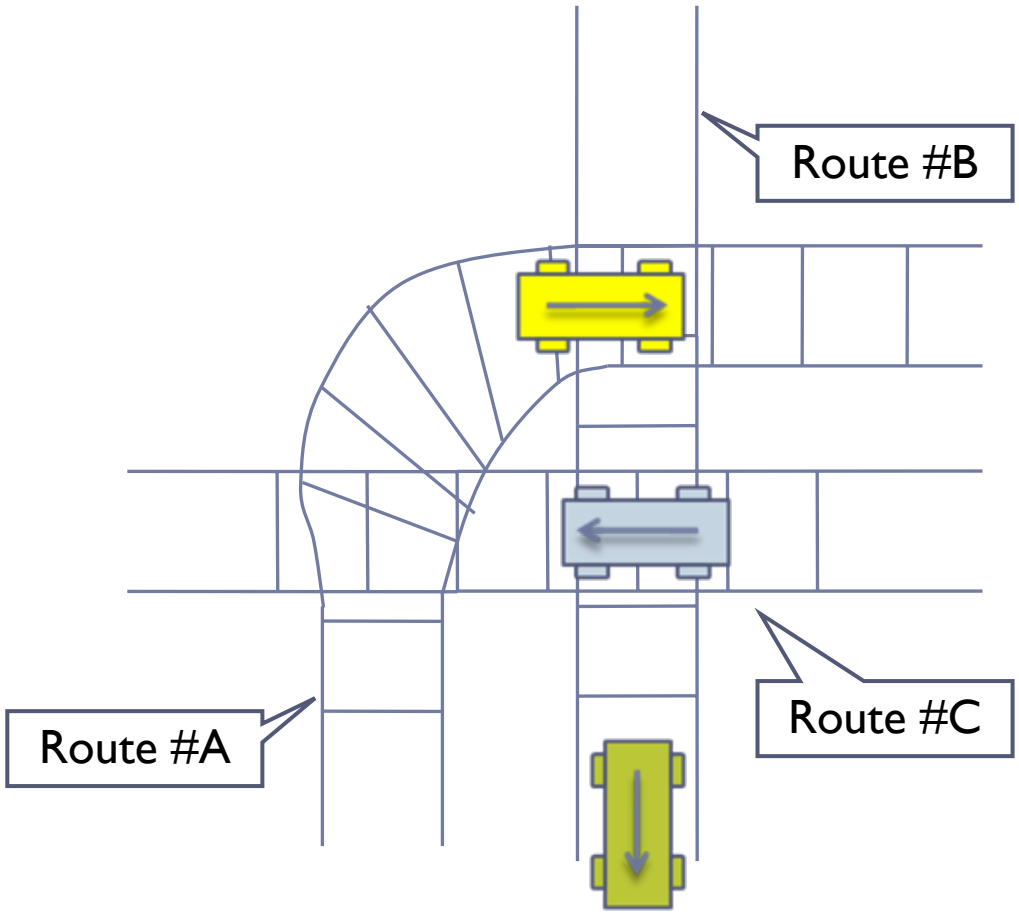
OA	Entering time	Leaving time
B_5	9	13
B_6	11	15

OA	Entering time	Leaving time
C_1	2	13
C_2	11	15

WAITING

Travel Scheduling

- Deadlock prevention



OA	Entering time	Leaving time
A_7	12	16
A_8	14	20

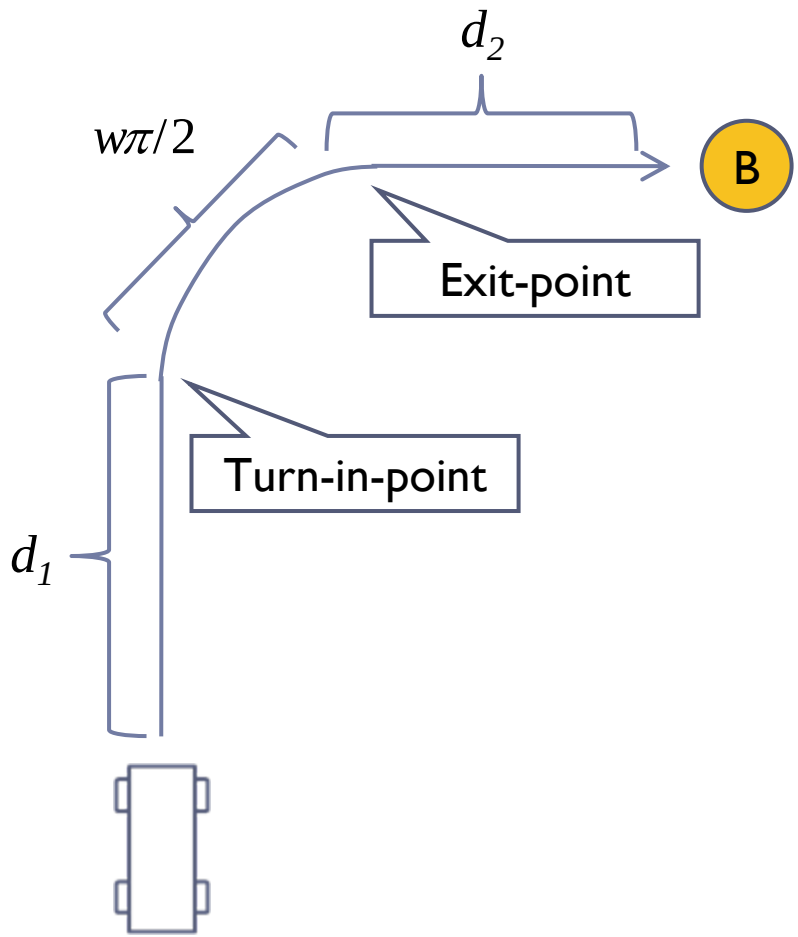
OA	Entering time	Leaving time
B_7	13	17
B_8	15	21

OA	Entering time	Leaving time
C_3	13	17
C_4	15	19

WAITING

Travel Time Estimation in Accelerated Motion

- Assume that an AGV travels with uniform acceleration
  - Initial velocity: v_0
  - Final velocity: v
  - Acceleration: a
  - Driving distance: d
  - Distance required to accelerate from v_0 to v: d_a
  - Wheelbase of an AGV: w
  - Turning distance: $w\pi/2$



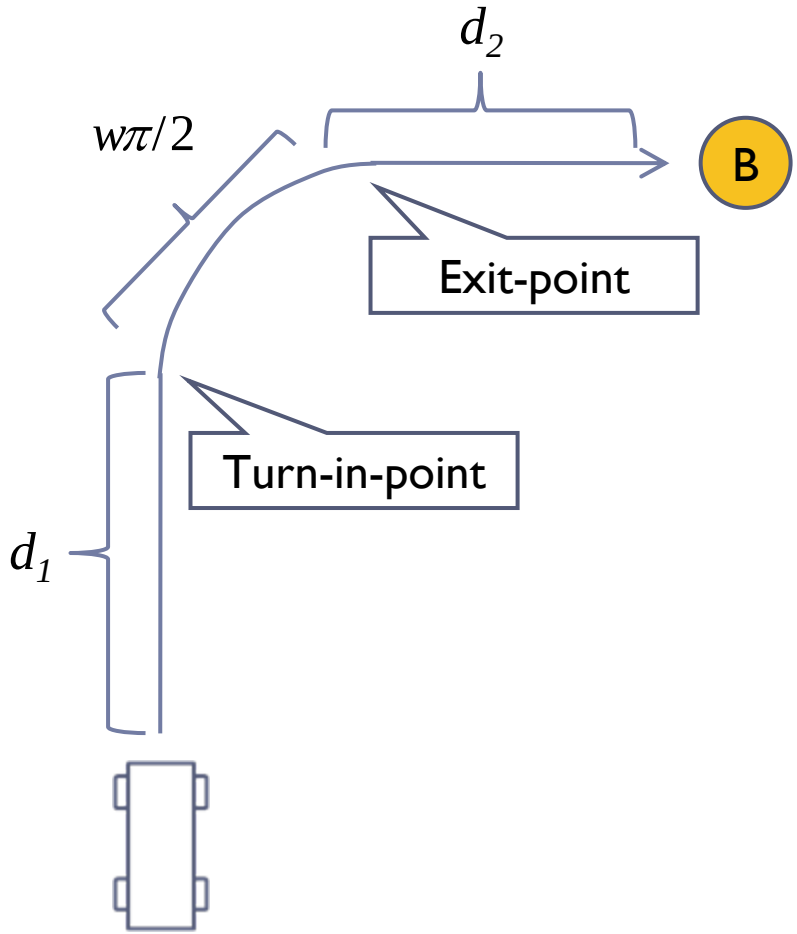
Travel Time Estimation in Accelerated Motion

- Travel time calculation:
  - Since $d_a = (v^2 - v_0^{\,2}) / 2a$
  - If $d \geq d_a$

$$t = \frac{v - v_0}{a} + \frac{d}{v} - \frac{v}{2a} + \frac{v_0^{\,2}}{2av}$$

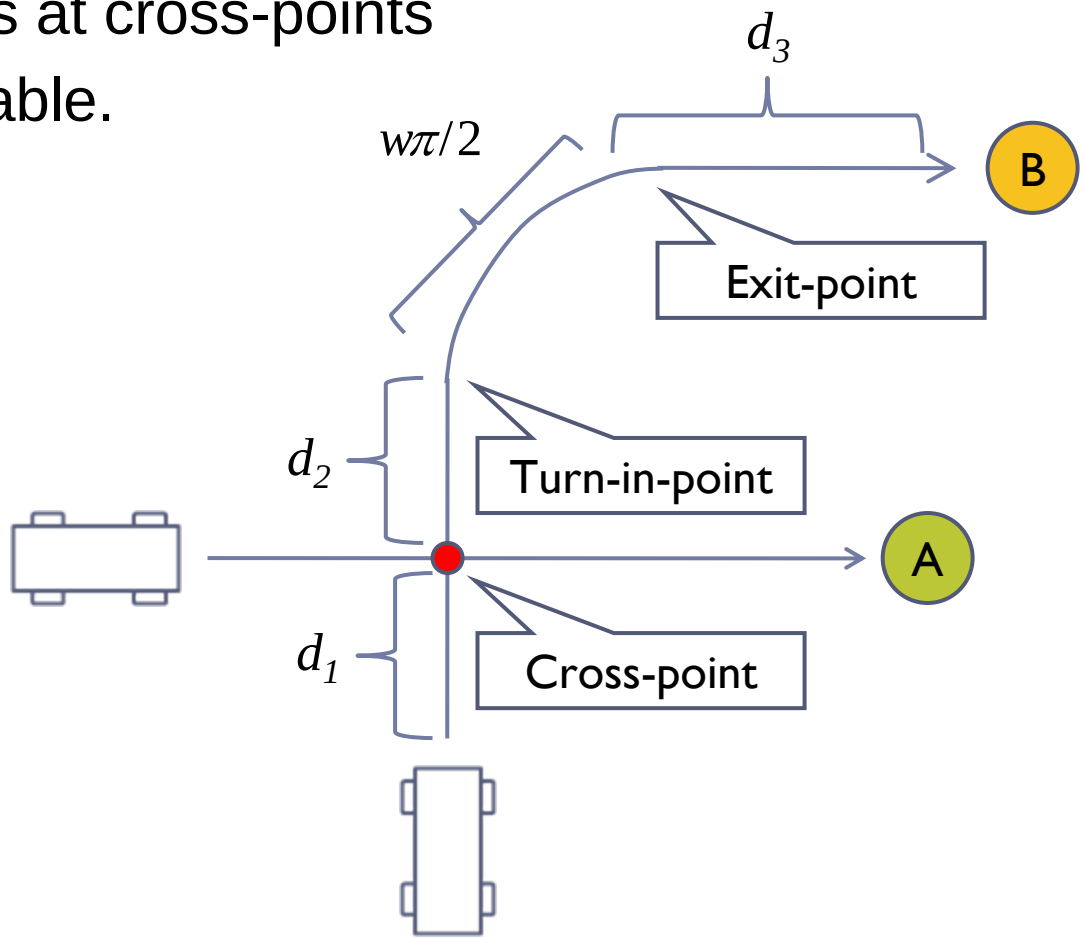
  - else

$$t = -\frac{v_0}{a} + \sqrt{\frac{v_0^{\,2}}{a^2} + \frac{2d}{a}}$$



Travel Time Estimation Considering Interference

- Travel time calculation:
  - Check the collisions at cross-points
  - Look up the OAR table.



Experimental setting

- The target container terminal:
  - One berth
  - Three QCs
  - Seven Blocks (with 7 ATCs)

- Maximum productivity:
  - QCs: 50 box/h
  - ATCs: 50 box/h

Experimental setting

- AGV specs:
  - Forward speed: 4 m/s
  - Cornering speed: 2 m/s
  - Acceleration: 0.64 m/s^2
  - Deceleration: 1.55 m/s^2

Experiments and Results

- The accuracy of travel time estimation

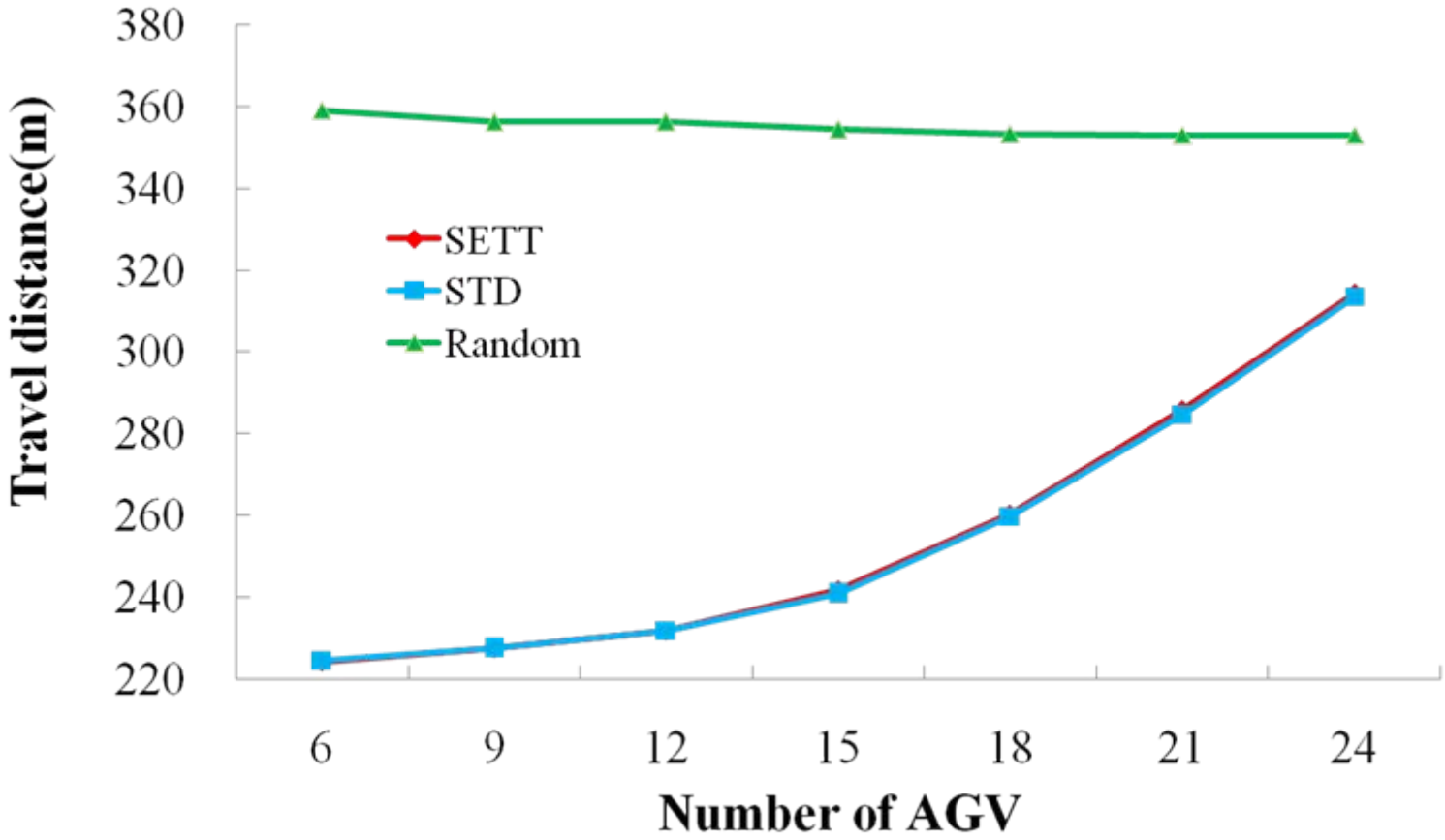
	Absolute error	Percent error	Mean squared error
All factors considered, except interference	99.0 s	13.4 %	152.4
All factors considered	84.6 s	11.5 %	126.7

Experiments and Results

- Applying travel time estimation to AGV routing
  - Three routing algorithms
    - Random path selection (Random)
    - Shortest travel distance (STD)
    - Shortest estimated travel time (SETT)
  - The number of AGV: from 6 to 24 by 3
  - Discharging process for 24 hours
    - Repeated 5 times, and the results averaged.

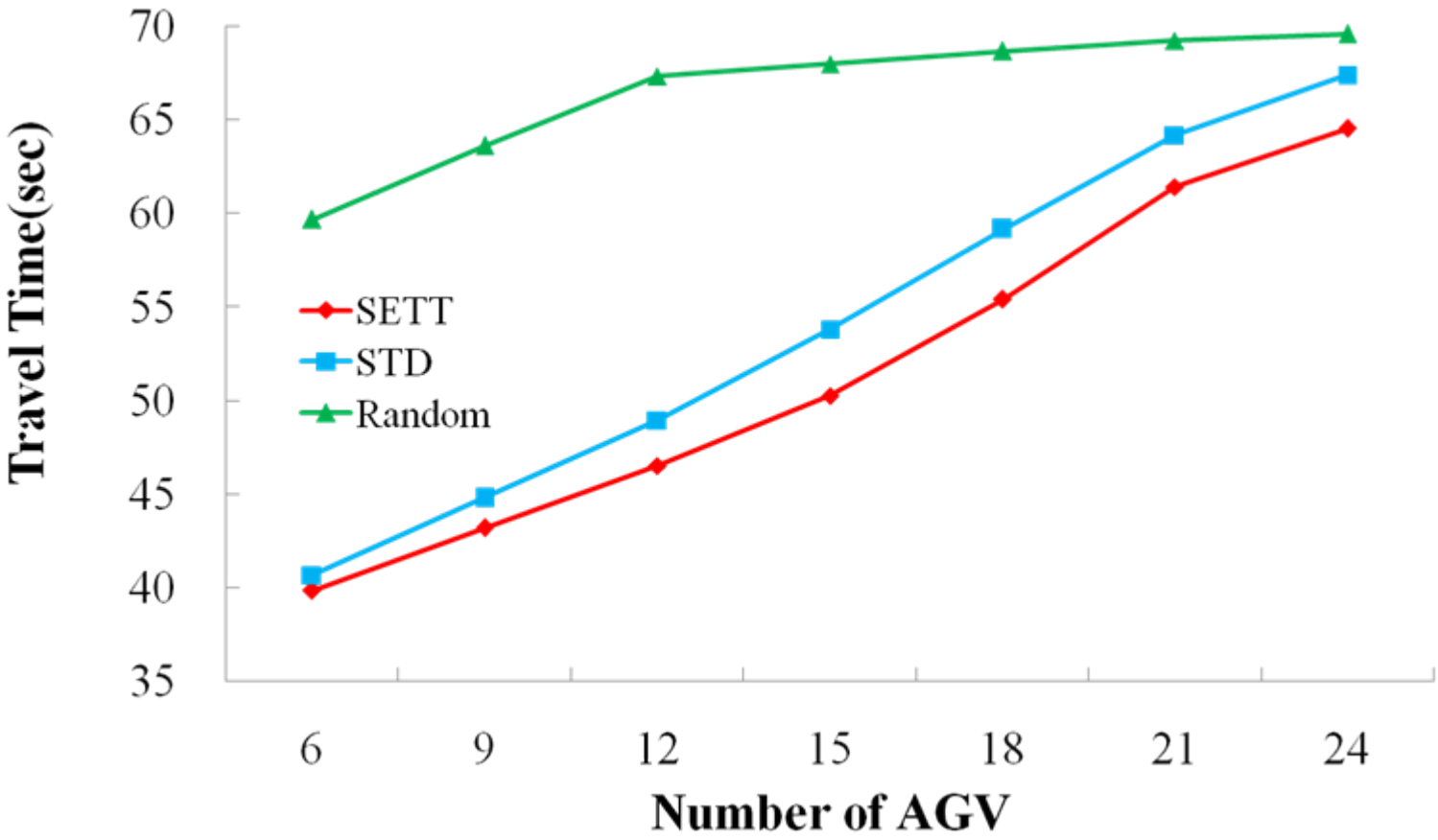
Experiments and Results

- Average travel distances of AGVs



Experiments and Results

- Average travel times of AGVs



Conclusions

- In this work, we proposed
  - An AGV routing process to prevent deadlocks
  - Methods for travel time estimation considering acceleration, deceleration, and interferences

- Future research
  - Consider the uncertainty
  - Apply the proposed method to estimate the entire duration of container transportation tasks for evaluating the job schedule of AGVs

Questions