

Integrated Electric Bus and Crew Scheduling with Realistic Charging Behavior

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Content

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 - Traditional
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- Research gap
- Contribution

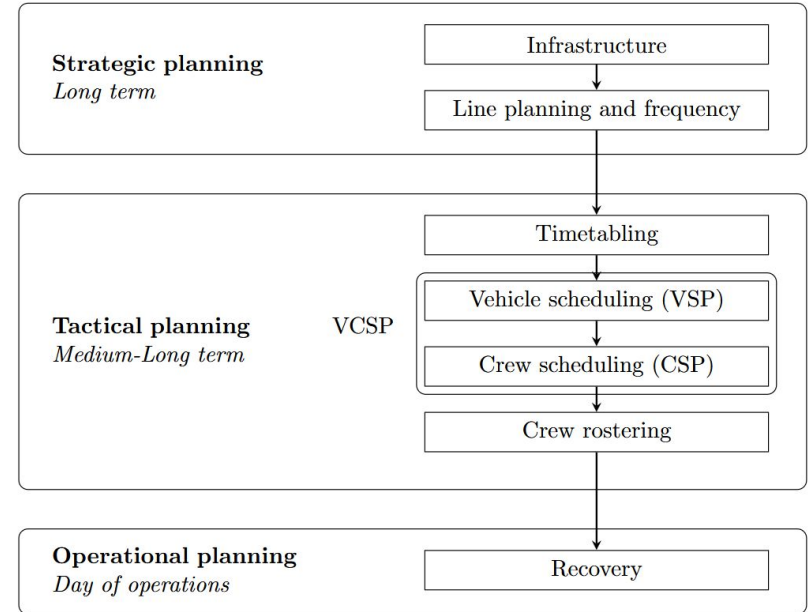
Context - General info

- Energy transition
 - 2025: no new combustion based vehicles
 - 2030: zero-emission public transport
- Fleets are becoming largely electric with batteries
- Results in new challenges throughout operations



Context - Operations overview

- Strategic
 - Where are charging stations placed?
- Tactical
 - How do we efficiently use electric buses?
- Operational
 - What happens if a bus runs out of battery?
- Our focus: Vehicle and Crew Scheduling



Bus scheduling - Recap of traditional planning

- Given: Set of trips to be driven, a depot, deadhead times between different trip starts/ends
- Goal: Cover all trips with minimum cost vehicle costs
- Solution: Min-cost flow in graph with trips

Bus scheduling - Traditional planning example

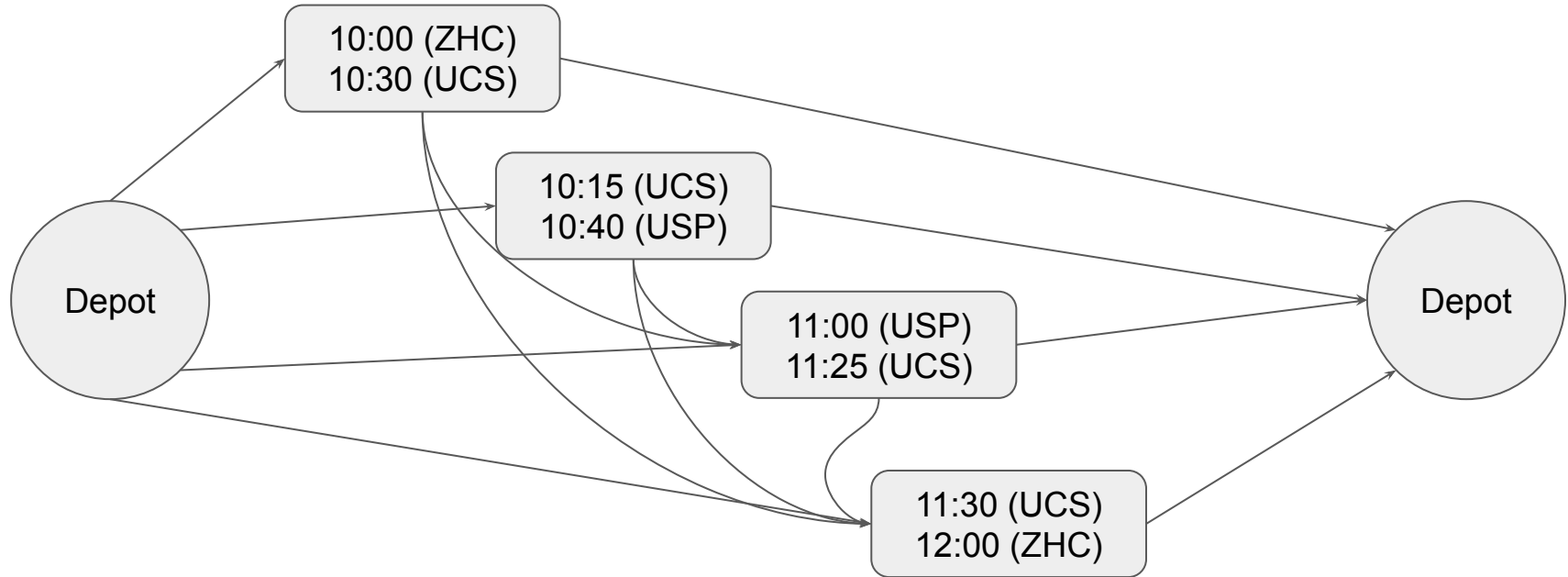
Trips

Time	From	To
10:00-10:30	Zeist HC	Utrecht CS
10:15-10:40	Utrecht CS	USP
11:00-11:25	USP	Utrecht CS
11:30-12:00	Utrecht CS	Zeist HC

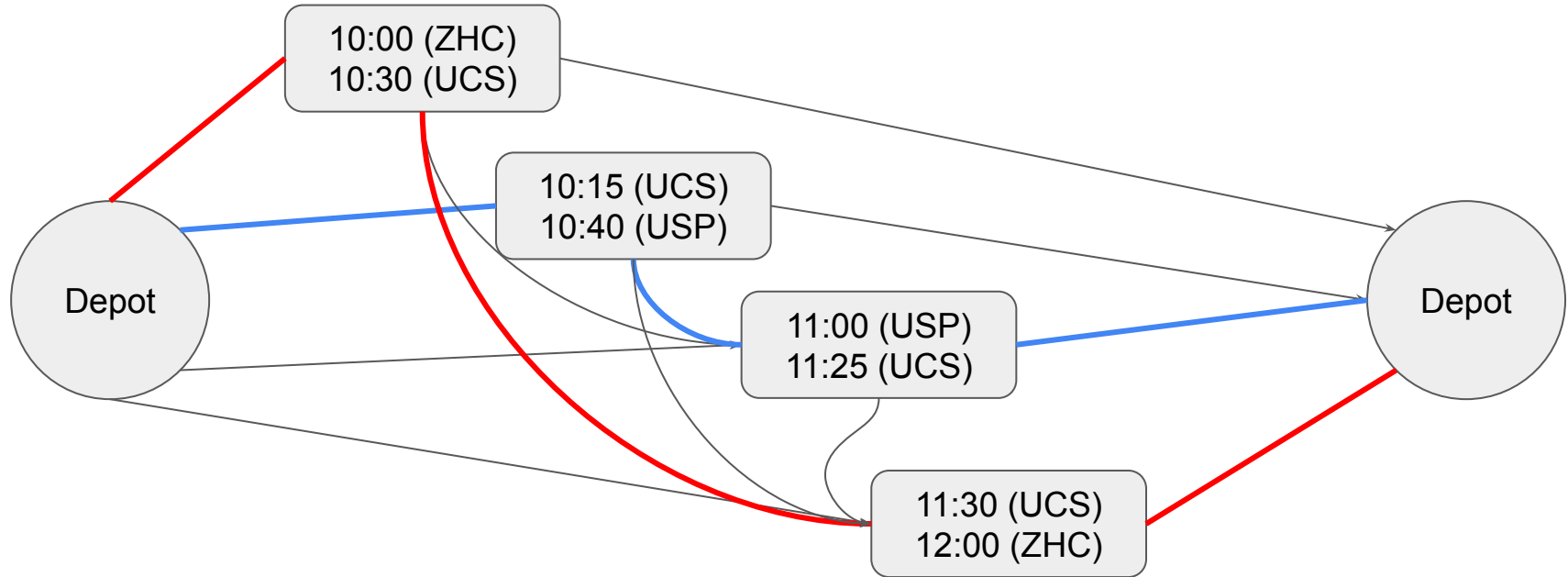
Deadheads

From	To	Time
Zeist HC	Utrecht CS	25min
Zeist HC	USP	20min
USP	Utrecht CS	20min
X	X	5min

Bus scheduling - Traditional planning example



Bus scheduling - Traditional planning example



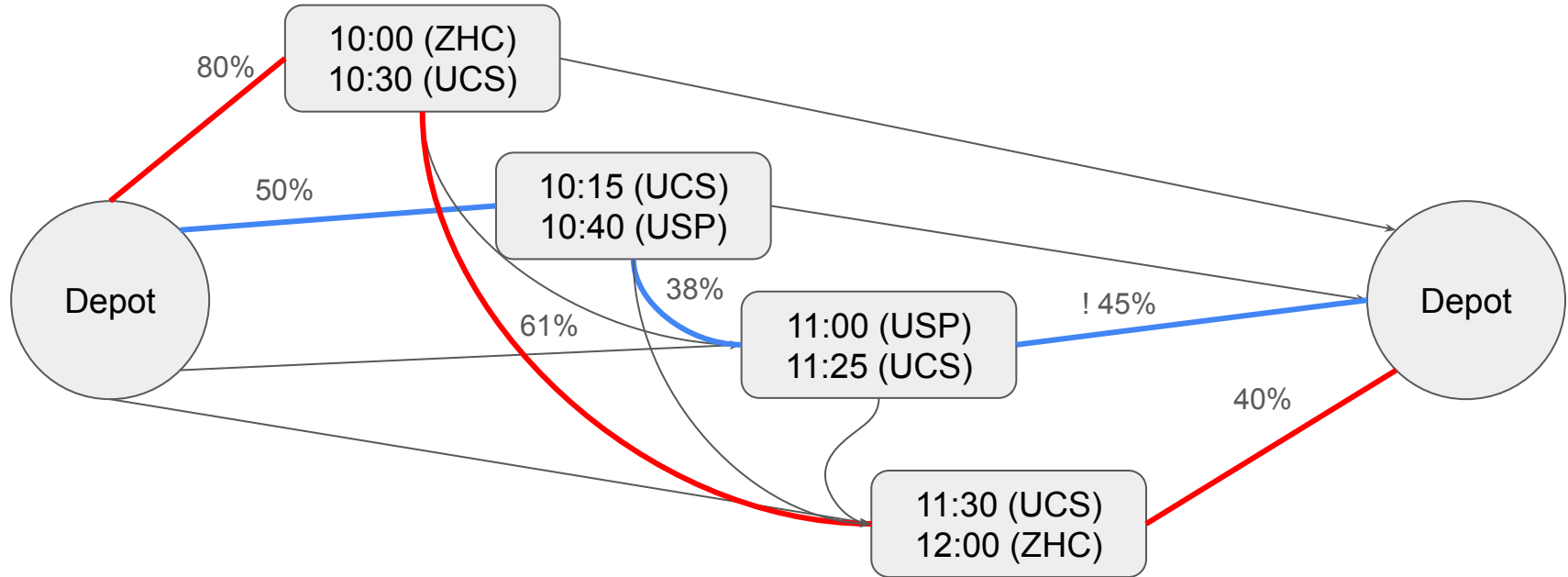
Bus scheduling - Changes with EVs

- Range is lower
 - Can't drive for an entire day
 - Must recharge throughout operating period
- Charging takes a long time
 - Order of hours instead of minutes for traditional refueling
- Battery use is complicated
 - Charge costs can be time/location-dependent
 - Charge gained is non-linear

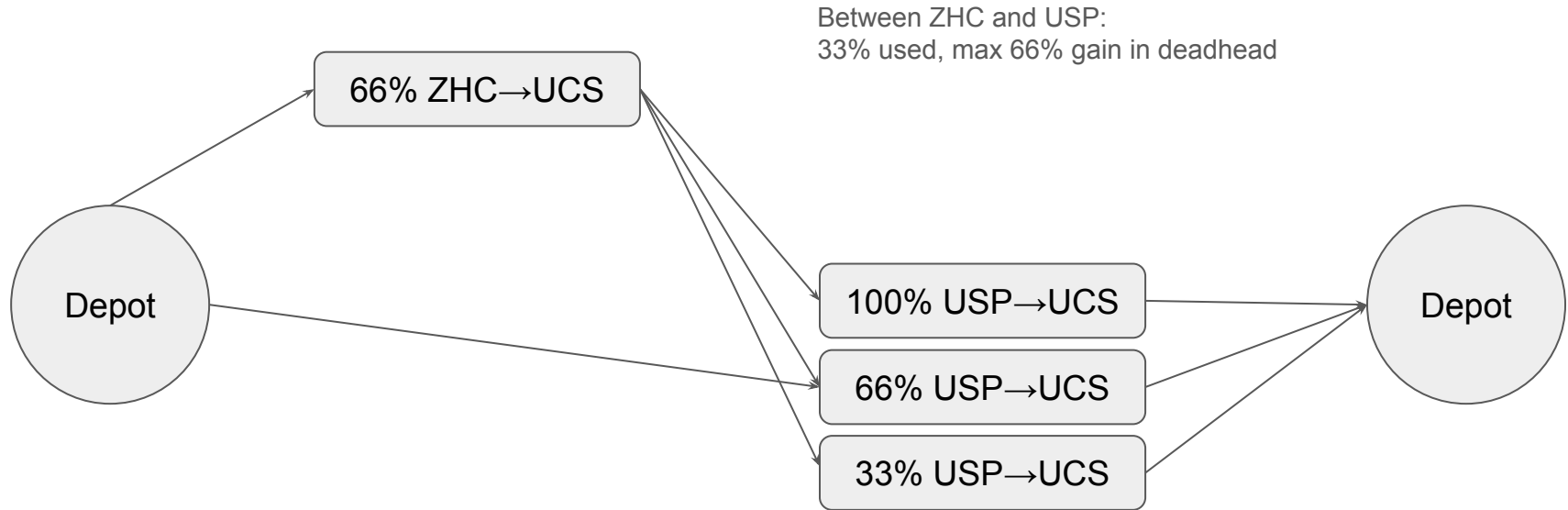
Bus scheduling - Adding EV constraints

- Adding vehicle range constraints is generally done in one of two ways
 - Adding continuous variables to schedule parts representing SoC
 - Add discrete nodes to represent SoC

Bus scheduling - Continuous electric planning



Bus scheduling - Discrete electric planning



Crew scheduling - Overview

- Regardless of vehicle type: vehicle planning results in a collection of vehicle tasks
- Each task can be broken up into blocks
 - Begin and end must be at relief points for crew members
- Crew scheduling now finds duties that cover these blocks

Crew scheduling - Continued

- Often modeled as a set covering/partition problem
- Additional constraints for maximum working time, breaks, walking to different locations, etc, etc.

Integration

- Optimizing vehicle schedules first might not be ideal
- When using electric buses: additional downtime due to charging can be combined break times
- Integrated often has reduced costs (max ~5%)
- Problem: Used deadheads and blocks aren't known

Research gap

- 5 works consider integrated electric planning
- None include non-linear charging
- None use the discrete model

Contribution

- Create integrated model for single depot single vehicle type instance which incorporates
 - Non-linear charging
 - Time of use pricing
 - Discrete model
- Exact solution method is wip, however
 - Using lagrangian relaxation on vehicle/crew link might be possible (Huisman RET)
 - Column generation over tasks has been done before (possibly using LS)
- Currently working on E-VSP implementation & further details

Contribution - Additional

- Extra constraints:
 - Battery degradation
 - Charging station capacity
 - Crew shift types



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