Increasing reliability
of the multi-depot vehicle scheduling problem

Léa Ricard*[1], Guy Desaulniers[2], Andrea Lodi[2], Louis-Martin Rousseau[2]

[1] Université de Montréal, Department of Computer Science

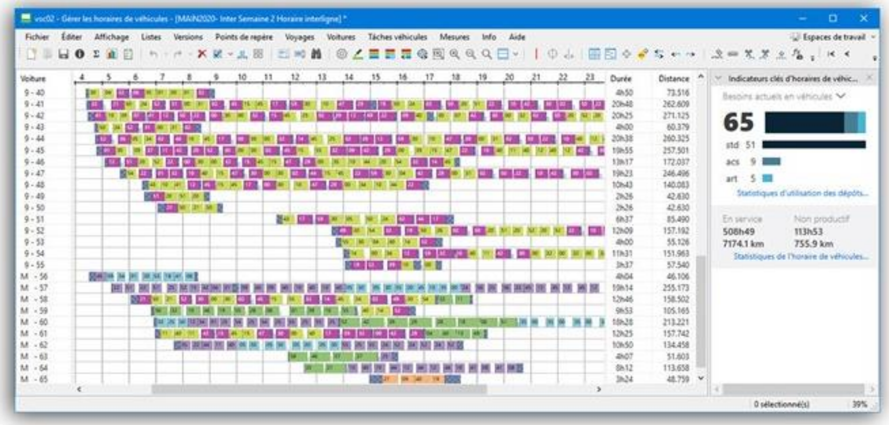
[2] Polytechnique Montréal, Department of Mathematics and Industrial Engineering

*Corresponding author: lea.ricard@umontreal.ca

TransitData, August 2020

Collaboration

GIRO HASTUS



From giro.ca

- World leader in the development and commercialization of optimization-based software for the planning of public transport and postal agencies
- Hastus software

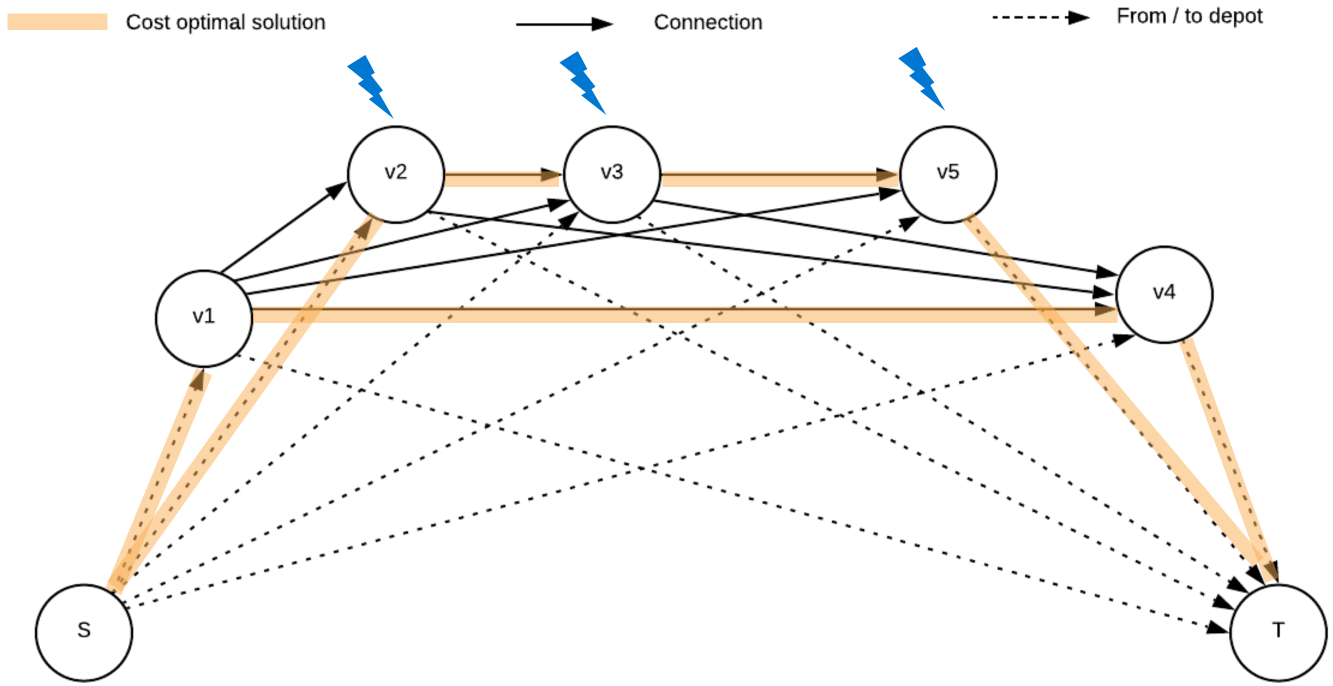
From stm.info

- Montréal trips and bus schedules planning
- AVL (Automatic Vehicle Location) data
- More than 41 000 trips
- 2 months

Operations planning in public transportation

Timetabling / frequency setting → Bus scheduling → Duty scheduling → Rostering → Driver assignment

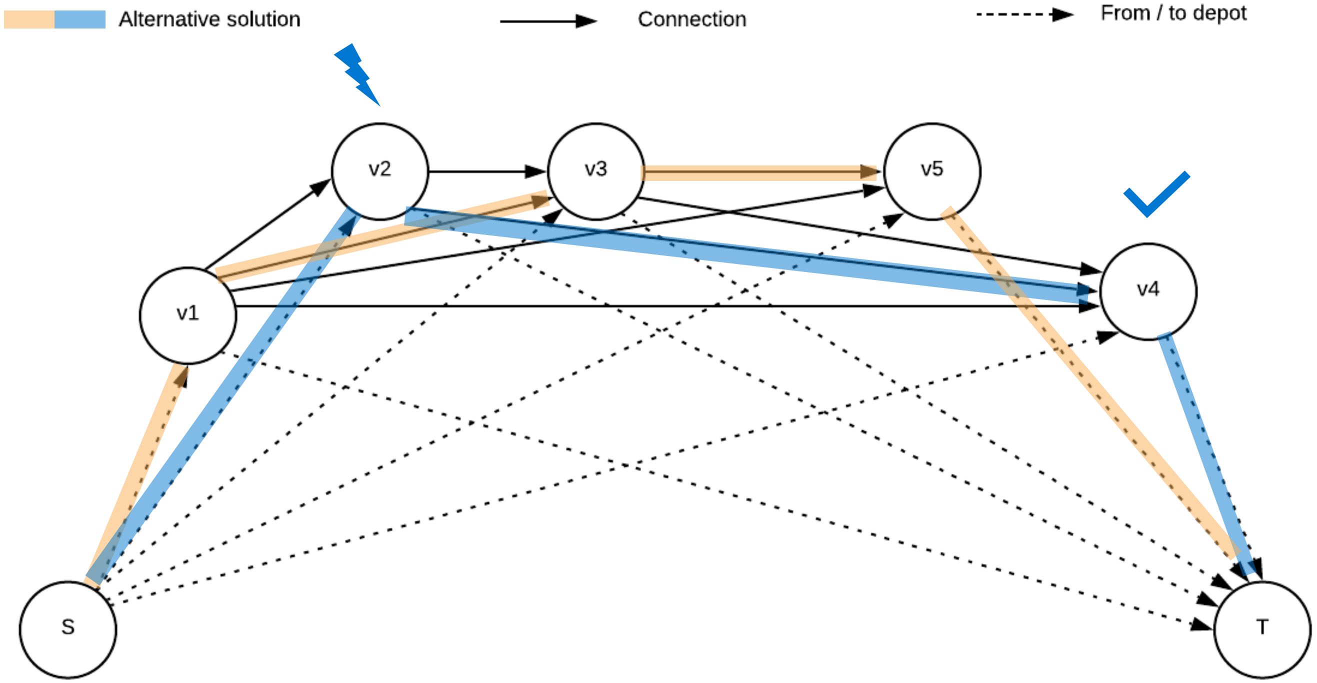
Motivation: disruption scenario



Primary delay
Secondary delay

Motivation: disruption scenario

What if we do not choose the cost optimal solution?



Primary delay

Why reliable bus schedules?

- Service unreliability affects the passenger perception of public transportation negatively
- Most passengers put more value on the reduction of travel time variability than over the reduction of travel time itself (Bates et al., 2001).
- ⬆ Reliability ⟶ ⬆ Ridership

Bates, J., Polak, J., Jones, P., & Cook, A. (2001). The valuation of reliability for personal travel. Transportation Research Part E: Logistics and Transportation Review, 37(2-3), 191-229.

Outline

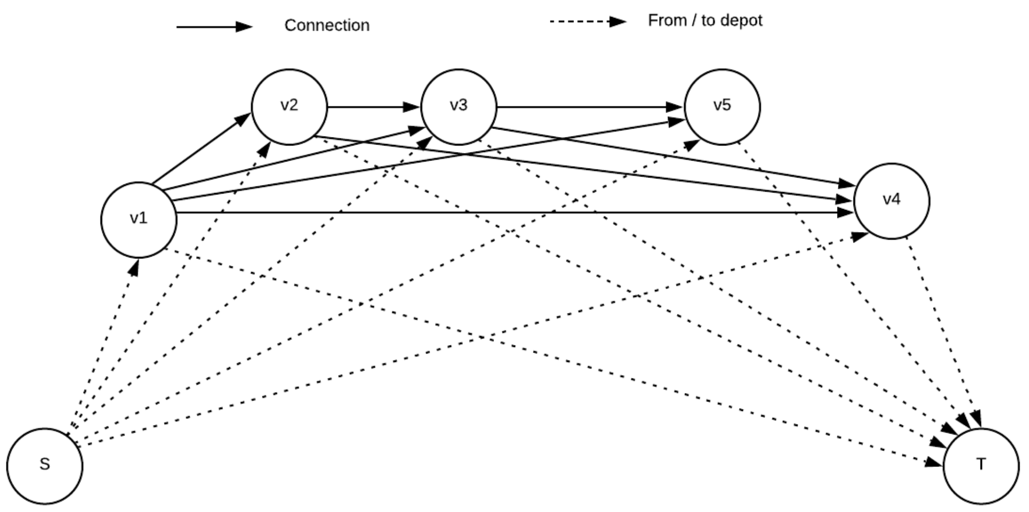
Reliable multi-depot vehicle scheduling problem (R-MDVSP)

Graph definition:

- Arc between two trips if the connection is possible
  - Buffer time between the trips $\geq$ transit time + minimum break for drivers

Problem definition

- Find a set of vehicle schedule
- All trips are covered by exactly one of the vehicle schedules
- Capacity (in terms of number of assigned vehicles) of each depot preserved
- Number of depots ≥ 2
- Each vehicle schedule starts and ends at the same depot



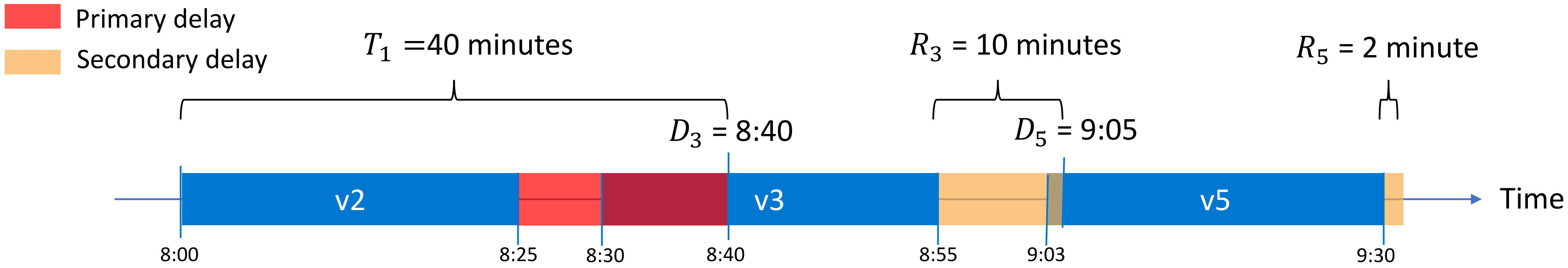
Stochastic travel times

- Secondary delay (R_i) and actual departure time (D_i) are recursively computed using the travel time (T_i) probability density function

Scheduled departure time

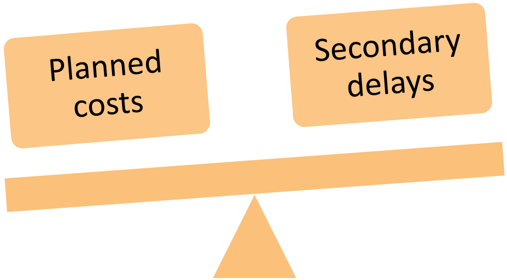
Minimum transit time

$$R_i = D_i - d_i$$
$$D_i = max\{D_{i-1} + T_{i-1} + l_{i-1,i}, d_i\}$$
$$D_1 = d_1$$



Objective function

- Bi-objective problem:
  - Planned costs
  - Expected secondary delay per passenger
- Use a weighting method in order to find good tradeoffs between the two objectives
- Cost of a vehicle schedule s:



Planned costs Penalty factor

$$c_s = \underbrace{p_s}_{\text{Planned costs}} + \underbrace{\beta}_{\text{Penalty factor}} E(R_s)$$

$$E(R_s) = \sum_{i=2}^{n_s-1} \alpha_i \times E(R_i)$$

Relative expected ridership of trip i

Algorithmic framework

Column generation embedded in a branch-and-bound algorithm (Ribeiro and Soumis, 1994)

➡ Allows to easily add constraints (e.g. related to electric buses)

- Solved heuristically
  - Branching heuristic: Diving method
  - Permutations
- Shortest path pricing problem
  - Solved by a labeling algorithm
    - Labels:
      I. Preceding label
      II. Accumulated reduced cost
      III. Cumulative distribution of the real departure time (D)

Ribeiro, C.C. , Soumis, F. (1994). A column generation approach to the multiple-depot vehicle scheduling problem. Oper. Res. 42 (1), 41–52 .

Reliability metrics

Passenger oriented reliability metric

1. Probability that a passenger boards a delayed trip

$$P(R > \delta^{max}) = \sum_{i=1}^{n} \alpha_i \times P(R_i > \delta^{max})$$

Delay tolerance

Relative expected ridership of trip i

2. Average secondary delay duration per passenger

$$E[R \,|R > \delta^{max}] = \sum_{i=1}^{n} \alpha_i \times E[R_i \,|R_i > \delta^{max}]$$

Delay tolerance

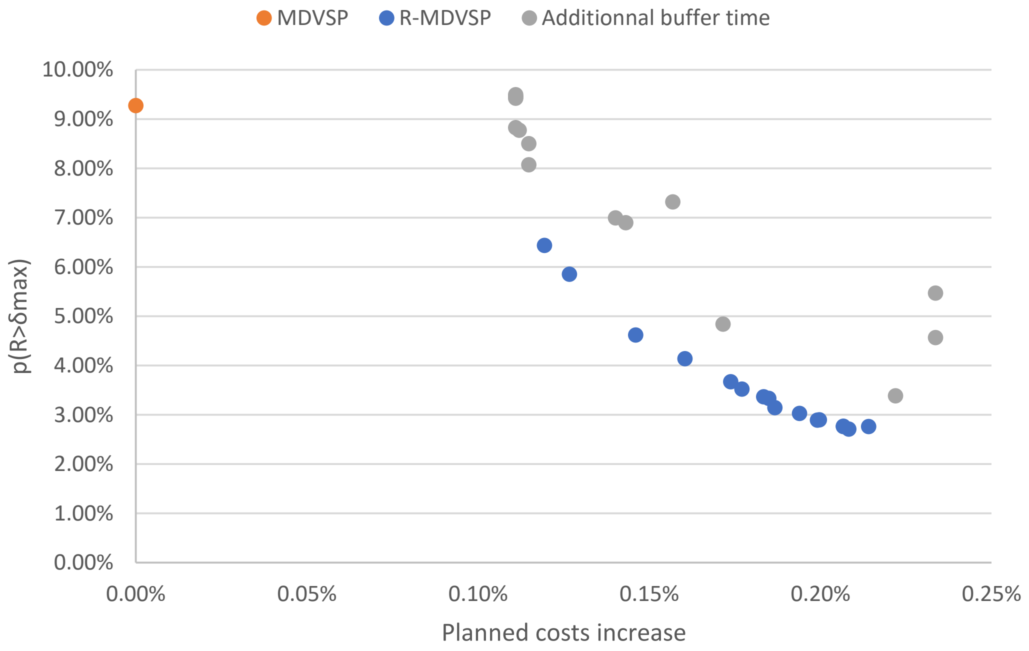
3. Average number of trips needed to get back on schedule after the first delayed trip

Experimental setup

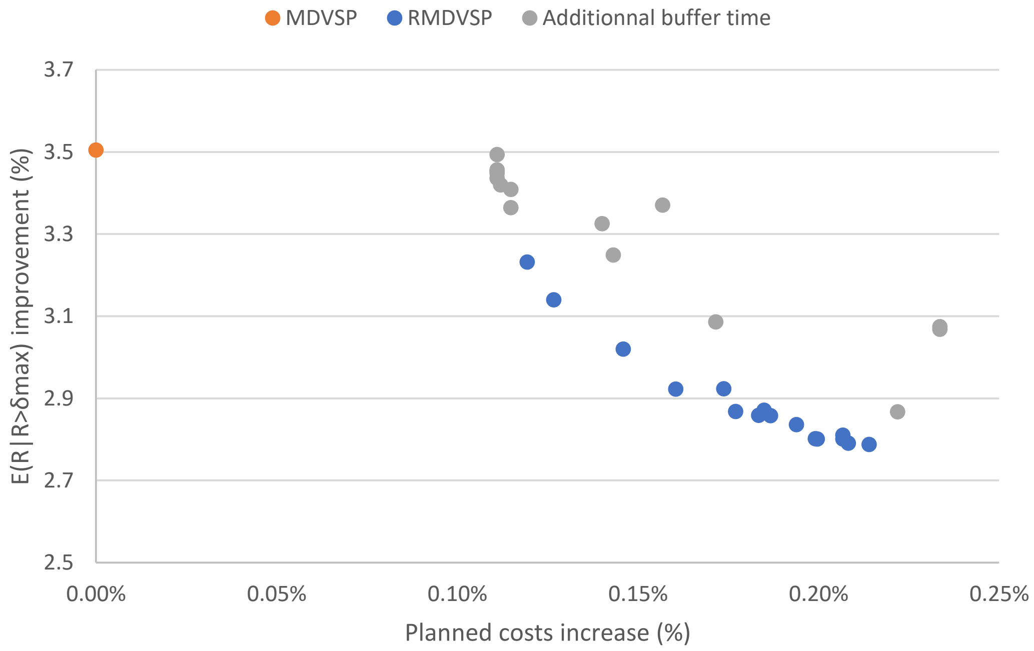
- The R-MDVSP results are compared to:
  1. MDVSP without any consideration to reliability
  2. MDVSP with mandatory waiting time after every trip (soft constraint)
     - I. Fixed fraction of the trip duration
     - II. Fixed minimum waiting time (1,2,…,10 minutes)
     - III. 50^{th}, 90^{th} and 95^{th} percentiles of the primary delay distribution
- $\delta^{max} = 2$ minutes
- Instance from Montréal's bus network
  - 1024 trips
  - 16 bus routes
  - 2 depots
  - From 06:00 AM to 22:00PM

Real-world instance results

- 1. Probability that a passenger boards a delayed trip

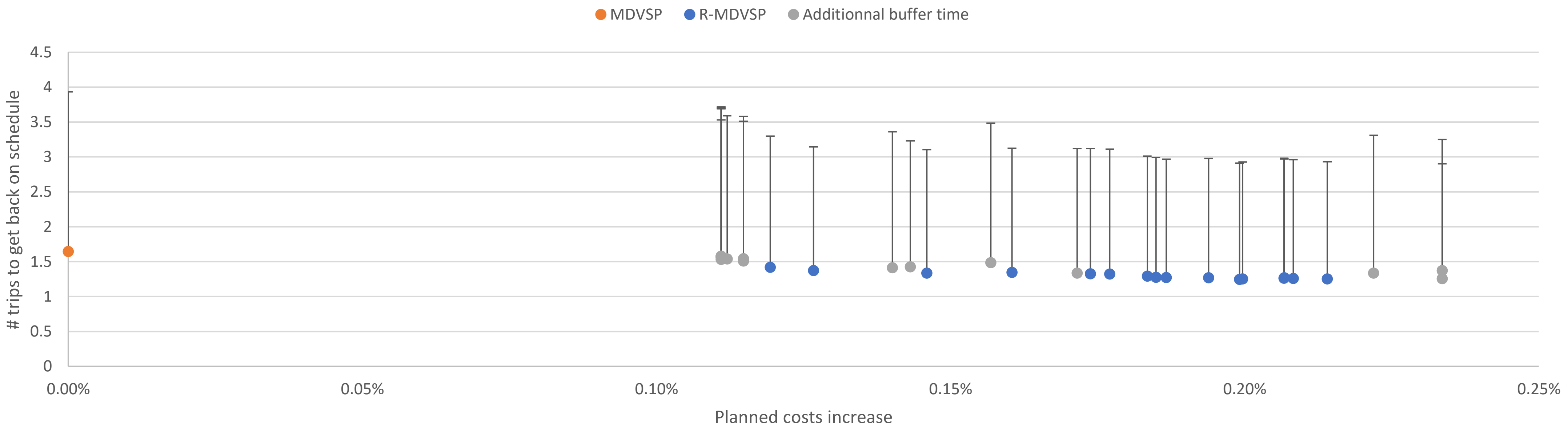


- 2. Average secondary delay duration per passenger



Real-world instance results

- 3. Average number of trips needed to get back on schedule after a first delayed trip



$$\text{solving } time \approx 1.5 \times MDVSP$$

Conclusion

- Proposed a new reliable approach to multi-depot vehicle scheduling problem (R-MDVSP)
  - Consider the stochasticity of travel times
- Defined three reliability metrics focused on passengers
- Presented preliminary results on an instance derived from Montréal's bus network
- Future work:
  - Compare the R-MDVSP on other instances (of larger size)

Thank you!

Contact: lea.ricard@umontreal.ca