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046 Emergent Train Scheduling under Restricted Electrical Energy with Considering Trade-off between Energy Consumption and Trip Time

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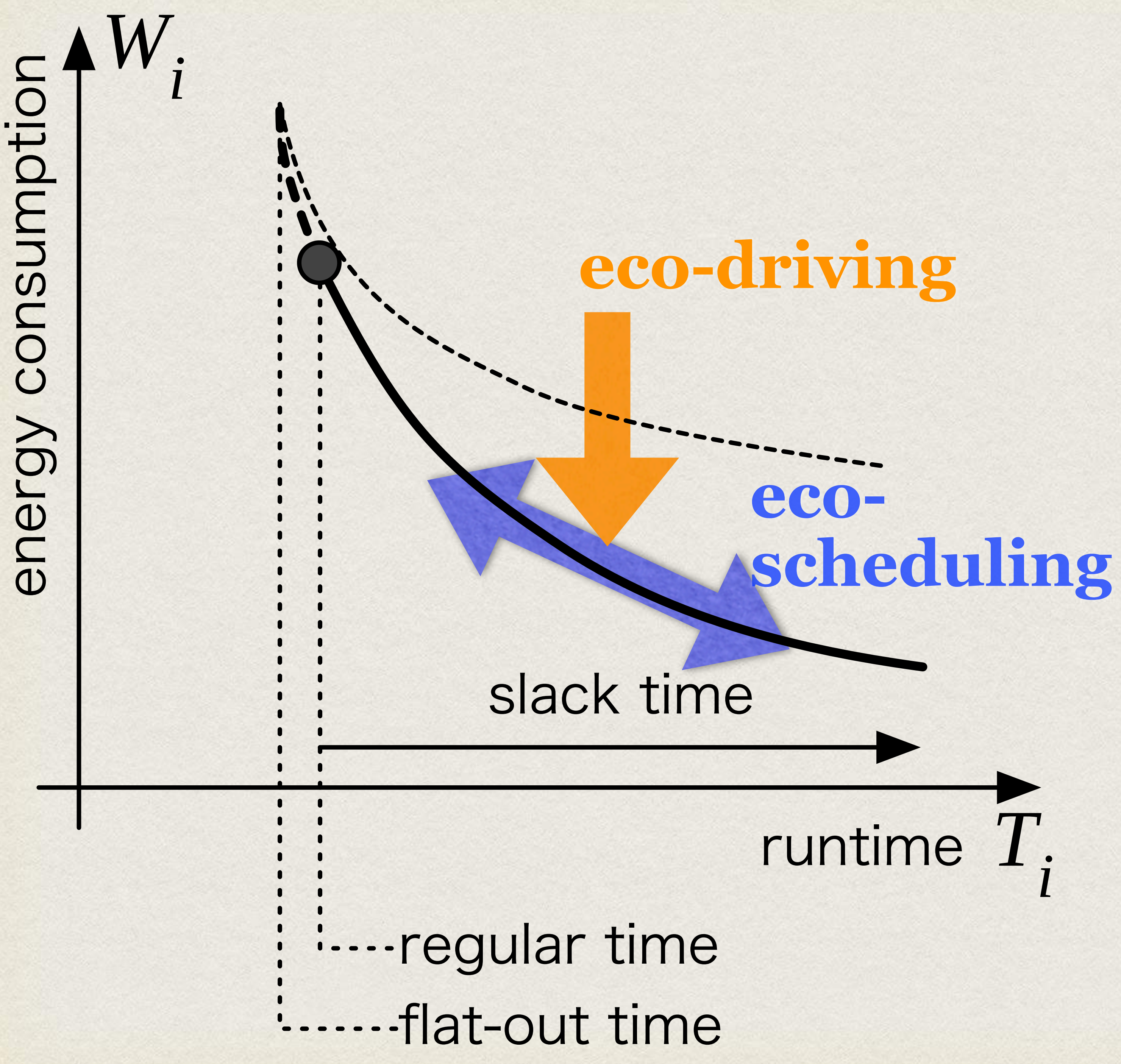
1. Introduction
2. Countermeasures against Power Shortage
3. Optimization of Train Timetables
4. Simulation, a Case Study
5. Conclusion

Background

- Uncertain power supply in Japan by
  - East Japan Earthquake Disaster
  - Accident of the Fukushima Nuclear Power Station
- Influence on train operation
  - 15% reduction of energy
  - reduced number of trains
  - lack of robustness
- **Need of countermeasures**
  - **studying them in advance**

Energy Savings in Train Operation



- Eco-driving
  - optimization of train speed profiles for each interstation
- Eco-scheduling
  - optimization of distribution of slack times for every interstations

Objectives

- comparing some countermeasures of train timetabling against such power shortage quantitatively
  - by macroscopic simulation
- evaluation of schedule by
  - **energy saving**
  - **passenger disutility**
  - (peak power shaving)
    - need of microscopic simulation

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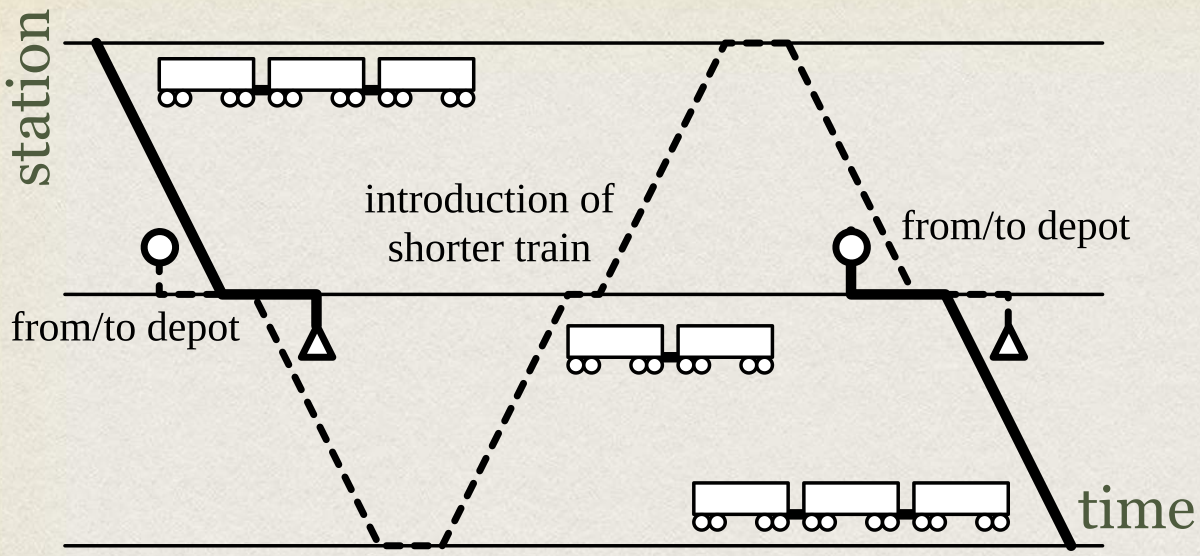
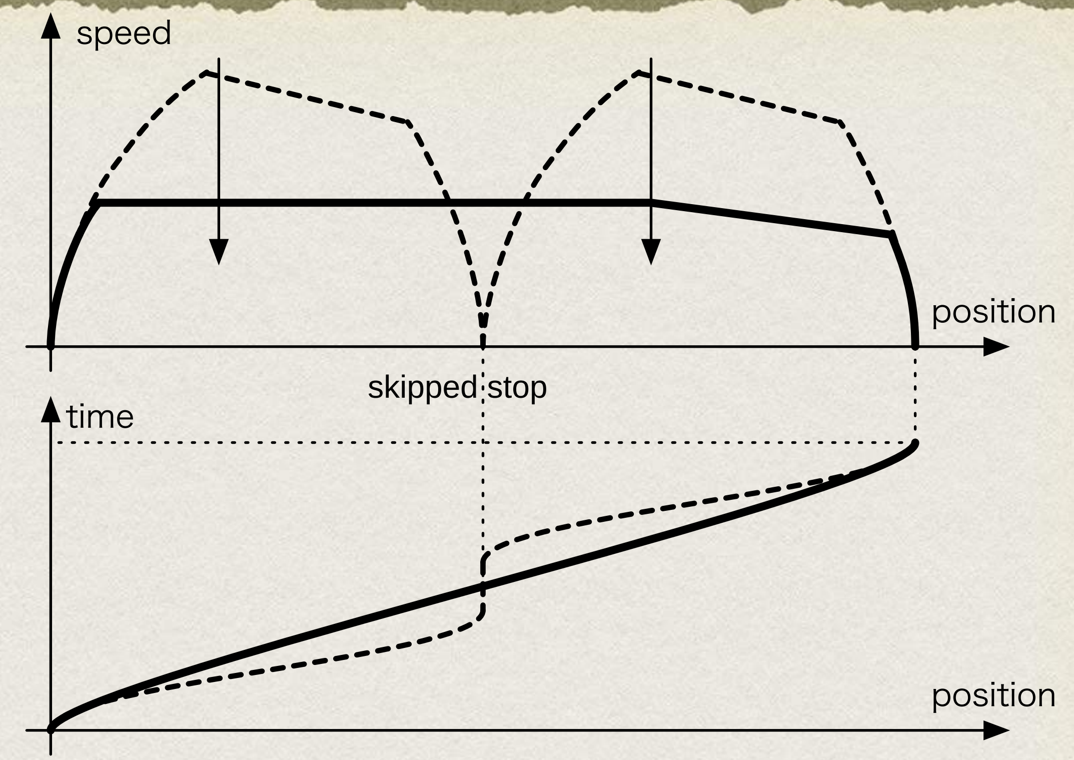
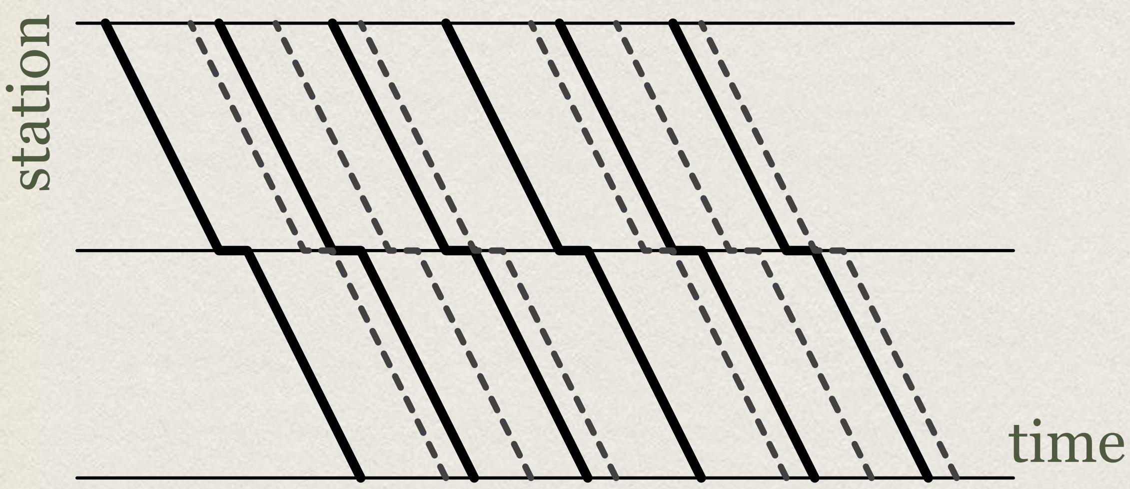
Four Major Countermeasures



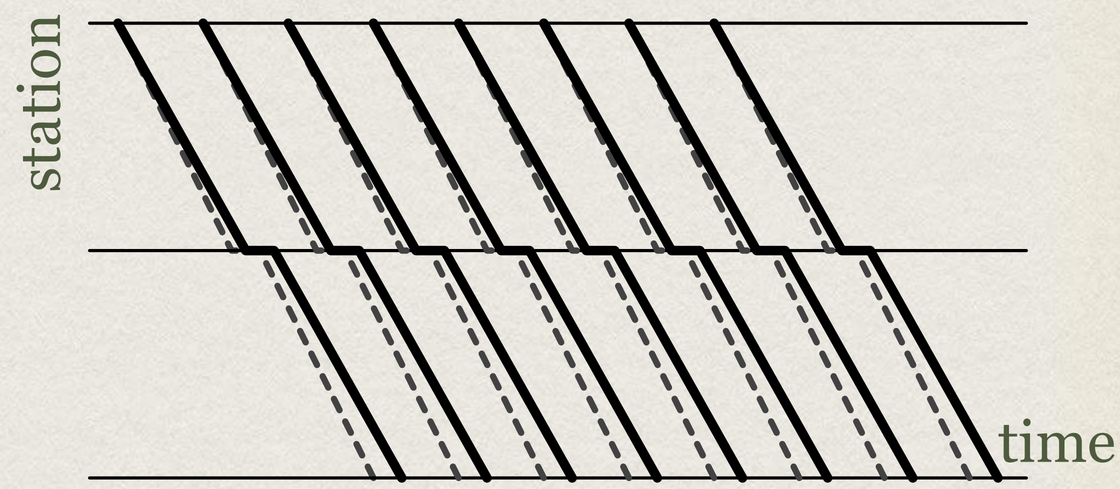
strategy 0: reduced number of cars per train



strategy 2: reduced number of stops



strategy 1: curtailed train service



strategy 3: slow down

Qualitative evaluation

	strategy 0	strategy 1	strategy 2	strategy 3
	reduced number of cars per train	curtailed train service	reduced number of stops	slow down
peak power	**very good**	fair	fair	fair
energy	**very good**	good	**very good**	**very good**
car scheduling	*bad*	good	**very good**	fair
crew scheduling	**very good**	good	**very good**	fair
transport capacity	fair	fair	**very good**	good
passenger utility	good	*bad*	fair	fair
easiness of passenger guidance	good	good	*bad*	good
robustness against train delay	good	good	good	fair

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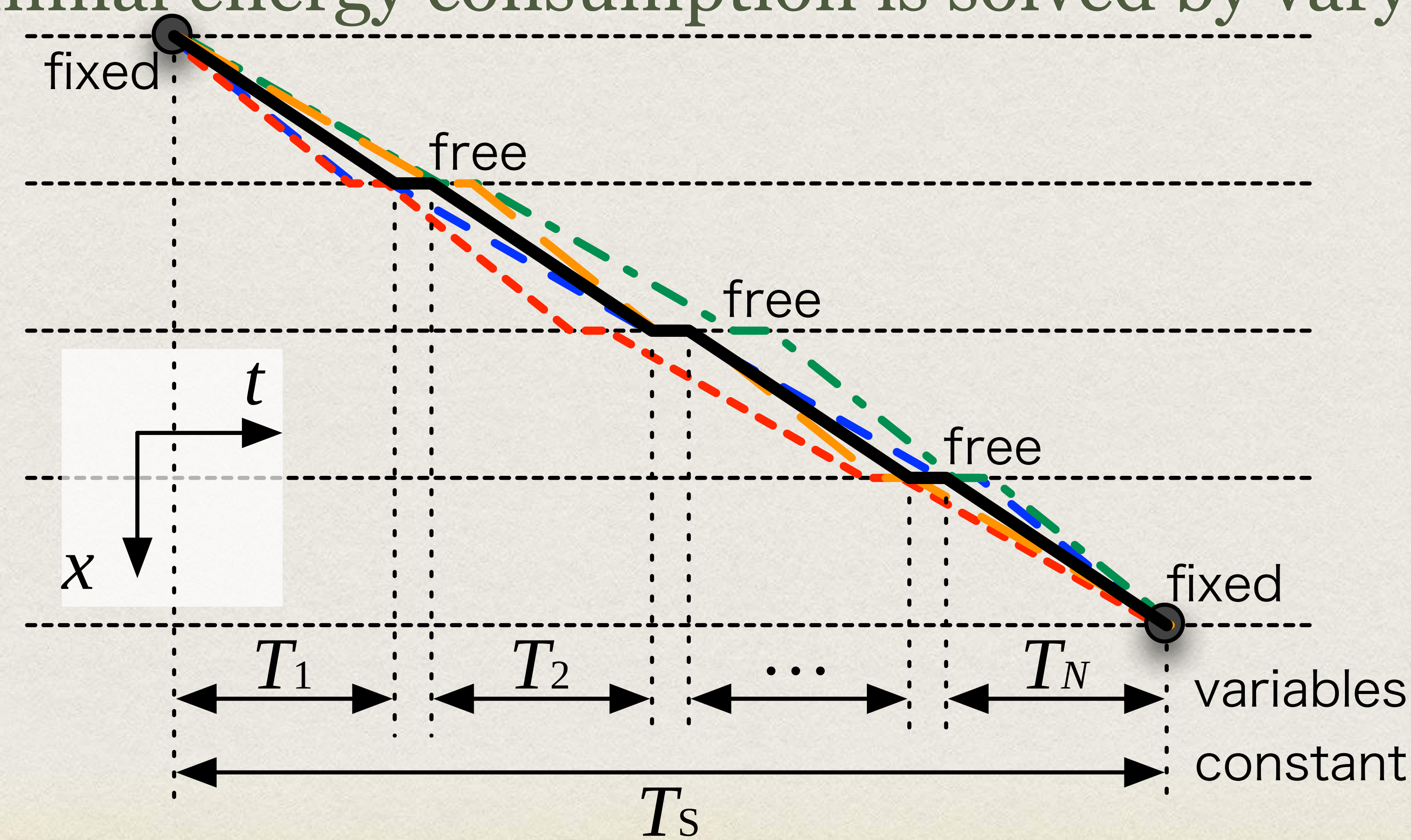
Energy-saving (Eco) Train Scheduling

- Total trip time T_S is given as a constant.
- Runtime for i-th interstation T_i is a variable.
  - by adjusting slack time
- The minimal energy consumption is solved by varying the T_i.



Formulation with Nonlinear Programming

$$J(T_1, \cdots, T_N) = \sum_{i=1}^{N} W_i(T_i) \to \min$$

total energy consumption

subject to $$\sum_{i=1}^{N} T_i = T_S$$

total trip time

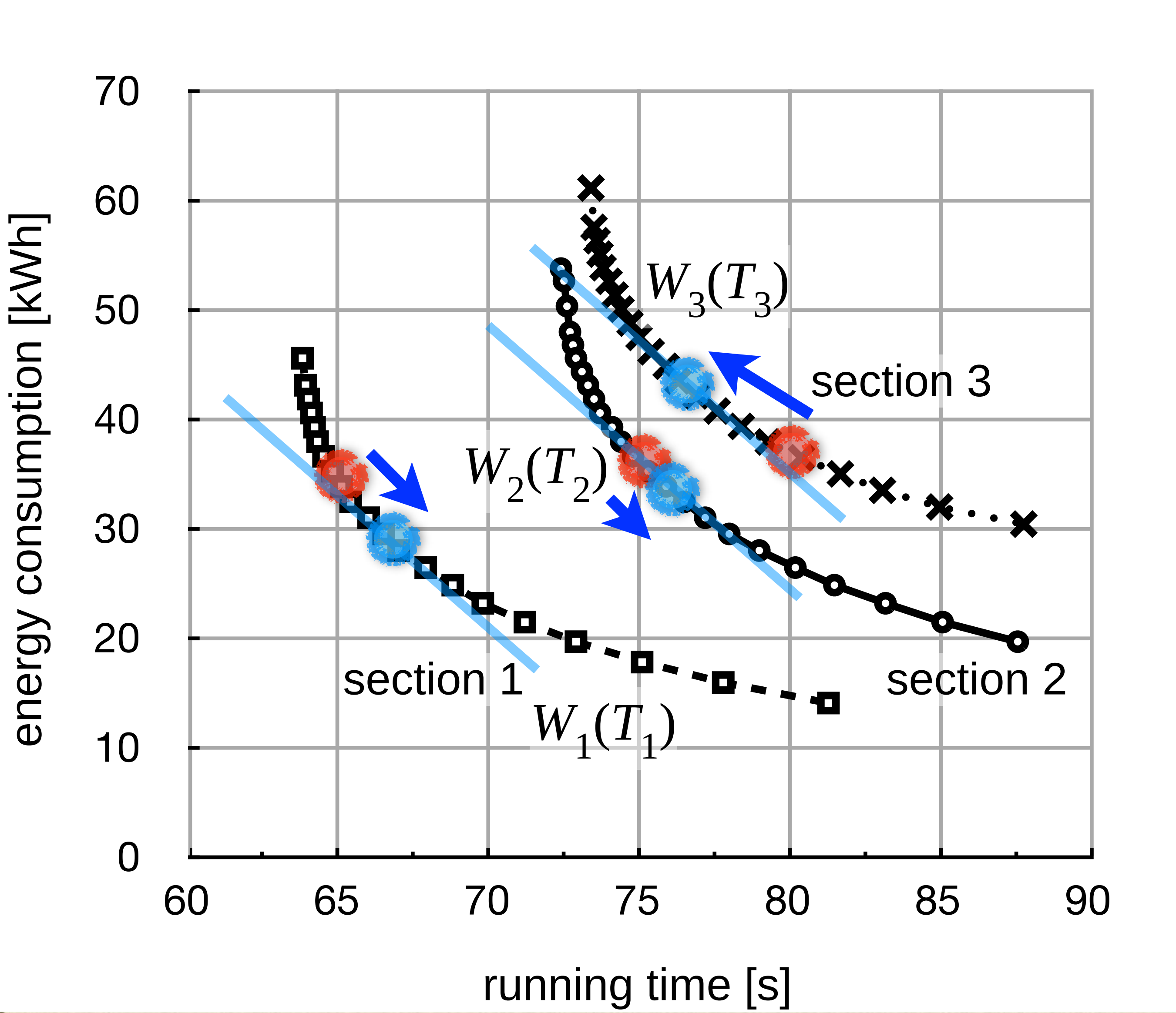
Applying Lagrange multiplier technique

$$L(T_1, \cdots, T_N, \lambda) = \sum_{i=1}^{N} W_i(T_i) + \underline{\lambda} \left(\sum_{i=1}^{N} T_i - T_S \right)$$

$$\frac{\partial L}{\partial T_i} = \frac{\partial L}{\partial \lambda} = 0 \quad (i = 1, 2, \cdots, N)$$

Derived Law

$$\frac{\partial W_1}{\partial T_1} = \frac{\partial W_2}{\partial T_2} = \cdots = \frac{\partial W_N}{\partial T_N} = -\lambda$$



Law of Identical Incremental Energy Consumption

If incremental energy for all interstations are identical, the schedule is optimal.

Passenger Trip Times

- giving number of passengers for each Origin-Destination (OD) pair
- evaluating the following items
  - waiting time at a station assuming uniform passenger arrival
  - running time between O and D
  - (transfer time)
- sum of total times for all passengers

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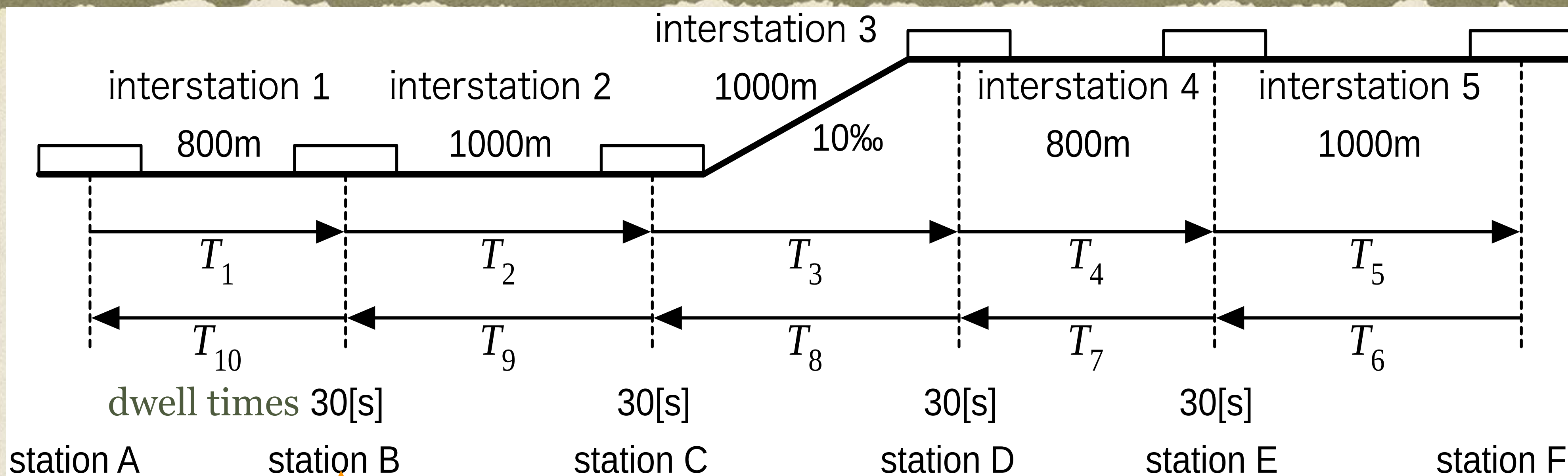
Assumed Conditions

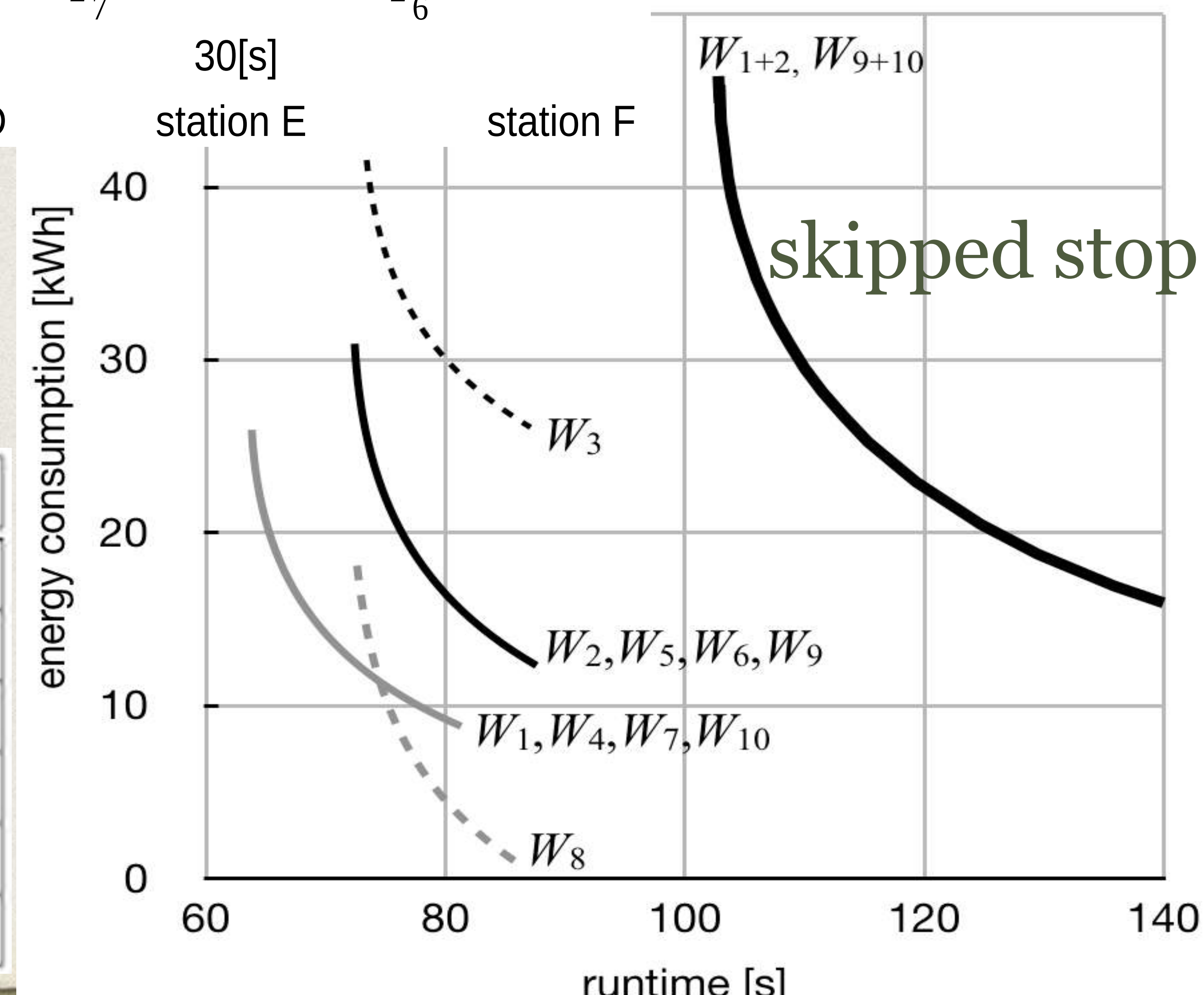


5 min. interval
= 12 trains/hour

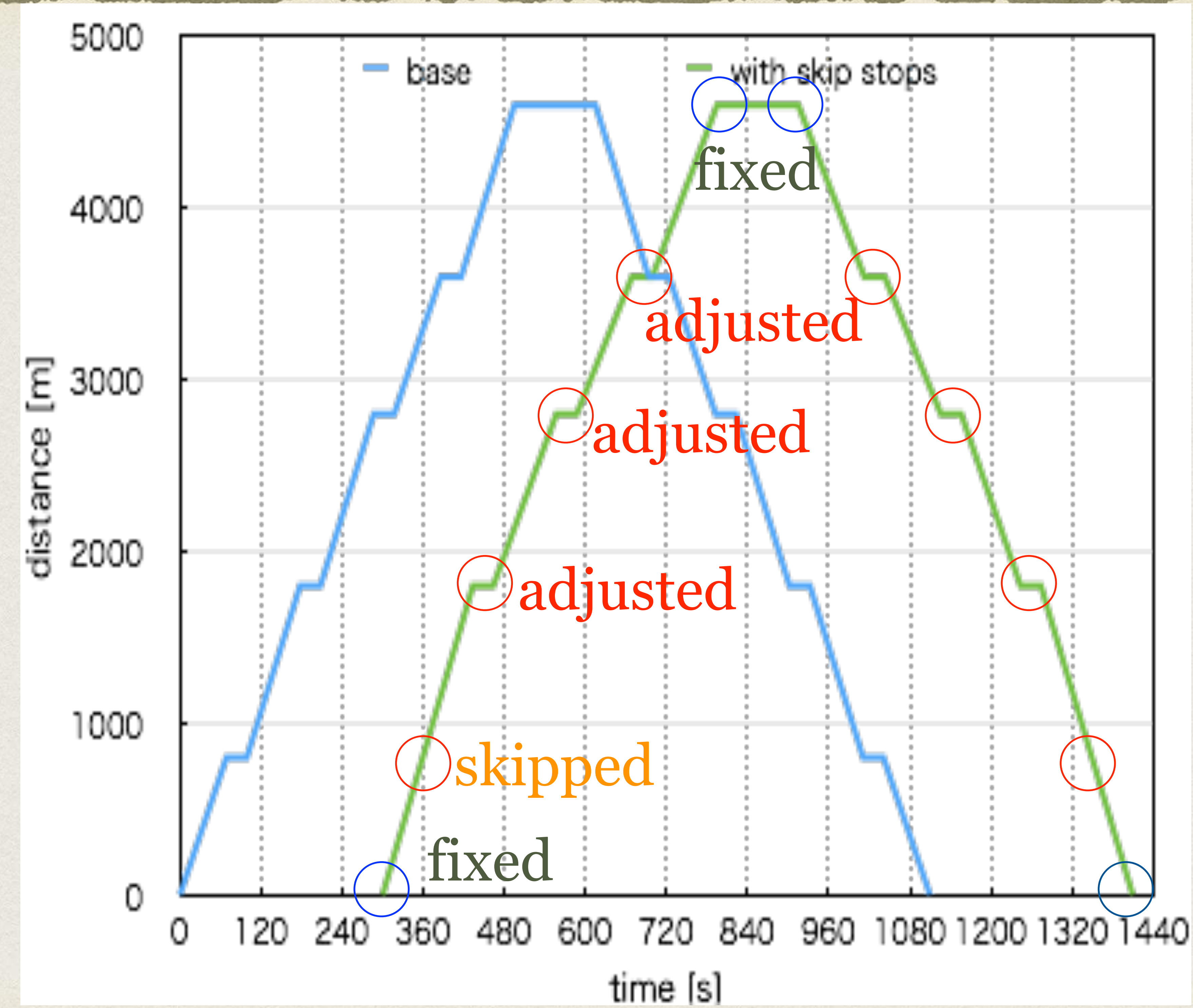
some trains passing

passenger demand per hour

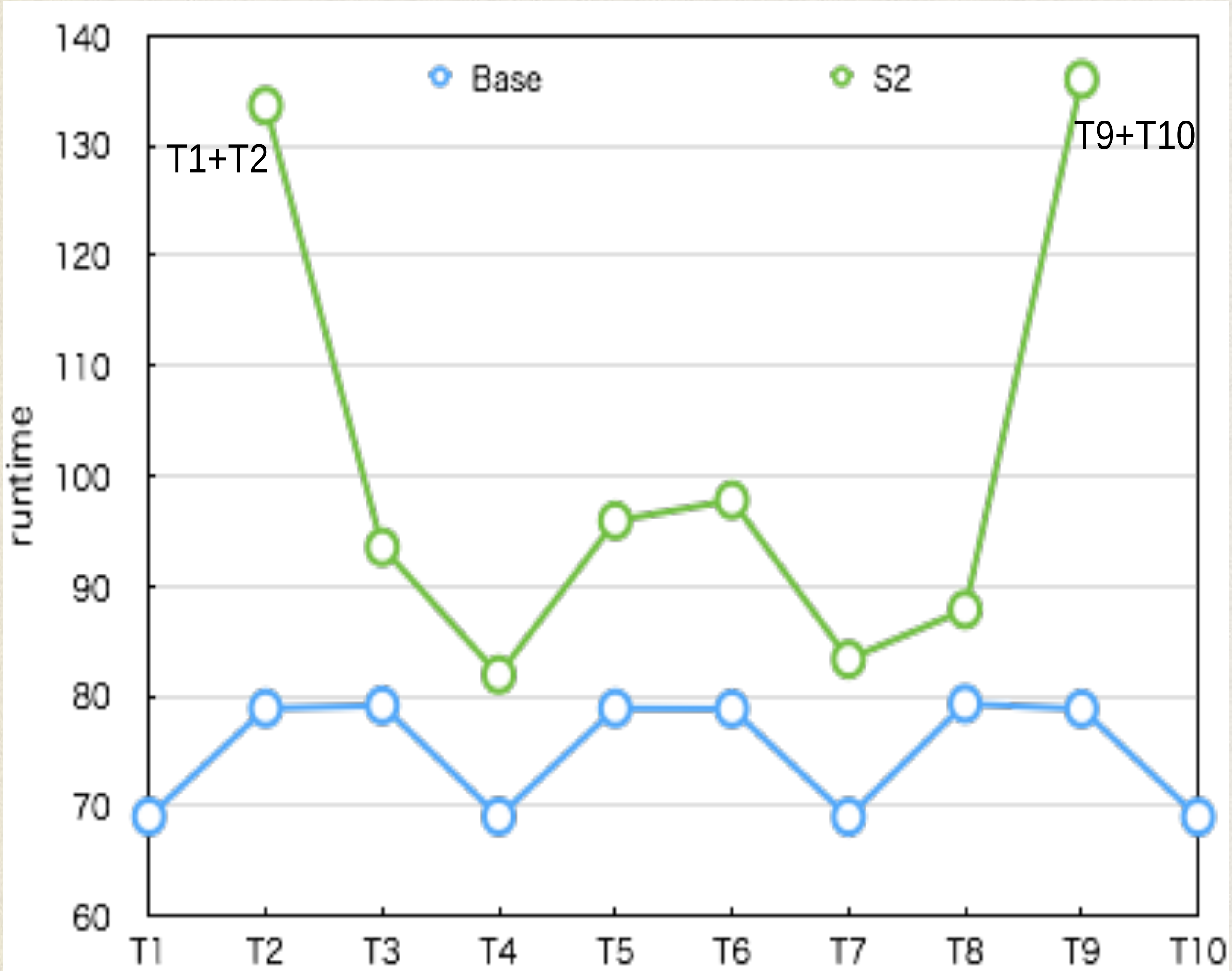
Origin \ Destination	A	B	C	D	E	F
A	–	600	900	1800	900	6000
B	600	–	300	600	300	1500
C	900	300	–	900	600	2100
D	1800	600	900	–	900	3000
E	900	300	600	900	–	2100
F	6000	1500	2100	3000	2100	–



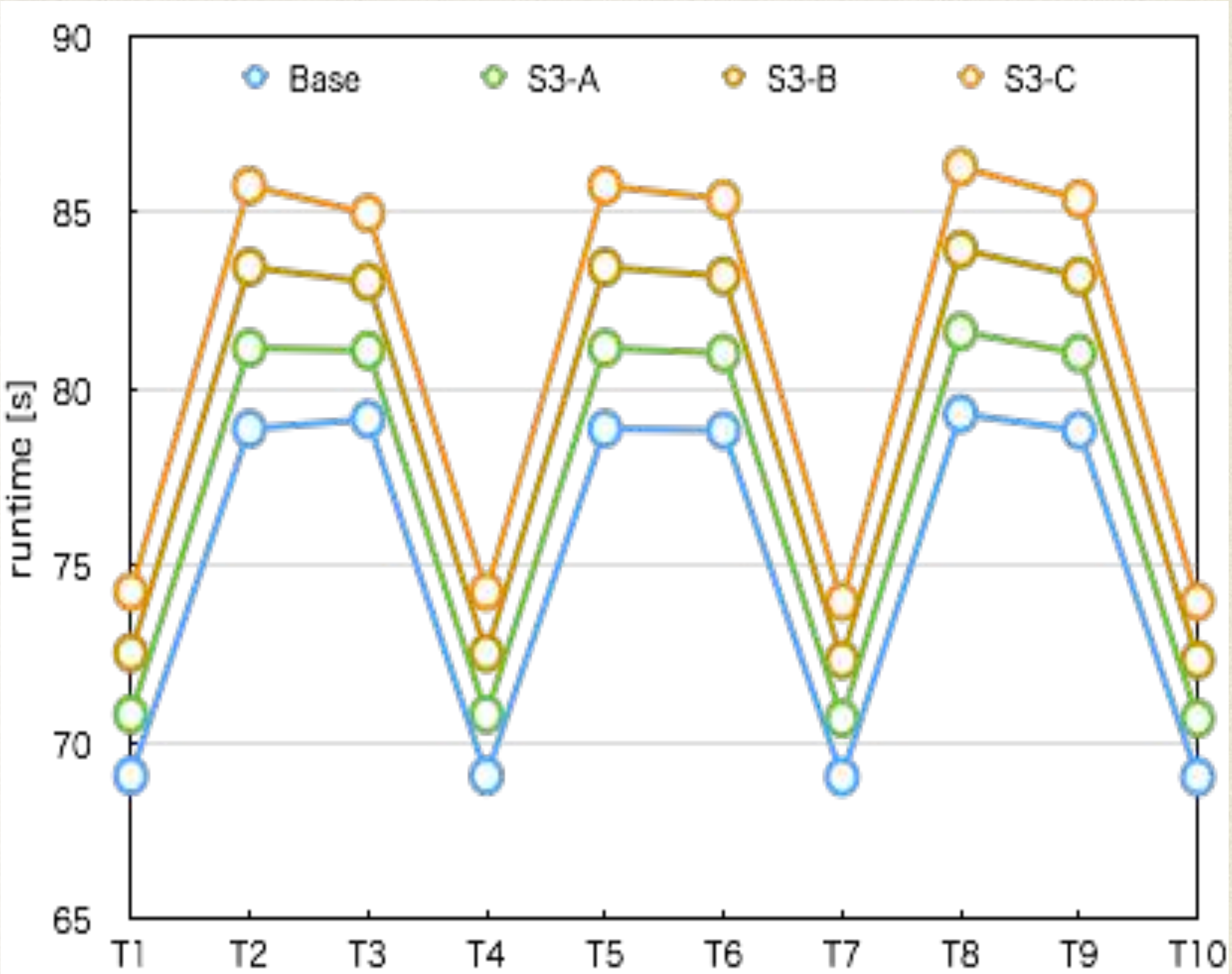
with/without Skips



Optimized Runtimes

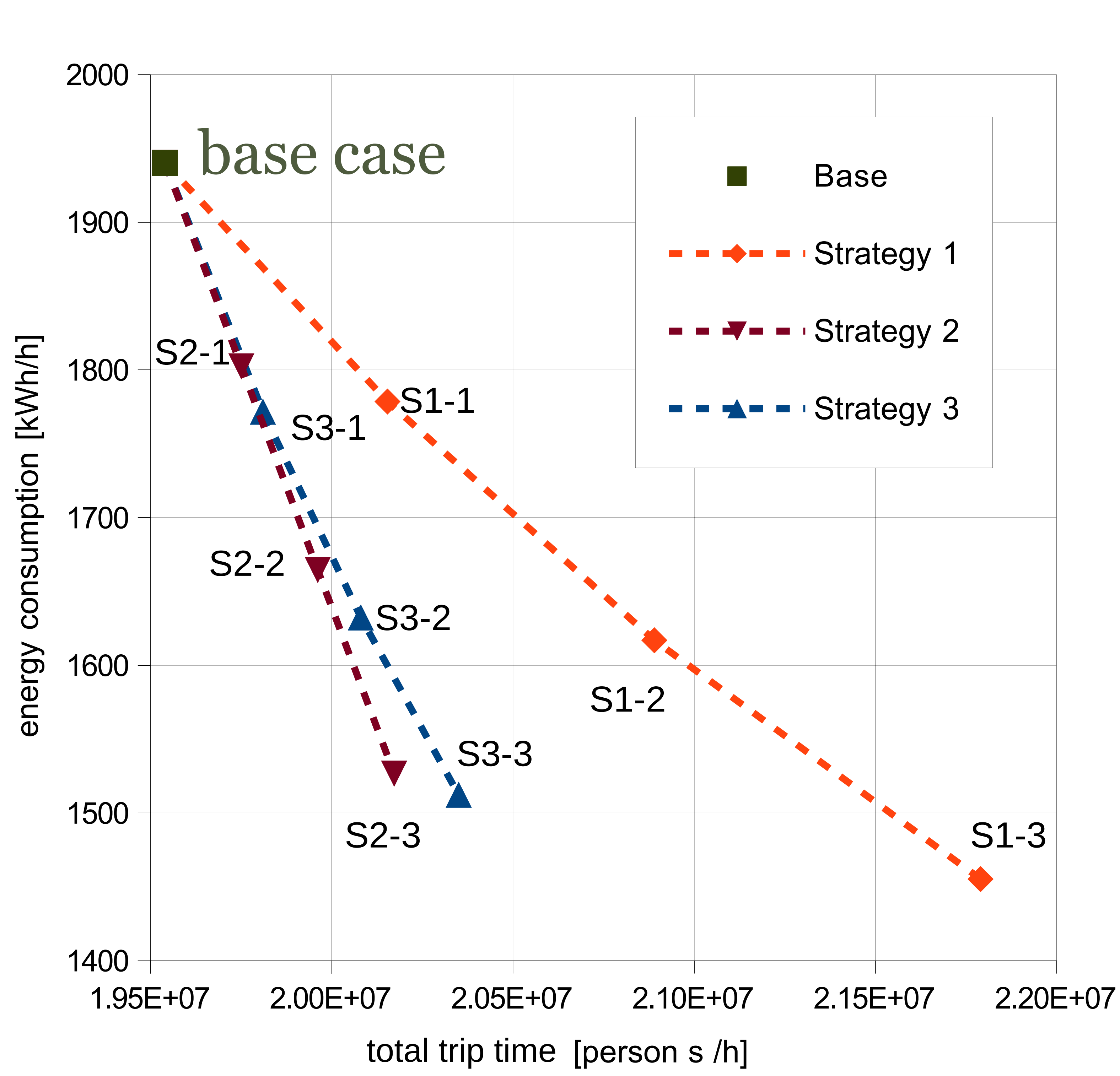


Strategy 2



Strategy 3

Comparative Results



curtailed trains
S1-1: 1/12 curtailed
S1-2: 2/12 curtailed
S1-3: 3/12 curtailed

reduced stops
S2-1: 2/12 passing B
S2-2: 4/12 passing B
S2-3: 6/12 passing B

slow down
S3-1: round trip+20[s]
S3-2: round trip+40[s]
S3-3: round trip+60[s]

Discussion

- Trade-off between energy consumption and trip times can be found.
- Curtailed train service (Strategy 1) had much higher increase of trip times than other strategies.
- Reduced train stops (Strategy 2) and slow down (Strategy 3) had very similar characteristics.

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Summary

- Emergent scheduling under restricted energy supply
  - some countermeasures compared
    - energy consumption
    - passenger trip times
  - "reduced number of stops" and "slow down" preferable
- Future scope
  - considering peak power, etc.

Thanks for your kind attention!

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