Modeling Within-day Schedule Adjustment Decision Consistent with Time-Varying Network Conditions

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THE 3RD CONFERENCE ON INNOVATIONS IN TRAVEL MODELING

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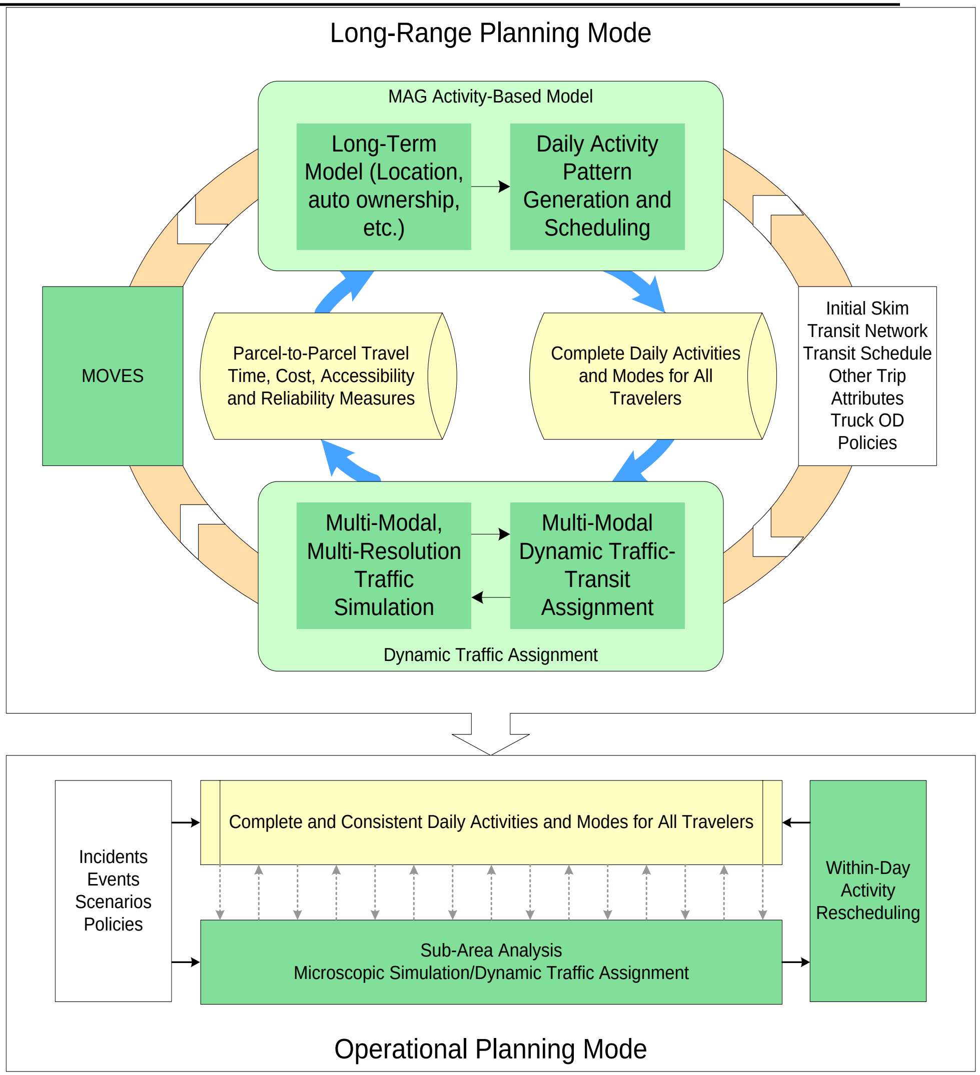
Outline

- Motivation and objectives
- Activity rescheduling decision process
- Mathematical decision model
- Algorithm
- Experiment
- Conclusions

Why Modeling Activity Rescheduling in an Integrated Framework

- Understand response to network disturbance
- Linking Planning and Operations
  - Supplement planning oriented ABM
  - Strengthen short-term choice/decision models
- Impact/value of Information

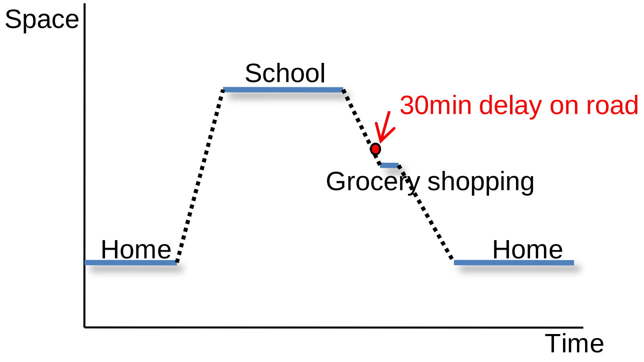


Premises

- Higher frequency of within-day activity timing adjustment (Joh and Doherty et al 2005; Roorda and Andre 2007)
- Time resource allocation decision based on utility maximization (Gan and Recker, 2008)
- Within-day travel decisions differ with presence of traveler information (Srinivasan and Mahmassani 2003, Chiu et al, 2010)

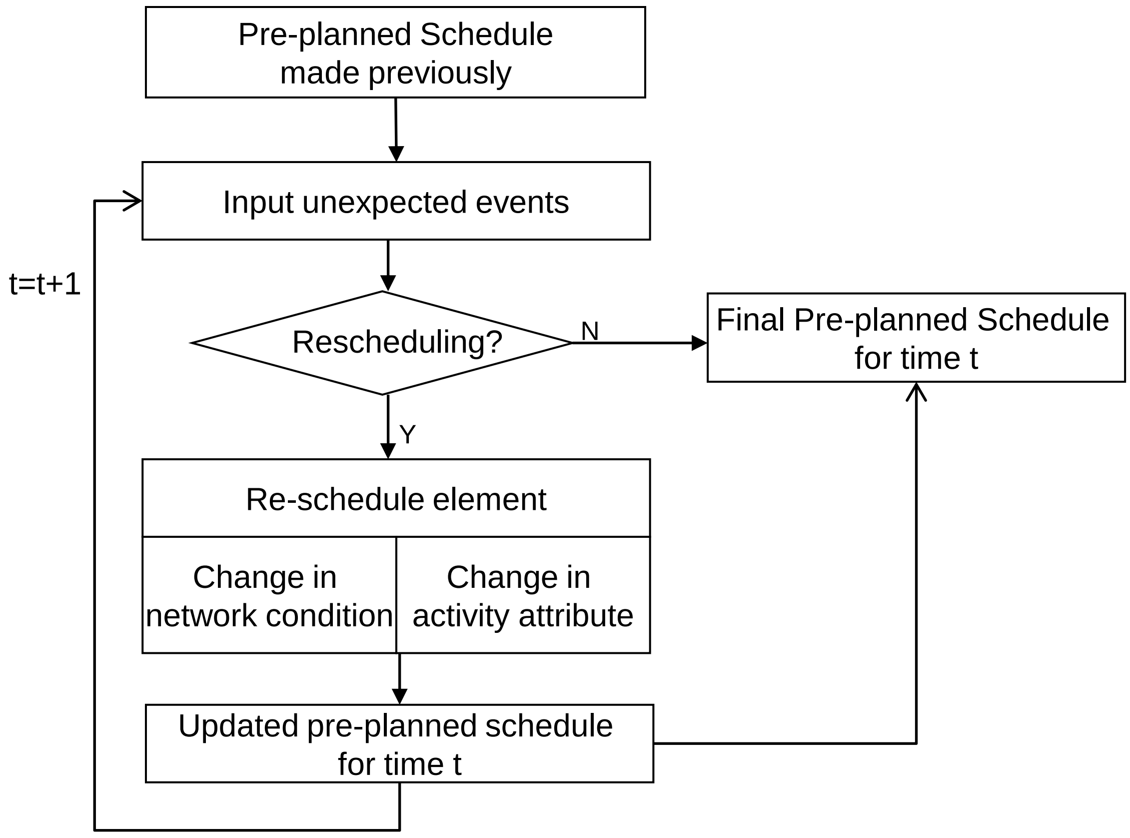
Rescheduling Decision Process

- Activity rescheduling decision problem
  - How to represent time budget constraints in the problem?
  - Consistent internal dynamics between activity rescheduling decision model and time-varying network information



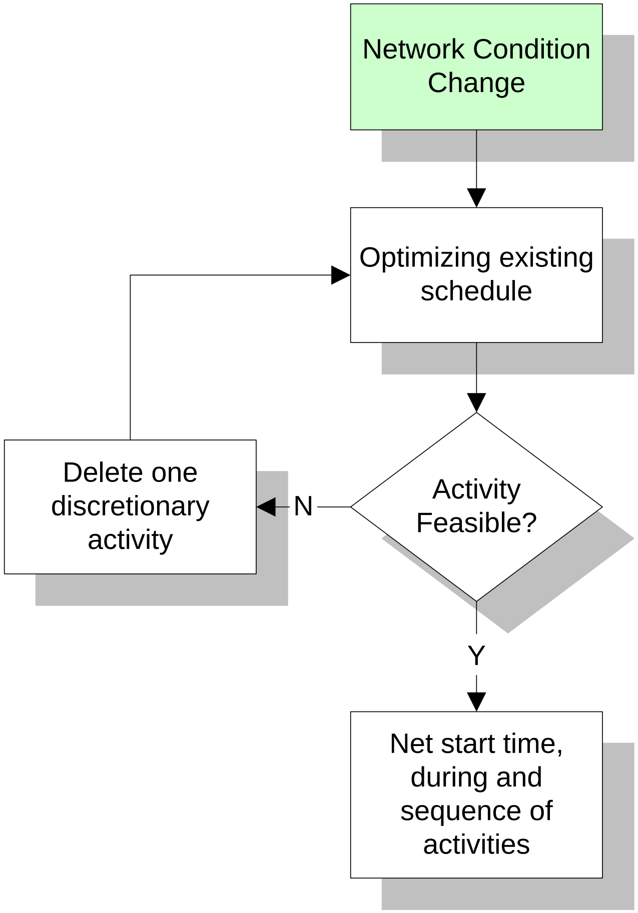
Reschedule? Or not?

Activity Rescheduling Decision Process



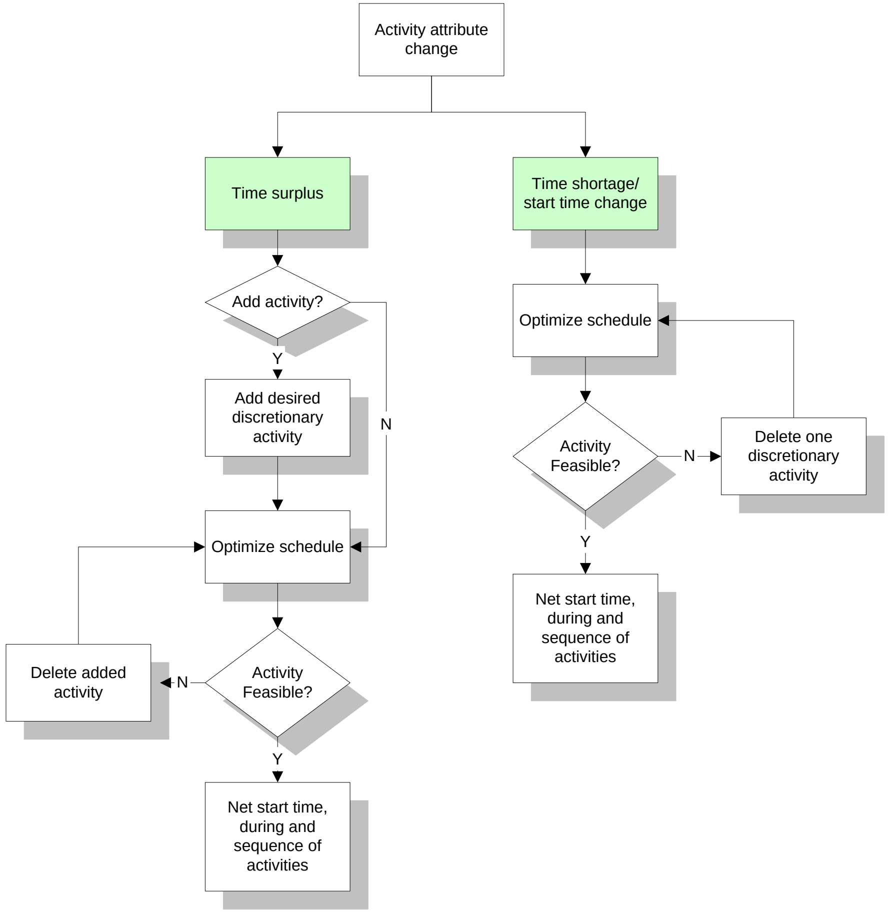
Schedule Modification Process

- Network condition change
  - Re-optimizing the remained activities with updated travel information
  - If no feasible solution found, one discretionary activity is removed
  - Re-optimize remaining activities
  - Repeat process until an optimal solution is found



Schedule Modification Process

- Activity attribute change
  - Time shortage
    - Insert new activity/extension of duration
    - Rescheduling
  - Time surplus
    - Delete a preplanned activity or shortening duration length
    - Rescheduling



Travel Cost Consistent Utility Maximization Rescheduling Problem

$$\underset{t_a^s, d_a, y_{g,a}}{Max} \; Z = \sum_{a \in A'(i)} \int_{t_a^s}^{t_a^s + d_a} MU_a(t)dt - \sum_{g \in A'(i)} \sum_{a \in A'(i)} \theta_{g,a} \cdot w_{g,a}(t_g^s + d_g) \cdot y_{g,a}$$

Subject to

$$t_a^s - t_h^s + My_{a,h} + d_a \leq M - w_{a,h} \qquad \forall a,h \;, \forall a \in A'(i), h \in A'(i), a \neq h$$

$$y_{a,h} + y_{h,a} = 1 \qquad \forall a,h \;, \forall a \in A'(i), h \in A'(i), a \neq h$$

$$t_a^{s_{min}} \leq t_a^s \leq t_a^{s_{max}} \quad , t_a^{e_{min}} \leq t_a^e \leq t_a^{e_{max}} \quad , d_a^{min} \leq d_a \leq d_a^{max} \quad , \forall a \;, \forall a \in A'(i)$$

Set

$A(i)$	Set of all activities in a schedule for traveler i
$A'(i)$	Set of remaining activities for traveler i, indexed by a

Decision Variables

t_a^s	start of activity $a \in A'(i)$
d_a	duration of activity $a \in A'(i)$
$y_{a,h}$	binary variable $, \forall a \in A'(i), h \in A'(i), a \neq h$. $y_{a,h} = 1$ if activity a precedes activity h

Parameters

MU_a	marginal utility for activity $a \in A'(i)$
$w_{g,a}(t)$	(non-negative) travel time from activity $g \in A'(i)$ to activity $a \in A'(i)$
$t_a^{s_{min}}$	(non-negative) earliest start time for activity $a \in A'(i)$
$t_a^{s_{max}}$	(non-negative) latest start time for activity $a \in A'(i)$
$t_a^{e_{min}}$	(non-negative) earliest end time for activity $a \in A'(i)$
$t_a^{e_{max}}$	(non-negative) latest end time for activity $a \in A'(i)$
d_a^{min}	(non-negative) shortest duration length for activity $a \in A'(i)$
d_a^{max}	(non-negative) longest duration length for activity $a \in A'(i)$
$\theta_{g,a}$	(between 0 to 1) weight of journey from activity $g \in A'(i)$ to $a \in A'(i)$
MU_a^{max}	maximum marginal utility value for activity $a \in A'(i)$
M	(positive) penalty value

Travel Cost Consistent Utility Maximization Rescheduling Problem

$$Max \underset{t_a^s, d_a, y_{g,a}}{Z} = \sum_{a \in A'(i)} \{ \int_{t_a^s}^{t_a^s + d_a} MU_a(t)dt - \sum_{g \in A'(i)} \sum_{a \in A'(i)} \theta_{g,a} \cdot w_{g,a}(t_g^s + d_g) \cdot y_{g,a} \}$$

Where $MU_a = a \cdot t^2 + b \cdot t + c$ and $\int_{t_a^s}^{t_a^s + d_a} MU_a(t)dt$ can be expressed as:

$$F_b(t) = \frac{1}{3} * \left\{ \frac{-U_b^{max}}{\left(\frac{t_b^{e\_max} - t_b^{e\_min}}{2} \right)^2} \right\} \left(t - \frac{t_b^{e\_max} + t_b^{s\_min}}{2} \right)^3 + U_b^{max} \left(t - \frac{t_b^{e\_max} + t_b^{s\_min}}{2} \right) + C$$

* Modified formulation

$$MAX\ Z = \sum_{a \in A'(i)} F_a(t_a^s + d_a) - F_a(t_a^s) + \sum_{g \in A'(i)} \sum_{a \in A'(i)} \theta_{g,a} \cdot w_{g,a}(t_g^s + d_g) \cdot y_{g,a}$$

Subject to $t_a^s - t_h^s + M y_{a,h} + d_a \leq M - w_{a,h}, \quad \forall a \in A'(i), h \in A'(i), a \neq h$

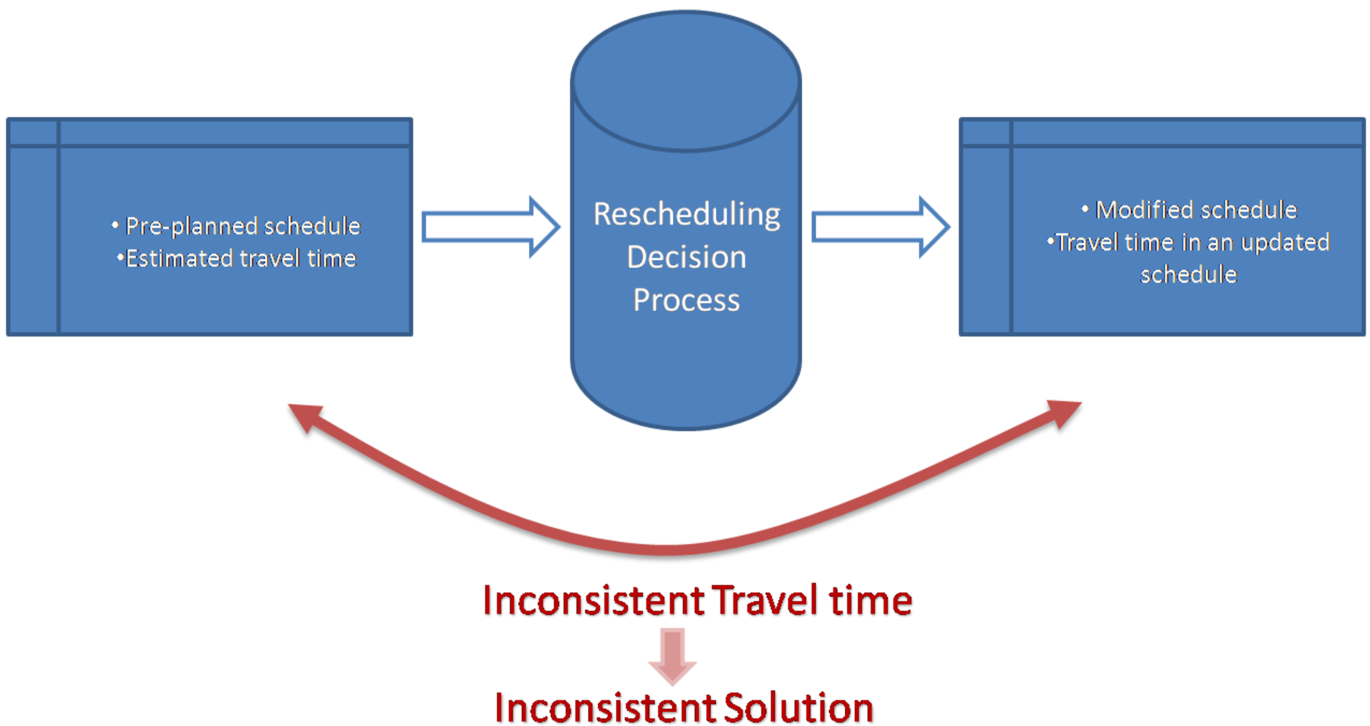
$$y_{a,h} + y_{h,a} = 1, \quad \forall a \in A'(i), h \in A'(i), a \neq h$$

$$t_a^{s_{min}} \leq t_a^s \leq t_a^{s_{max}}, \quad \forall a \in A'(i)$$

$$d_a^{min} \leq d_a \leq d_a^{max}, \quad \forall a \in A'(i)$$

$$t_a^{e_{min}} \leq t_a^s + d_a \leq t_a^{e_{max}}, \quad \forall a \in A'(i)$$

Consistent Solution with Time-Varying Travel Cost



Solution Algorithm

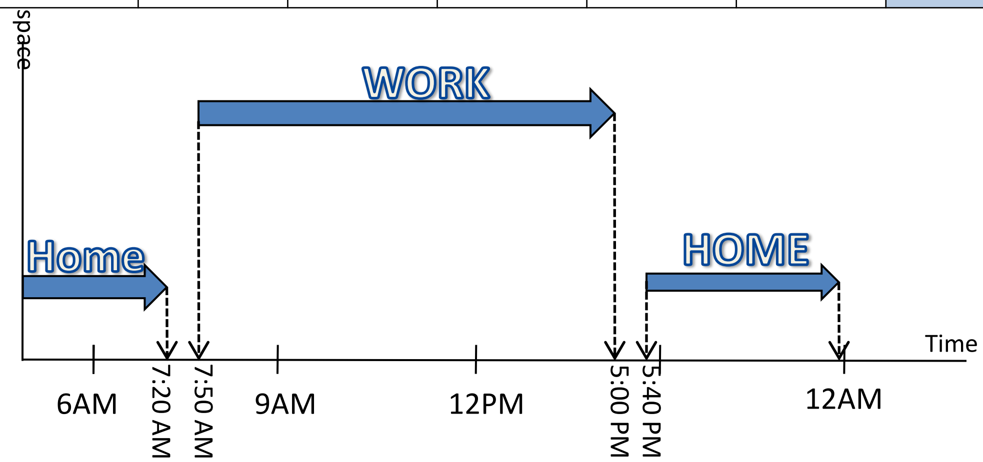
- Pre-iteration: Average travel time + non-integer sequence variable
- Initial-Iteration: Average travel time + integer sequence variable
  - A branch and cut algorithm – to find best *k* solutions
- Main-iteration: Time-varying travel time + integer sequence variable
  - Step *a*: Find end time of activities of a node having max utility value
  - Step *b*: Find time-varying travel time (according to updated end time)
  - Step *c*: Solve for the optimal schedule
  - Step *d*: Check convergence criterion; stop if criterion met; otherwise repeat steps *a* – *c*
  - Iteration:

$$
\begin{aligned}
&\text{for } (\textit{best } k \textit{ sequences})\{\\
&\quad \text{do}\{\\
&\qquad \textit{perform steps a to c};\\
&\quad \}\text{while}\left(\sum_{a\in A'}\left|t_a^{s\_new} - t'^{s\_previous}_a\right| + \sum_{a\in A'}\left|d_a^{new} - d'^{previous}_a\right| \geq \varepsilon\right)\\
&\}
\end{aligned}
$$

Experiment : Time Shortage Case

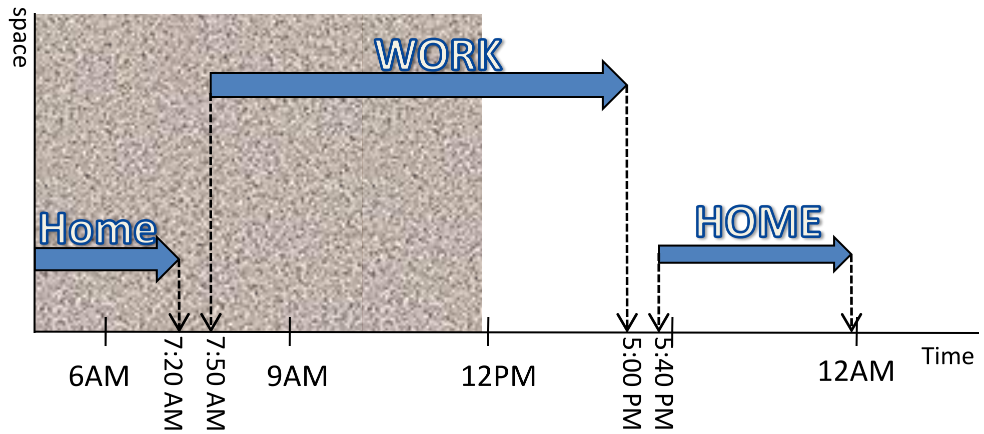
- Preplanned schedule: home - work - home

id	Activity	min duration	max duration	earliest start time	latest start time	earliest end time	latest end time	Maximum Utility	start time	duration	end time
A1	H (home)	6 hr	8 hr	0	0	6:00 AM	8:00 AM	40	0	7 hr 20 min	7:20 AM
A2	W (work)	5 hr	10 hr	7:30 AM	10:00 AM	1:00 PM	7:00 PM	120	7:50 AM	9 hr 10 min	5:00 PM
A3	H (home)	30 min	10 hr	1:00 PM	11:30 PM	12:00AM	12:00AM	40	5:40 PM	6 hr 20 min	12:00 AM



Experiment : Time Shortage Case

- Preplanned schedule: home - work - home



- An unexpected event will be given at 12:00 PM

id	Activity	min duration	max duration	earliest start time	latest start time	earliest end time	latest end time	Maximum Utility
A4	Going to postal office	20 min	60 min	12:00 PM	4:40 PM	8:20PM	5:00 PM	-20

Experiment : An event given at 12:00 PM

- Pre-iteration
  - Average travel time + non-integer sequence variable

	W-H	W-PO	H-W	H-PO	PO-W	PO-H
Average travel time	40 min	20 min	40 min	30 min	20 min	30 min

  - At 12 PM, a preplanned schedule has work activity and home activity
  - After initial decision process, the rescheduling set includes new event
  - Rescheduling set: work activity, home activity, and post office activity

Experiment : An event given at 12:00 PM

- Updated Preplanned schedule at Pre-iteration
  - Total Utility: 61,992
  - Non-integer variable for sequence

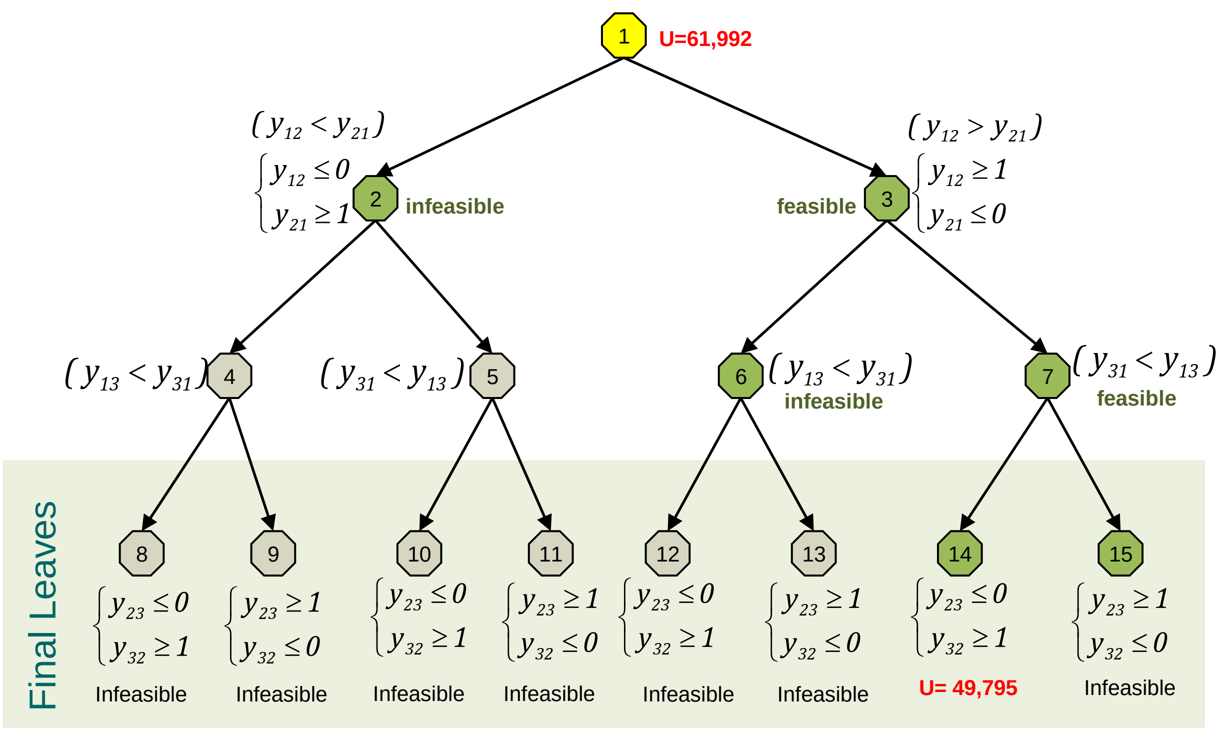
y23	y32	y24	y42	y34	y43
0.5	0.5	0.5	0.5	0.5	0.5

  - Schedule conflict

	Start time	Duration	End time
A2	12:00 PM	6 hr 10 min	6:10 PM
A3	2:00 PM	10 hr	12:00 AM
A4	12:00 PM	20 min	12:20 PM

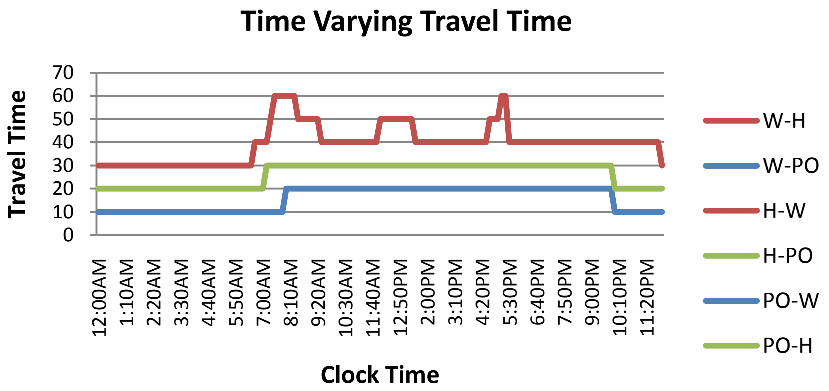
Experiment : An event given at 12:00 PM

- Zero-iteration
  - Average travel time + integer variable for sequence



Experiment : An event given at 12:00 PM

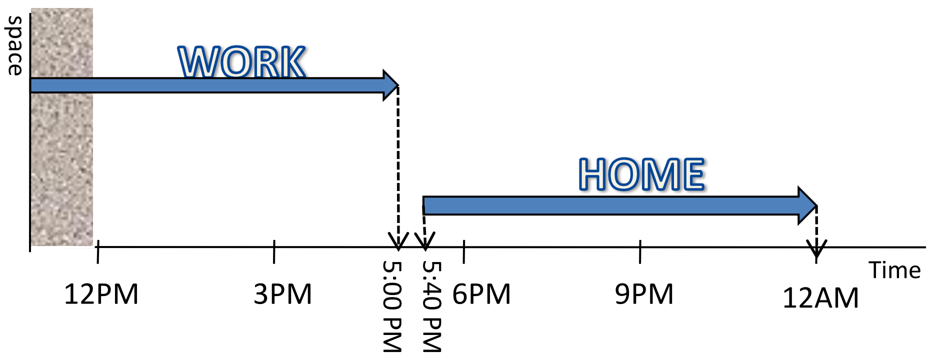
- Main-iteration
  - Time dependent travel time + non-integer variable for sequence



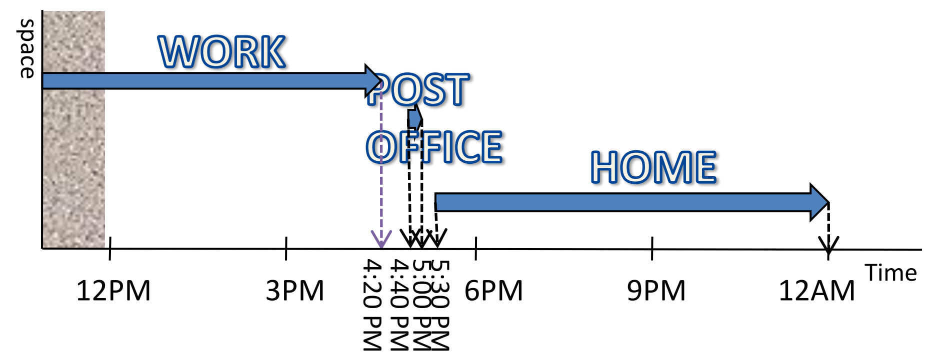
  - Consistency of a solution is checked by convergence criteria
    - Inconsistent solution: Discrepancy between travel time in use and actual travel time in a solution
    - Convergence criterion: $\sum_{b \in A'} \left| t_b^s - t'^s_b \right| + \sum_{b \in A'} \left| d_b - d'_b \right| < \varepsilon$

Experiment : An event given at 12:00 PM

- Results



Previous schedule



Modified schedule

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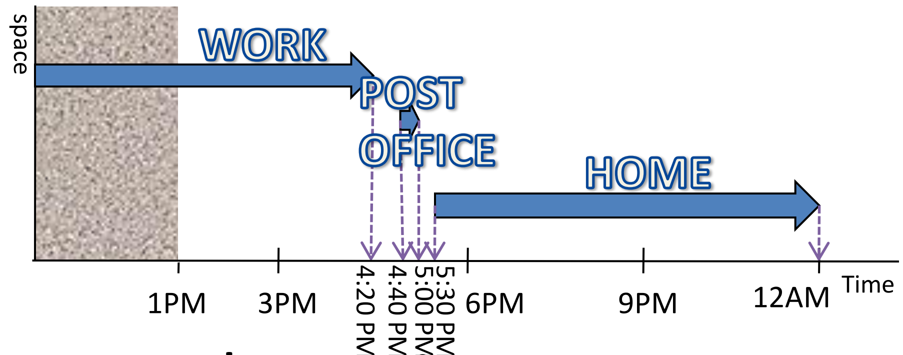
Experiment : Time Surplus Case

- Preplanned schedule at 1 PM: work–post office-home

	Start time	Duration	End time
A2	1:00 PM	4 hr 20 min	4:20 PM
A4	4:40 PM	20 min	5:00 PM
A3	5:30 PM	6 hr 30 min	12:00 AM



- Two events given: Pick-up and meeting

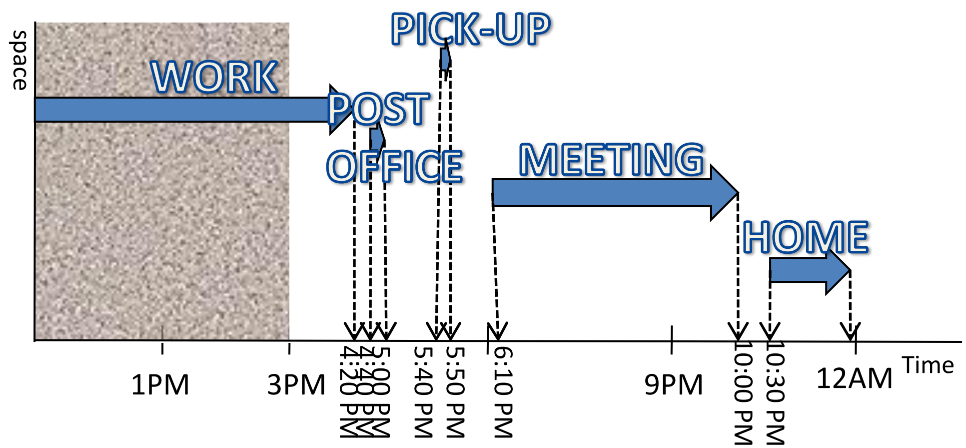
11	Activity	min duration	max duration	earliest start time	latest start time	earliest end time	latest end time	Maximum Utility
5	Pick-up	10 min	60 min	1:00 PM	6:30 PM	1:10PM	7:00 PM	-60

id	Activity	min duration	max duration	earliest start time	latest start time	earliest end time	latest end time	Maximum Utility
6	meeting	30 min	5 hr	5:00 PM	7 PM	5:30PM	10:00 PM	60

Experiment : Time Surplus Case

- At 3 PM, a pre-planned schedule

id	Activity	start time	duration	end time
A2	Work	3:00 PM	1 hr 20 min	4:20 PM
A4	Post office	4:40 PM	20 min	5:00 PM
A5	Pick up	5:40 PM	10 min	5:50 PM
A6	Meeting	6:10 PM	3 hr 50 min	10:00PM
A3	Home	10:30 PM	1 hr 30 min	12:00 AM



- At 3 PM, pick-up and meeting event are canceled
  - Will a person add more activity after canceling two activities?
  - If yes, one alternative activity is selected

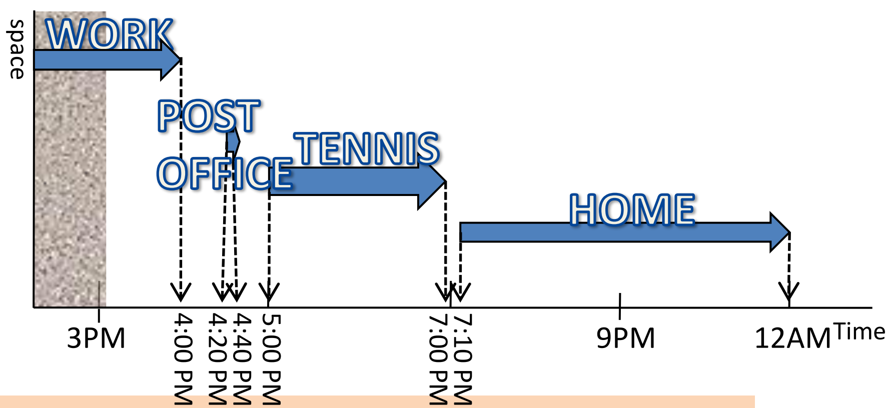
Experiment : Time Surplus Case

Alternative activities

id	Activity	Description	min duration	max duration	earliest start time	latest start time	earliest end time	latest end time	Maximum Utility
A7	PB2(Personal business 2)	Grocery shopping	20 min	1 hr 30 min	3:00 PM	10:00 PM	3:30 PM	12:00 AM	-20
A8	PB3(Personal business 3)	Grocery shopping	30 min	60 min	3:00 PM	5:00 PM	3:40 PM	9:00 PM	60
A9	PB4(Personal business 4)	Shopping	30 min	2 hr	3:00 PM	6:00 PM	9:30 PM	8:00PM	50
A10	PB5(Personal business 5)	Hospital	40 min	2 hr	3:00 PM	4:20 PM	3:40 PM	5:00 PM	50
A11	SR2(Social recreation 2)	Tennis	30 min	2 hr	3:00 PM	5:00 PM	4:30 PM	7:00 PM	80

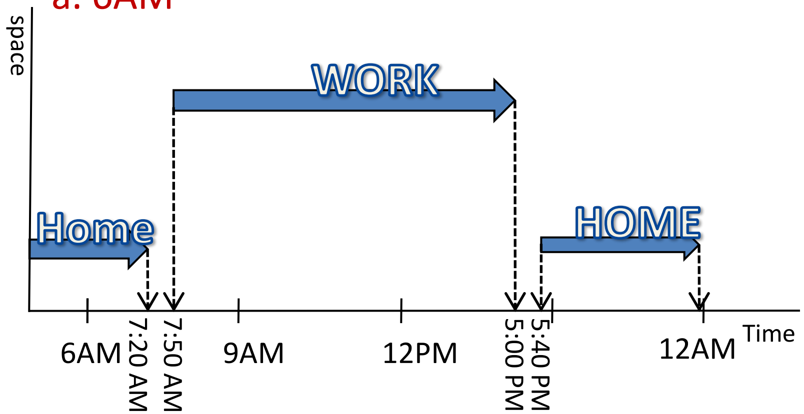
Updated schedule at 3PM

Id	Activity	start time	duration	end time
A2	Work	3:00 PM	1 hr	4:00 PM
A4	Post office	4:20 PM	20min	4:40 PM
A11	Tennis	5:00 PM	2 hr	7:00 PM
A3	Home	7:10 PM	4 hr 50 min	12:00AM

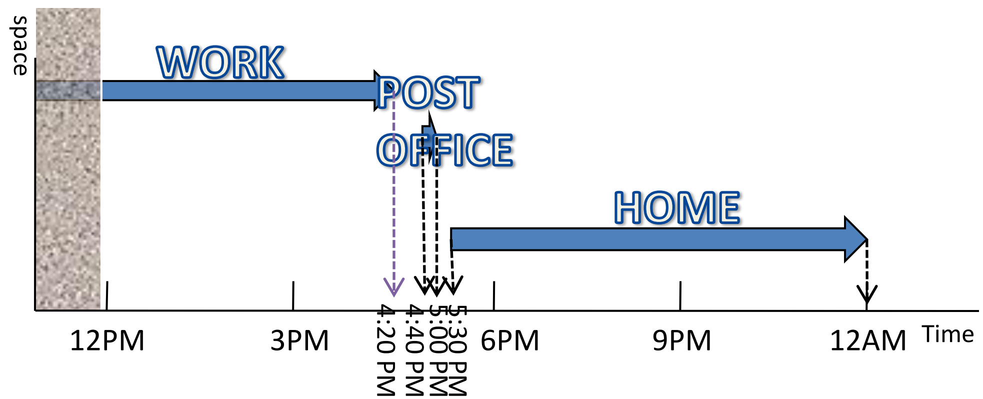


Experiment : Activity Attribute Change

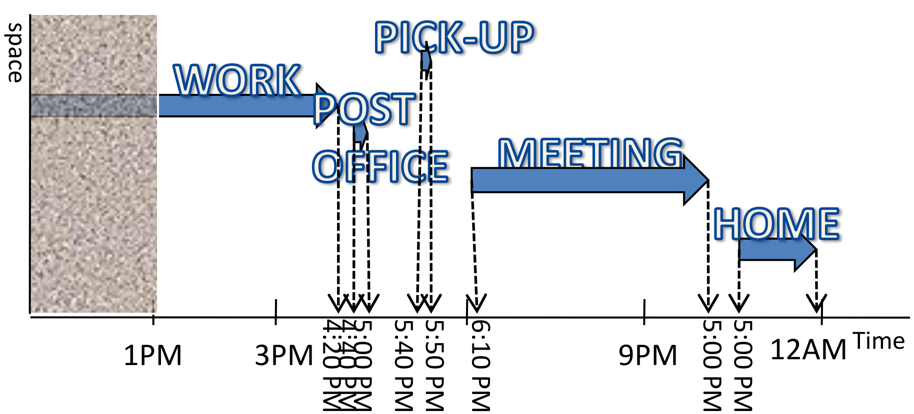
a. 6AM



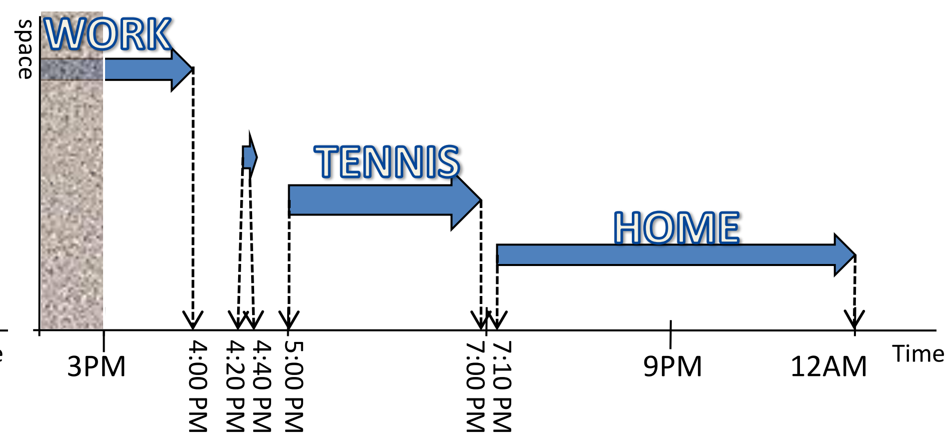
b. 12PM



c. 1PM



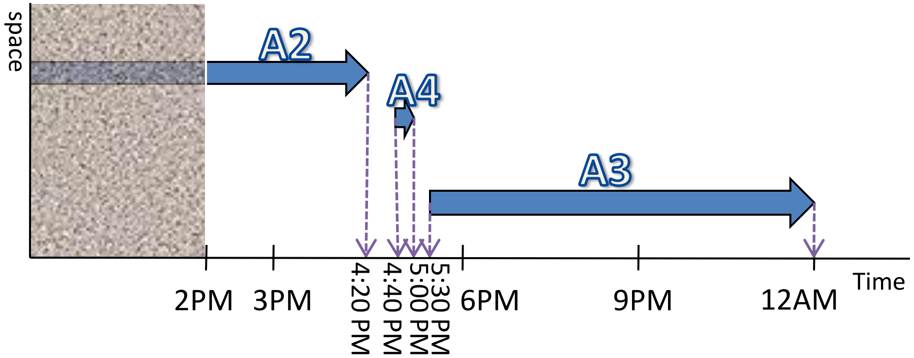
d. 3PM



Experiment : Network Condition Change

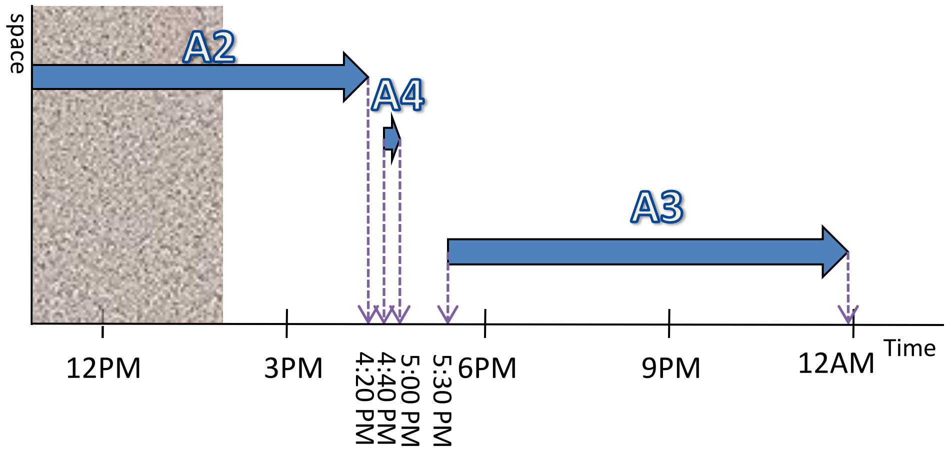
- Preplanned schedule at 2 PM: work–post office-home

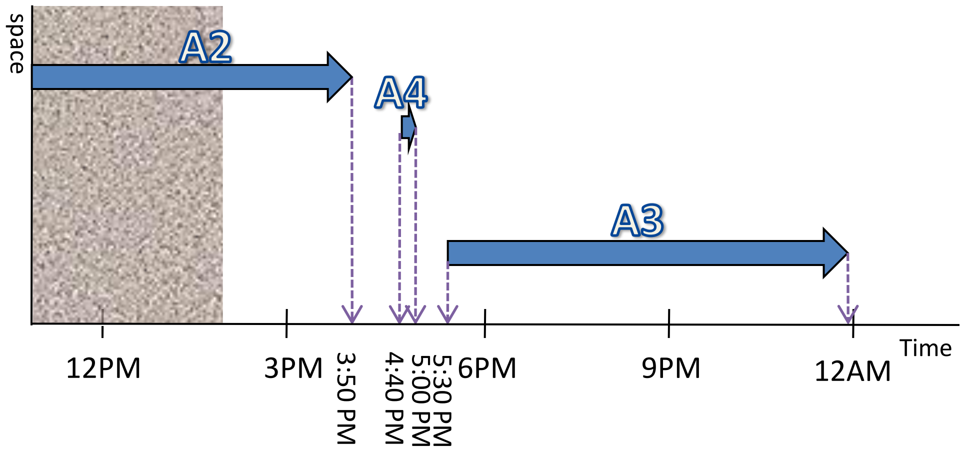
	Start time	Duration	End time
Work	2:00 PM	2 hr 20 min	4:20 PM
Post office	4:40 PM	20 min	5:00 PM
Home	5:30 PM	6 hr 30 min	12:00 AM



- Will travel cost change affect remaining schedule?
  - A traveler receives roadway construction information at 2 PM, become aware of tentative delayed travel time from 4 PM to 5 PM

Experiment : Network Condition Change





id	activity	Start time	Duration	End time
A2	Work	2:00 PM	2 hr 20 min	4:20 PM
A4	Post office	4:40 PM	20 min	5:00 PM
A3	Home	5:30 PM	6 hr 30 min	12:00 AM

id	activity	Start time	Duration	End time
A2	Work	2:00 PM	1 hr 50 min	3:50 PM
A4	Post office	4:40 PM	20 min	5:00 PM
A3	Home	5:30 PM	6 hr 30 min	12:00 AM

Conclusions

- Proposed model solves for utility-maximizing sequence, start time and duration of remaining activities
- Consistency between activity scheduling decision and time-varying travel cost
- Integrated with DTA model *DynusT*
- Further tested within an integrated ABM-DTA framework

Thank you