A DRIVING OPERATIONAL BEHAVIOR ANALYSIS BASED ON THE STATE TRANSITION MODEL FOR AUTONOMOUS VEHICLES

Yasuhiro, Akagi*, Pongsathorn Raksincharoensak*
* Tokyo University of Agriculture and Technology
akagi-y@cc.tuat.ac.jp

Introduction

Shared control / Cooperative driving

is a practical method for complicated traffic environment like urban areas.

Role of systems:

instruct the safe driving plan
trough display, sound, haptic and force feedback HMI devices.

Role of human drivers:

follow (override) the system instructions
to keep safety.

Complementing the weak points of
both the human and systems realizes safe driving.

Problems

If systems present the multiple operational orders to the driver through multiple HMI devices at the same time.

HUD shows slow down operation.

Steering wheel gives force feedback for avoidance operation.

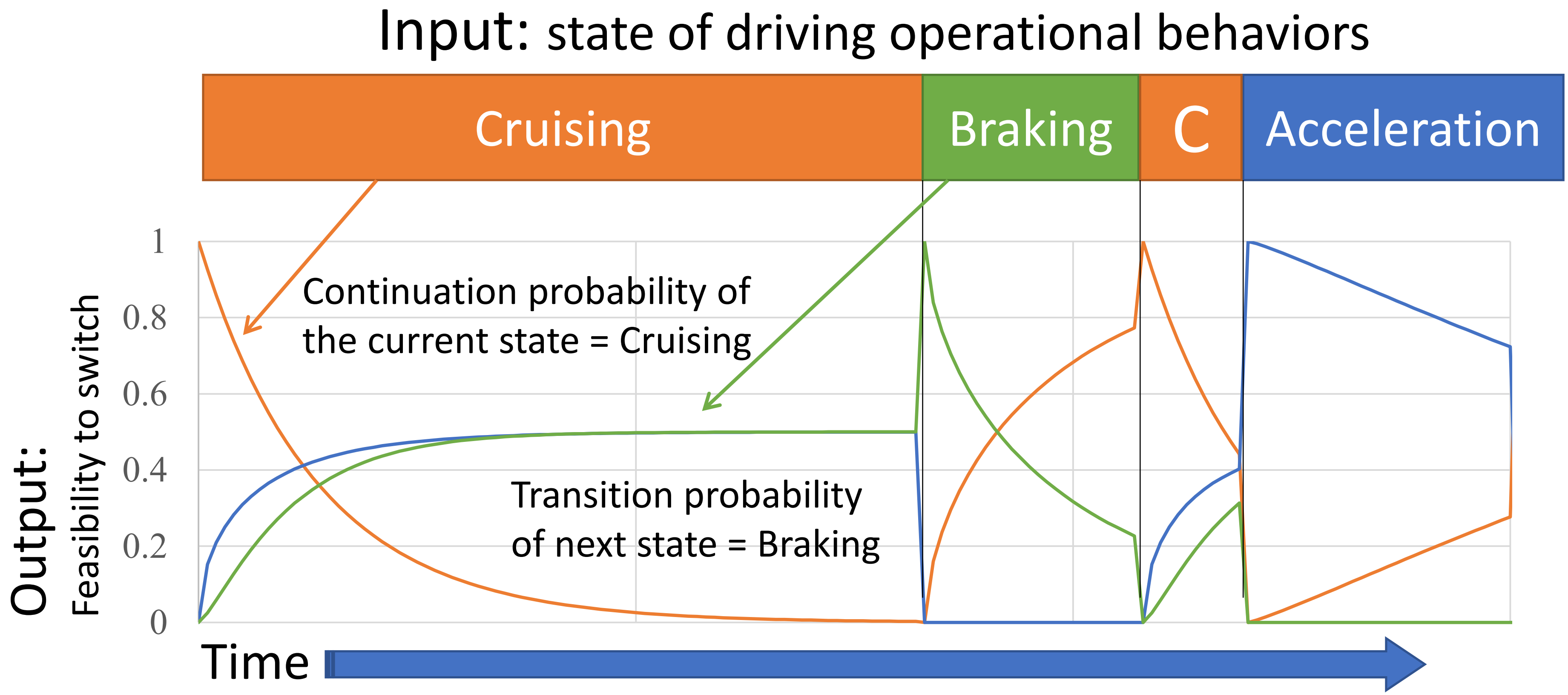
Sound explains the situations.

Gas pedal gives haptic feedback to release.

It is difficult for the driver to understand the multiple kind instructions in a short time.

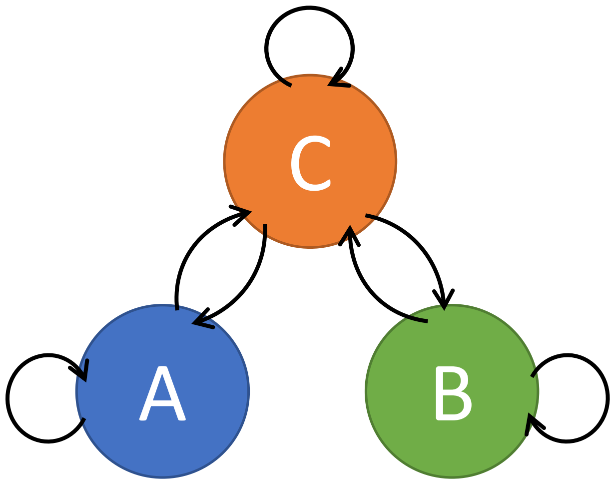
Goal

An evaluation model gives the feasibility of switching driving behaviors by using the state transition model.



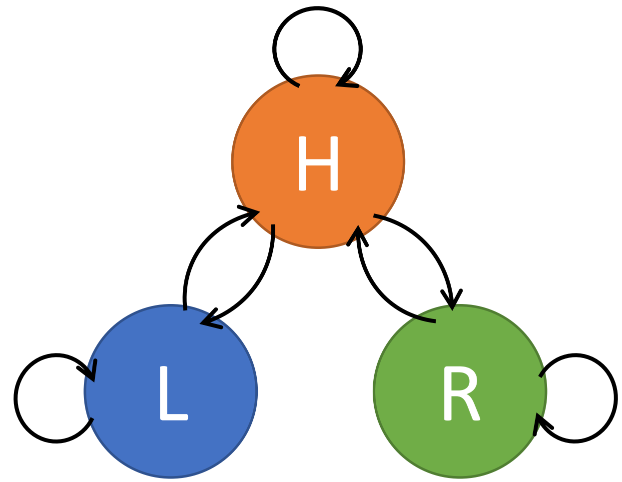
State transition model of driving behaviors

Longitudinal state transition model



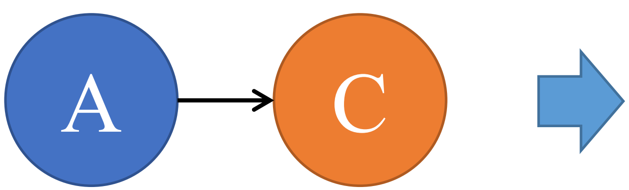
A:Acceleration
B:Braking
C:Cruising

Lateral state transition model



L:Left
R:Right
H:Holding

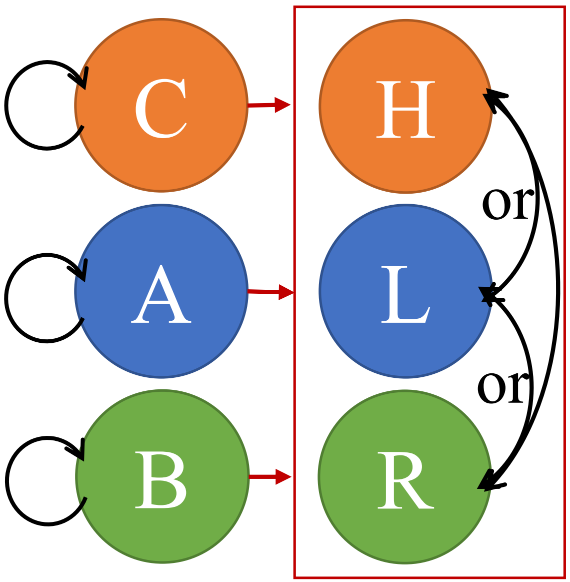
State transition probability is denoted by the conditional probability model.



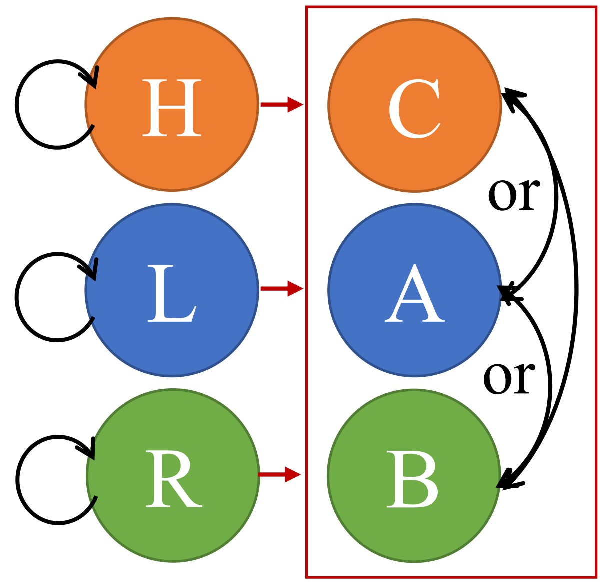
$P(C|A)$

State transition model of driving behaviors

State transition model of the steering wheel operations when a foot pedal is operated.



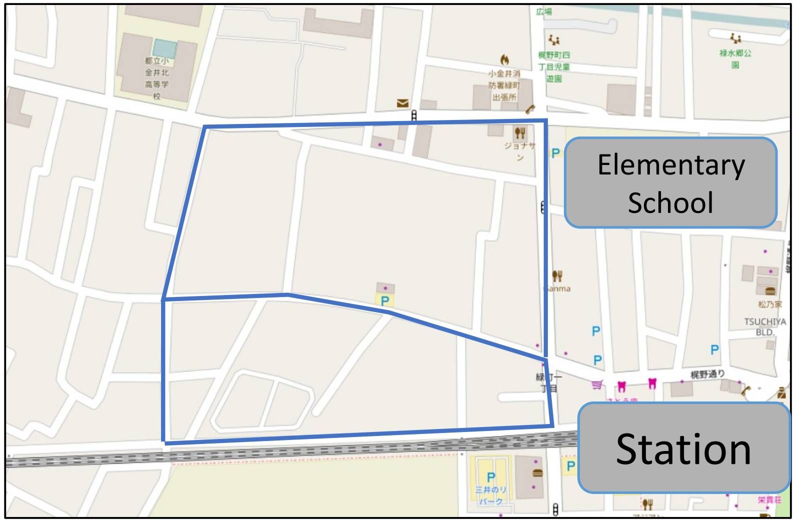
State transition model of the foot pedal operations when a steering wheel is operated.



This model represents the co-occurrence probability of the state transition of a driving interface (foot pedal or steering wheel) while the driver is operating another interface.

Data collection

Subjects ： 6 instructors of a driving school
Time ： 9 am, 4 pm
Route ： 4 km × 2 sessions
Area : Residential area near the train station



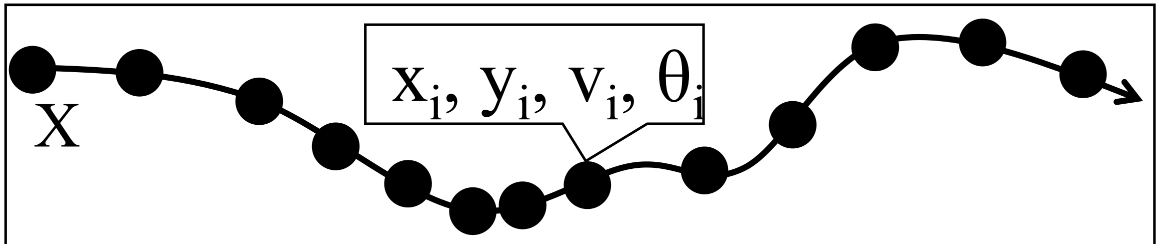
Data types:

- GNSS positioning
- Steering wheel angle
- Gas pedal operation
- Brake pedal operation
- Velocity
- Acceleration
- Yaw rate

https://www.openstreetmap.org/#map=17/35.70374/139.51991

Initial labeling of driving behaviors

The input motion data is divided every 0.1 second to classify.



The pedal control state is decided with the acceleration value a.

Threshold: $a_t = 0.1\ \mathrm{m/s^2}$

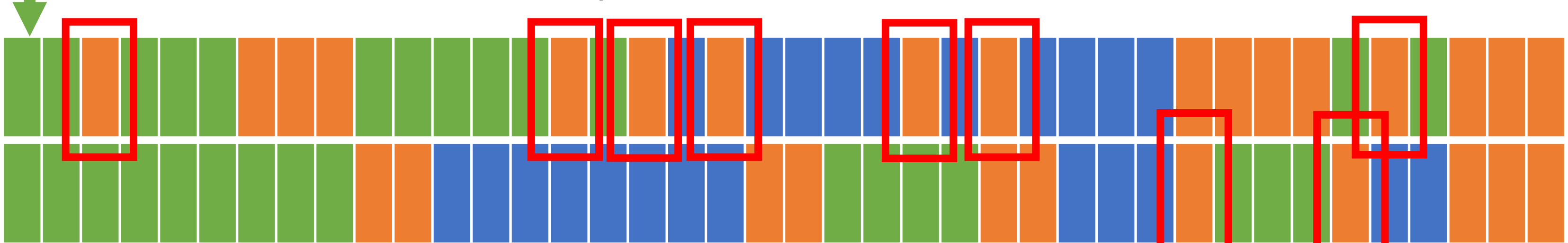
$$S_p(a) = \begin{cases} \text{Acceleration} & (a > a_t) \\ \text{Cruising} & (-a_t \geq a \geq a_t) \\ \text{Braking} & (a < -a_t) \end{cases}$$

The steering wheel operation state is decided with the yaw rate $\dot{\psi}$.

Threshold: $\dot{\psi}_t = 0.05\ \mathrm{rad/s}$

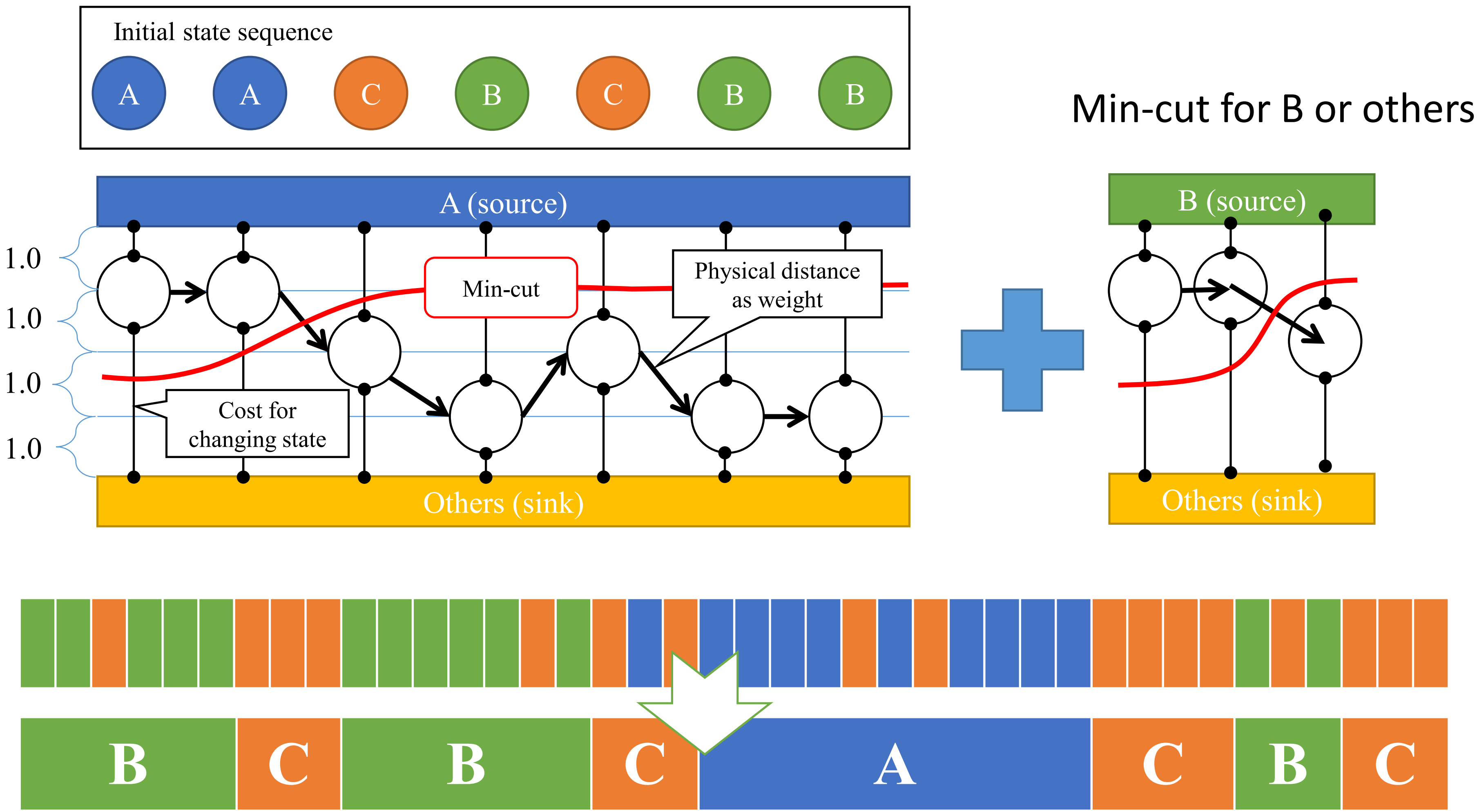
$$S_s(\dot{\psi}) = \begin{cases} \text{Left} & (\dot{\psi} < -\dot{\psi}_t) \\ \text{Holding} & (-\dot{\psi}_t \geq \dot{\psi} \geq \dot{\psi}_t) \\ \text{Right} & (\dot{\psi} > \dot{\psi}_t) \end{cases}$$

Initial label list: many discontinuous state transitions.



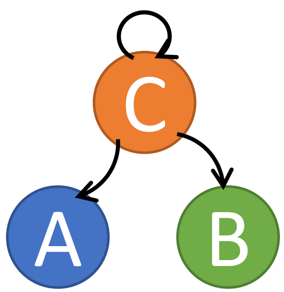
Integration of the driver states based on minimum cut algorithm

By applying the minimum cut algorithm,
the driver states are classified in two states.



Probabilistic models of the driver state transition

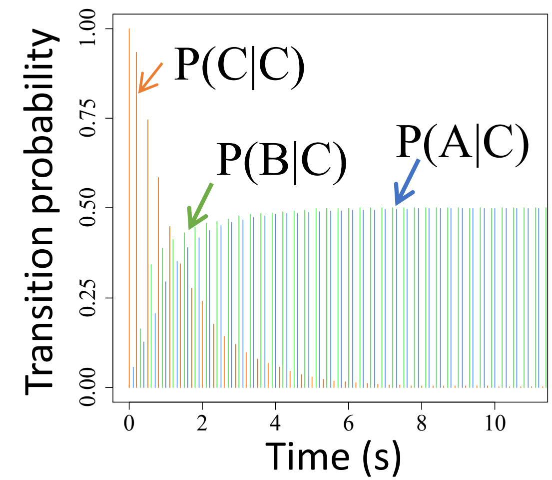
Longitudinal state transition model



Destination state / Source state

	C	A	B
C	$P(C \mid C)$	$P(A \mid C)$	$P(B \mid C)$

Actual state transition probability



Approximation function:

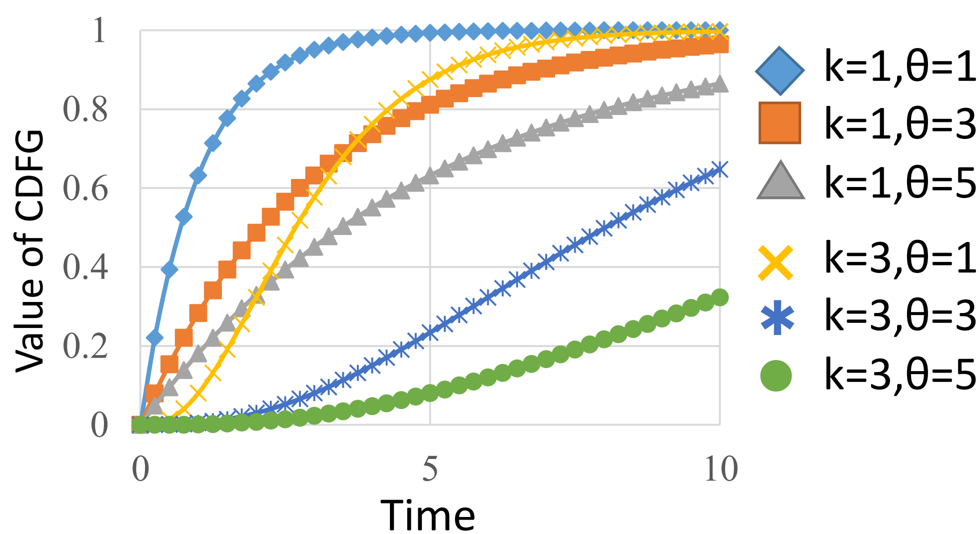
Cumulative distribution function of Gamma distribution (CDFG)

$$CDFG(t,k,\theta) = \frac{\gamma(k,t/\theta)}{\Gamma(k)}$$

t: Continues time of the current state

Γ: Gamma function

γ: Incomplete Gamma function



Results and discussions

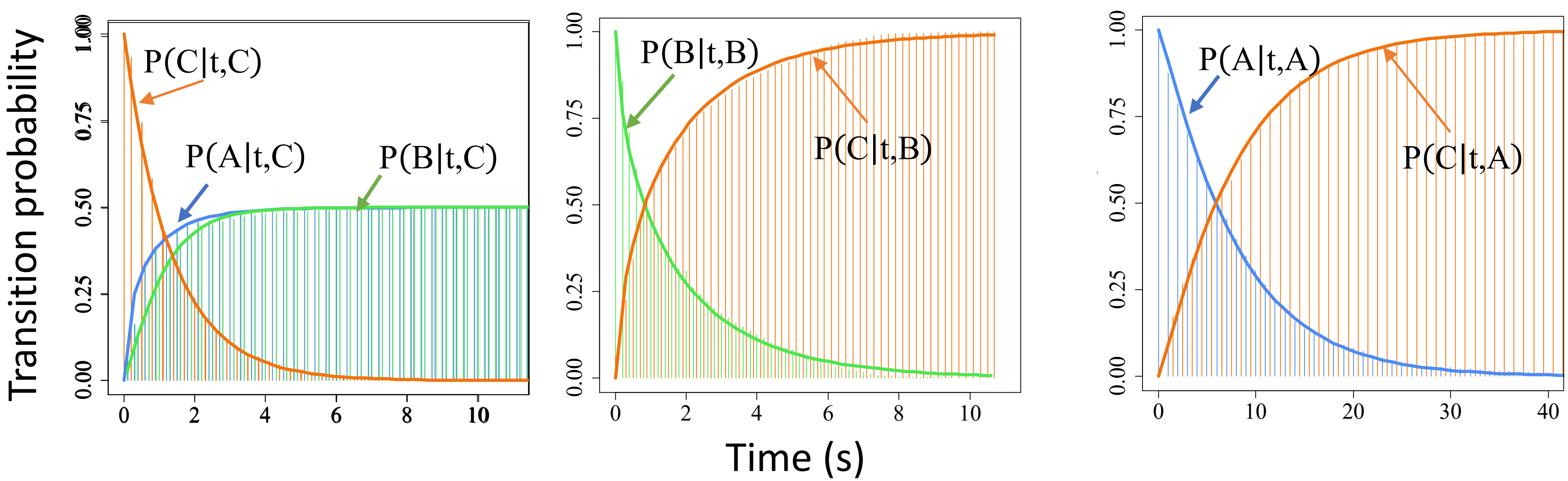
Destination state

Source state	C	A	B
C	P(C|t,C)	P(A|t,C)	P(B|t,C)
A	P(C|t,A)	P(A|t,A)	0
B	P(C|t,B)	0	P(B|t,B)

$$P(A|t,C) = \mathrm{CDFG}(t,k_{ca},\theta_{ca})/2$$
$$P(C|t,C) = 1 - P(A|t,C) - P(B|t,C)$$
$$P(B|t,C) = \mathrm{CDFG}\left(t,k_{cb},\theta_{cb}\right)/2$$

$$P(C|t,A) = \mathrm{CDFG}(t,k_{ac},\theta_{ac})$$
$$P(A|t,A) = 1 - P(C|t,A)$$

$$P(C|t,B) = \mathrm{CDFG}\left(t,k_{bc},\theta_{bc}\right)$$
$$P(B|t,B) = 1 - P(C|t,B)$$



Results and discussions

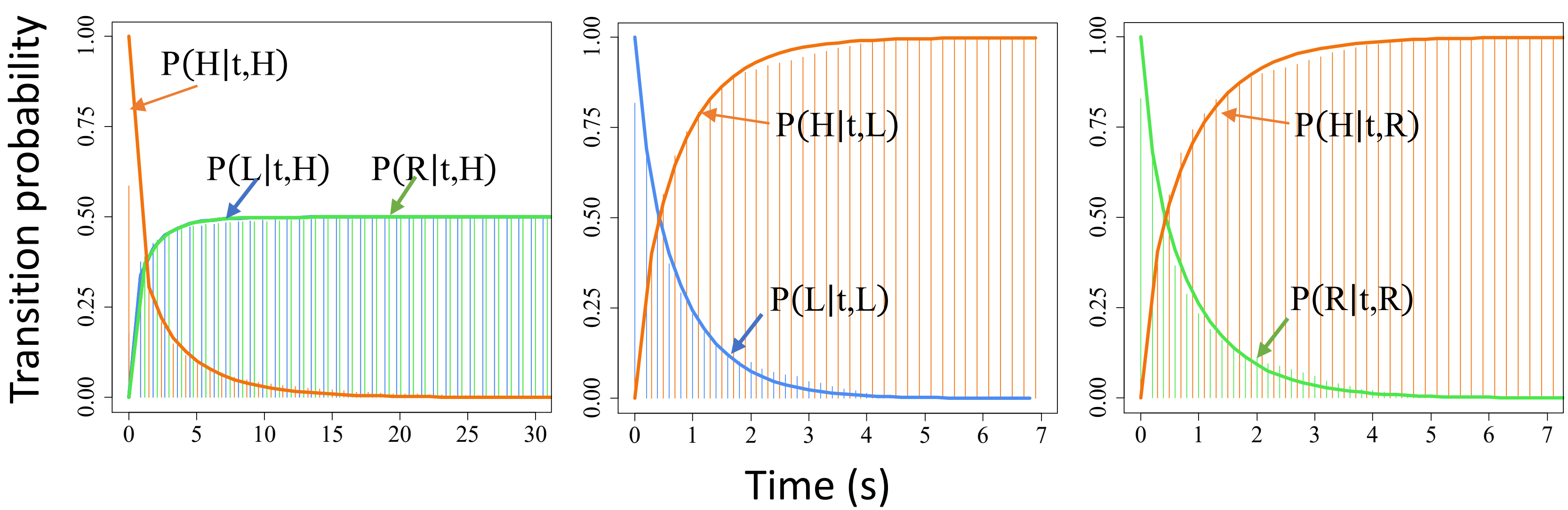
Destination state

Source state	H	L	R
H	P(H|t,H)	P(L|t,H)	P(R|t,H)
L	P(H|t,L)	P(L|t,L)	0
R	P(H|t,R)	0	P(R|t,R)

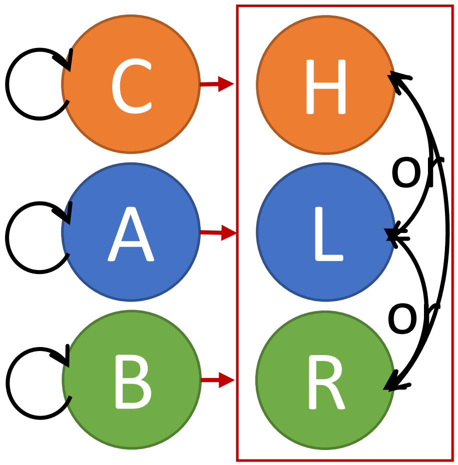
$$P(L|t,H) = CDFG(t,k_{hl},\theta_{hl})/2$$
$$P(H|t,H) = 1 - P(L|t,H) - P(R|t,H)$$
$$P(R|t,H) = CDFG(t,k_{hr},\theta_{hr})/2$$

$$P(H|t,L) = CDFG(t,k_{lh},\theta_{lh})$$
$$P(L|t,L) = 1 - P(H|t,L)$$

$$P(H|t,R) = CDFG(t,k_{rh},\theta_{rh})$$
$$P(R|t,R) = 1 - P(H|t,R)$$



Results and discussions



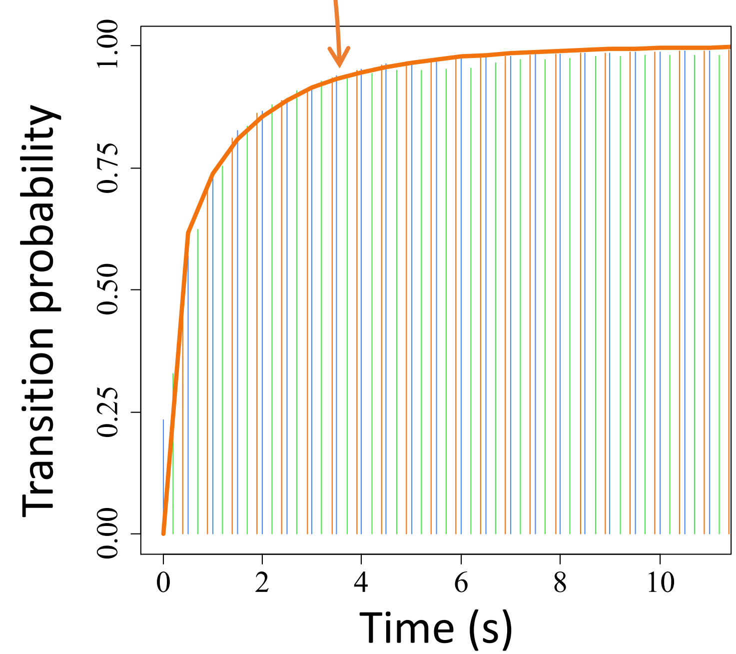
	Lat^C
C	$P(Lat^c, C \mid t, Lat, C)$
A	$P(Lat^c, A \mid t, Lat, A)$
B	$P(Lat^c, B \mid t, Lat, B)$

$Lat = \{H \cup L \cup R\}$

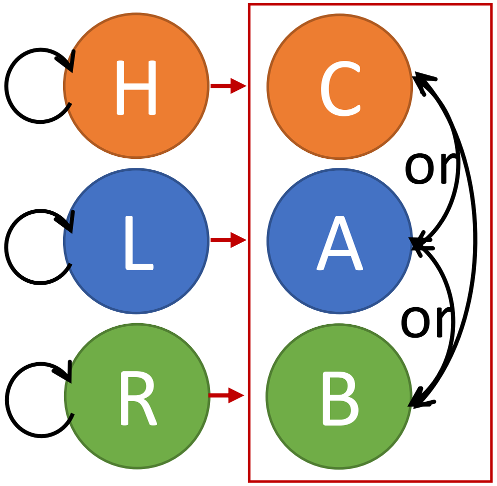
$$= CDFG(t, k_{lat}, \theta_{lat})$$

State transition model of the steering wheel operations when a foot pedal is operated.

Feasibility of switching the steering wheel operation is not related to the operation type of the pedals.



Results and discussions



	Lon^C
H	$P(Lon^c, H \mid t, Lon, H)$
L	$P(Lon^c, L \mid t, Lon, L)$
R	$P(Lon^c, R \mid t, Lon, R)$

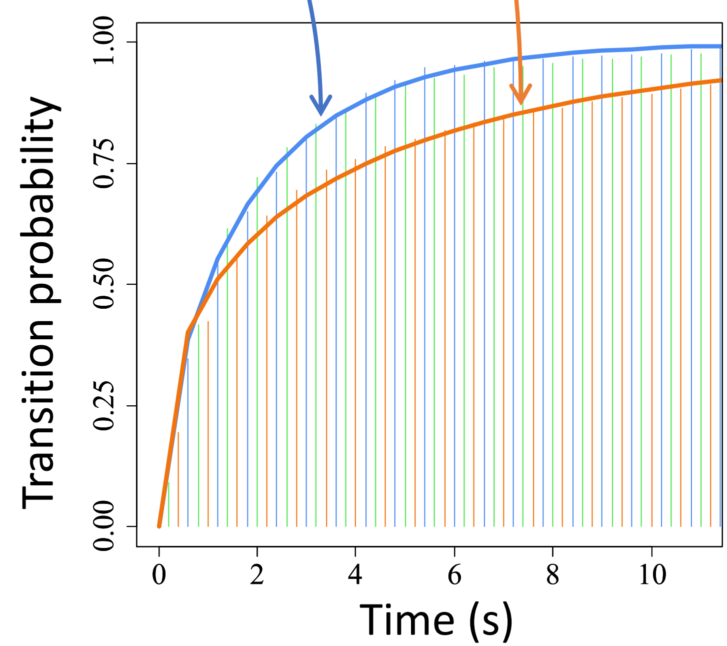
Lon={C U A U B}

$= CDFG(t, k_{lonH}, \theta_{lonH})$

$= CDFG(t, k_{lonLR}, \theta_{lonLR})$

State transition model of the foot pedal operations when a steering wheel is operated.

Feasibility of switching the foot pedal operation depends on the operation type of the steering wheel.



Results and discussions

Parameters of the state transition probabilities

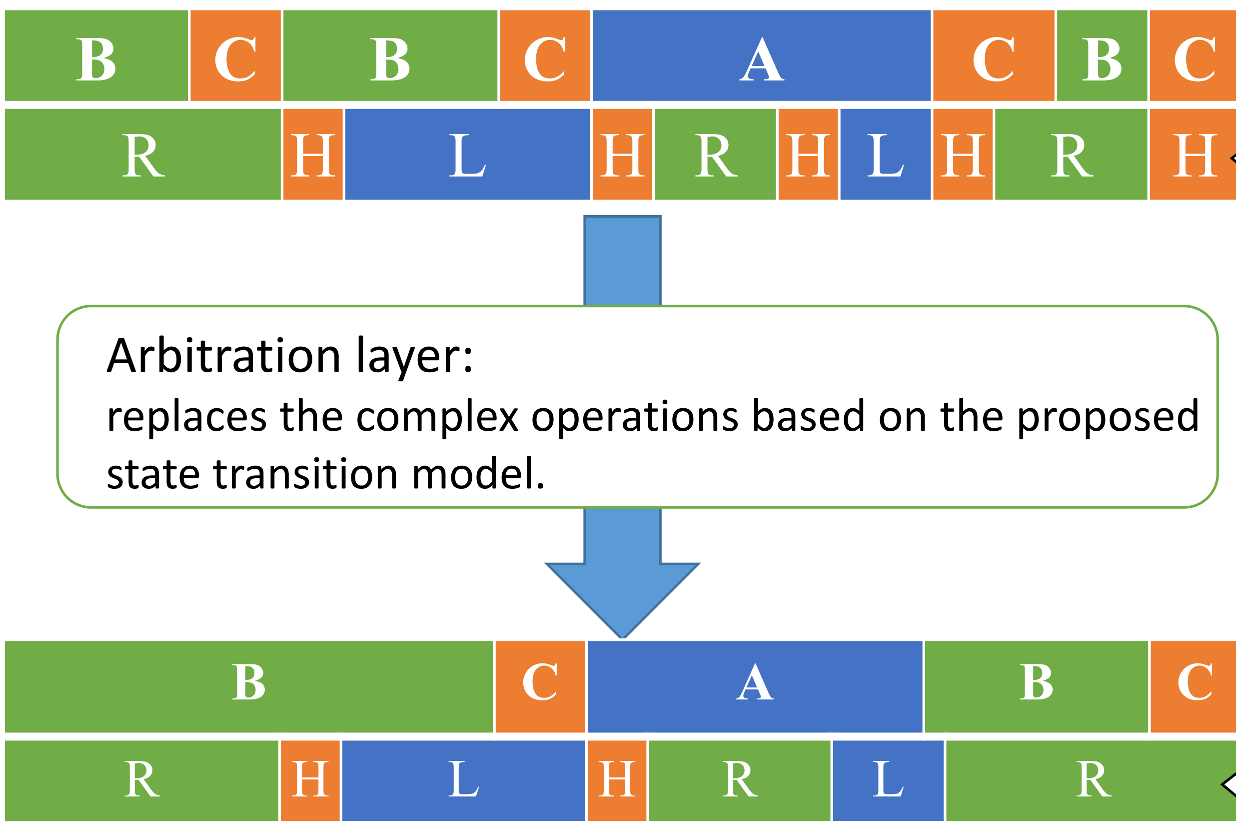
Longitudinal control state			Lateral control state		
transition	K	θ	transition	K	θ
P(A|t,C)	0.5	1.31	P(L|t,H)	0.43	2.27
P(B|t,C)	1.31	0.82	P(R|t,H)	0.43	2.27
P(C|t,A)	1.18	6.81	P(H|t,L)	0.75	0.95
P(C|t,B)	0.58	2.8	P(H|t,R)	0.68	1.12
Longitudinal co-occurrence state			**Lateral co-occurrence state**		
$P\left(Lat^C,C \middle\| t,Lat,C\right)$ $P\left(Lat^C,A \middle\| t,Lat,A\right)$ $P\left(Lat^C,B \middle\| t,Lat,B\right)$	0.31	2.96	$P\left(Lon^C,H \middle\| t,Lon,H\right)$	0.37	9.2
			$P\left(Lon^C,L \middle\| t,Lon,L\right)$ $P\left(Lon^C,R \middle\| t,Lon,R\right)$	0.63	2.84

Application

Behavior Planner for Autonomous Vehicles

which translates the motion plan can be easier to control by the driver.

Input: motion plan generated by a driving support system

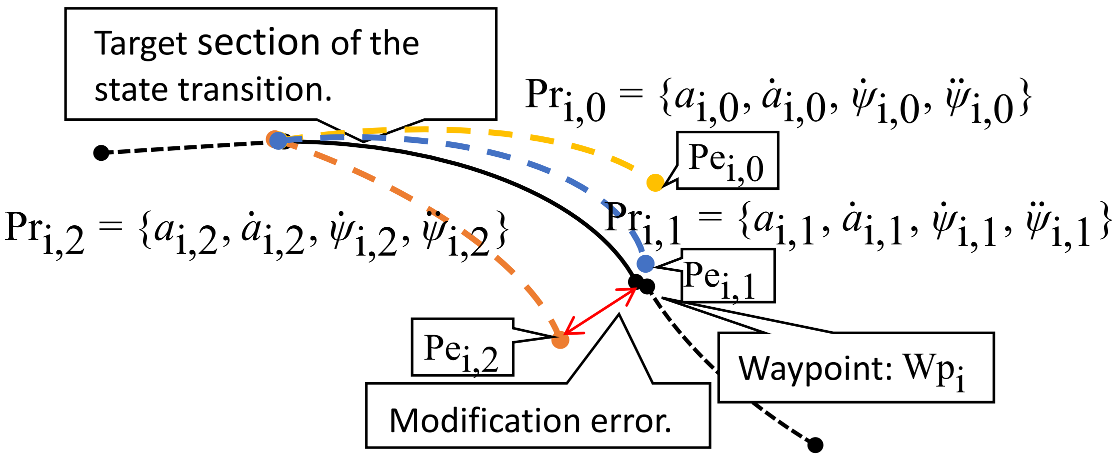


- Frequent
- Simultaneous operation switching

- Reduce switching

Is it possible to follow the original path?

Application

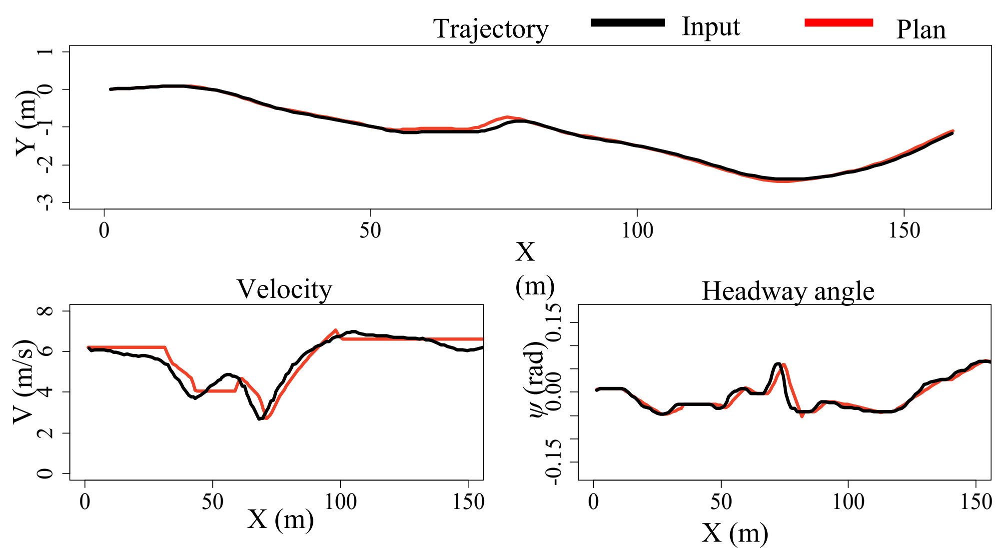


The control parameters are optimized to minimize the sum of the difference from the input path plan.

Results:

Simplification level and path error

Feasibility threshold (%)	Mean error (m)	Standard deviation (m)
0	0.11	0.20
5	0.13	0.30
10	0.17	0.41
15	0.59	1.90
20	1.22	3.87
25	1.97	5.46



Conclusion

- The state transition models of the driving operations are proposed.
- The feasibility of the operation switching of drivers can be approximated by using Cumulative distribution function of Gamma distribution.
- The driving behavior planner for the arbitration layer between the motion planner and HMI devices is shown as the application.

- As a future work, the comparative experiments of the acceptability of HMI devices equipped with/without the arbitration layer will be performed.

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http://www.coi.nagoya-u.ac.jp/en

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