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Design and Multiobjective Optimization of Efficient Vehicle Management Framework for Cyber-Physical Intelligent Transport Systems

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Introduction

Intelligent Transportation System (ITS)

- Information and communication technologies (ICT) are applied in the field of road transport, including infrastructure, vehicles and users, and traffic management and mobility management, as well as for interfaces with other modes of transport [1]
- **Smart transportation**: provides the real-time and reliable delivery of traffic-related information to drivers, e.g., blind spot warnings during lane changing, notification of congestion, and rerouting advise that can help to reduce traffic congestion

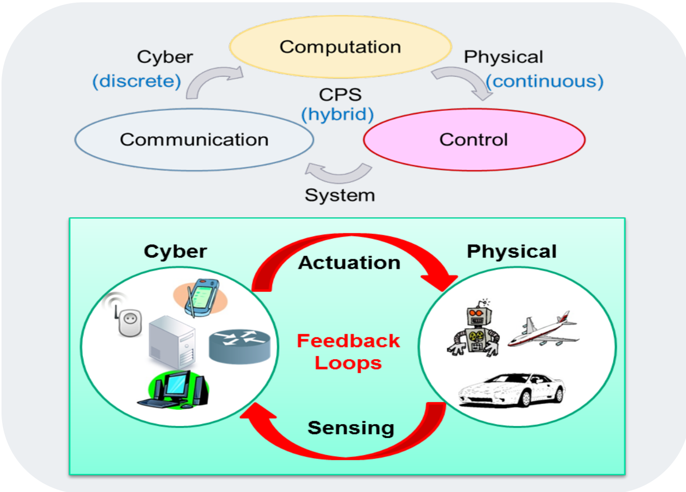
Cyber-Physical systems (CPS)

- a collection of computing devices communicating with one another and interacting with the physical world via sensors and actuators in a feedback loop [2]

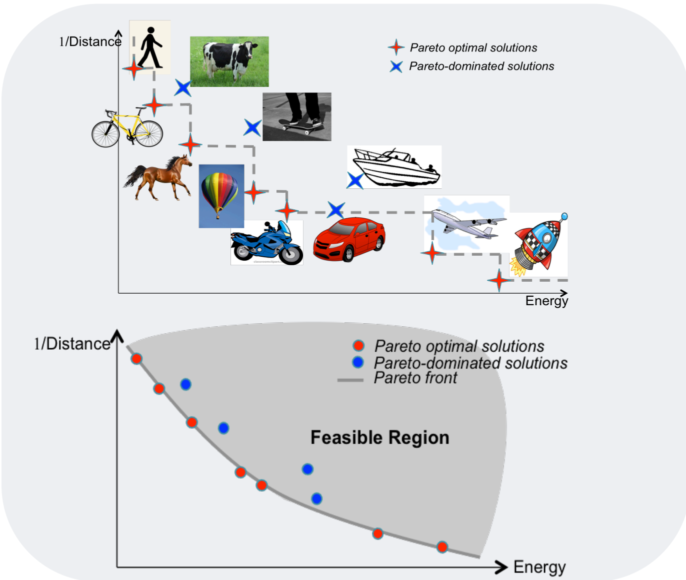
Multiobjective Optimization (MOO)

- Task of finding one or more optimum solutions for an optimization problem involves more than one objectives functions.
- Different solutions may produce trade-offs (conflicting scenarios) among the different objectives
- Goal: To generate these tradeoff which try to satisfy the two or more objectives simultaneously

Components of CPS



Example of MOO



References:
[1] DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010. http://eur-lex.europa.eu [Online Available]
[2] E. A. Lee and S. A. Seshia, Introduction to Embedded System, A Cyber-Physical System Approach, Second Edition, http://LeeSeshia.org [Online Available]

Motivation and Objective

Motivation

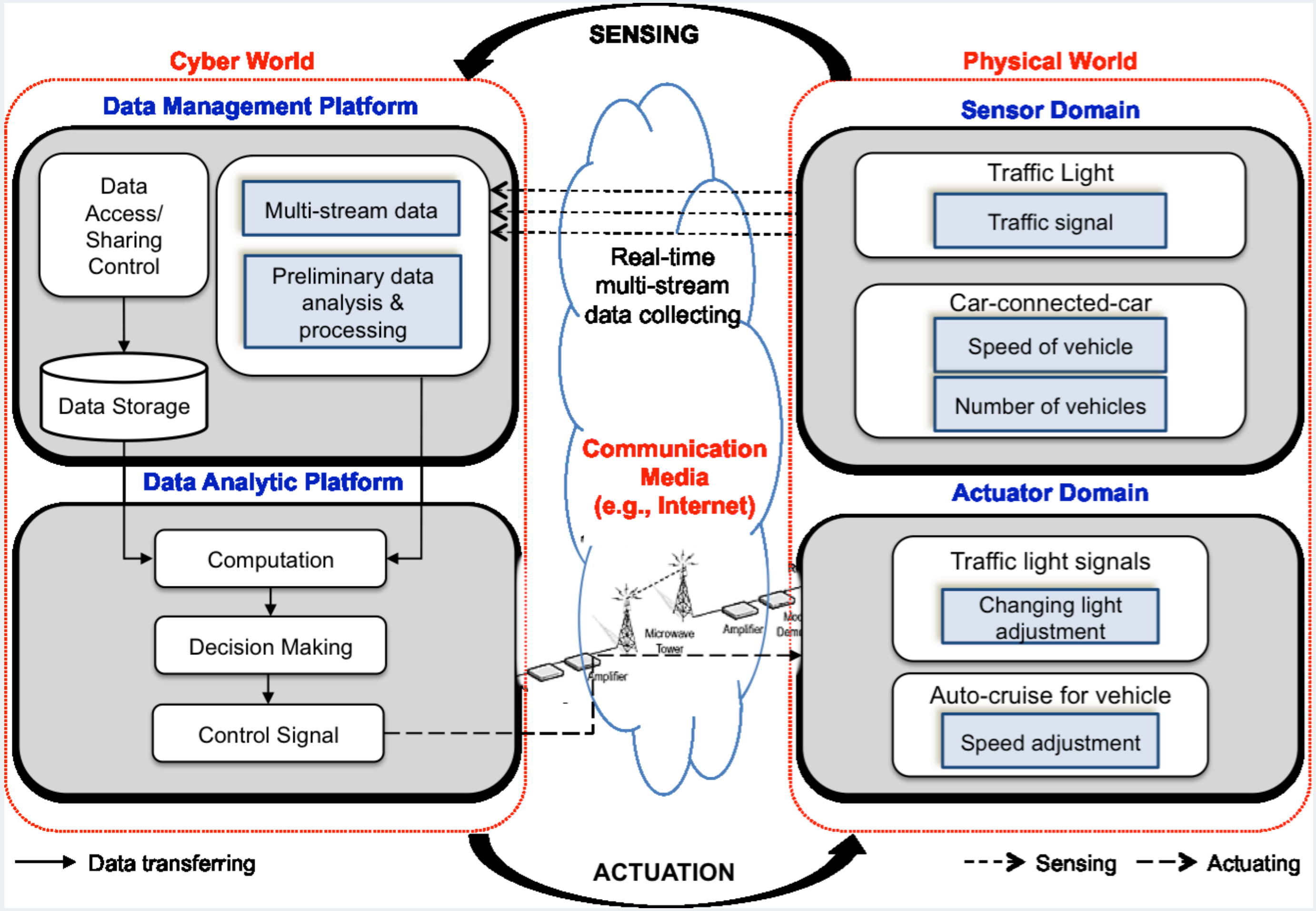
- Many researches had studied on the optimal control for the collision prevention using MOO by converting into many single objective (SO) functions
- With MOO, two or more objectives have to be satisfied simultaneously
  - Driver's behavior and preference of reach destination in the shortest travel time might lead to the highest chance of accident risk on road
- With CPS
  - For efficient vehicle management, the conflicts between driver's preferences like the shortest travel time and the accident risk should be taken into consideration in timely manner for efficient and reliable transportation

Research Objective

- To study the relationship between the models of travel time and accident risk
- To apply Pareto MOO and study the tradeoffs in between the shortest travel time and the potential of accident risk
- To apply the optimal solutions into the efficient vehicle management framework for cyber-physical ITS

Proposed Framework

Next generation ITS is able to communicate with other vehicle and roadside infrastructure by exchanging information such as speed and distance between the vehicles, number of vehicles, and status of traffic light in real-time, efficient, reliable, safe manners

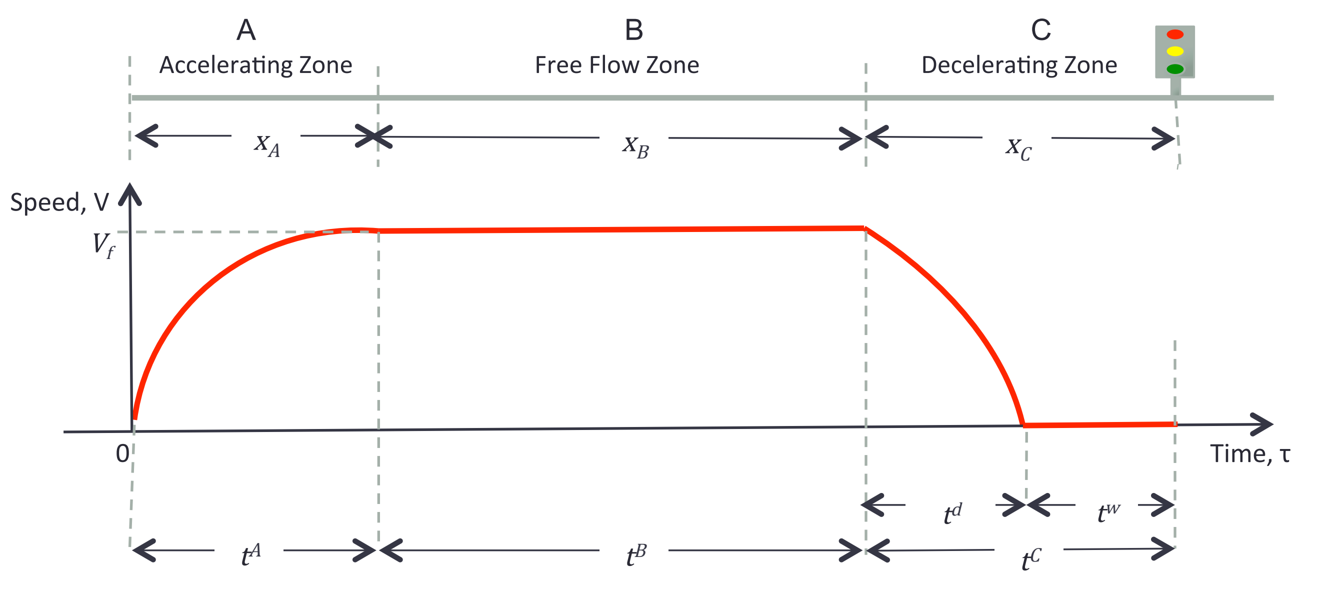


Efficient Vehicle Management (EVM) framework for cyber-physical ITS

Travel Time Model

We adopt R. Akcelik and M. Besley models (acceleration and deceleration models with non-constant acceleration/deceleration) into our travel time model

- Considering free-flow traffic, vehicle move from stationary, accelerate and move in a driver's preference speed in free-flow zone, and finally stop for the red traffic light/destination
- Total travel time can be measured by parts



x_A : Accelerating distance
x_B : Free-speed distance
x_C : Decelerating distance
V_f: Free flow speed
t^A : Accelerating time
t^B : Free-speed time
t^C : Time of traffic light in red
t^d : Decelerating time
t^w : Waiting timez

Travel time, T:

$$T = t^A + t^B + t^C$$
$$= t^A + t^B + t^d + t^w$$

$$t^A = \frac{V_f}{a_{aa}} \qquad t^B = \frac{x^B}{V_f} = \frac{D - x^A - x^C}{V_f}$$

where a_{aa} and a_{ad} is average acceleration and deceleration rate (m/s^2)

$$t^d = -\frac{V_f}{a_{ad}} \qquad t^w = t^C - t^d = t^C + \frac{V_f}{a_{ad}}$$

where $D = x_A + x_B + x_C$

where t^C is the time length of red traffic light

Travel time: $T_i = \sum_{k=1}^{K+1} \left(t_{i,k}^A + t_{i,k}^B + t_{i,k}^d + t_{i,k}^w\right)$

where K is the total number of traffic lights

References:
R. Akcelik and M. Besley, "Acceleration and deceleration models", 23rd Conference of Australian Institute of Transport Research (CAITR 2001), Monash University, Melbourne, Australia, December 2001.

Accident Risk Model

We adopt and refine M.A.S. Kamal risk indicator to become our accident risk model

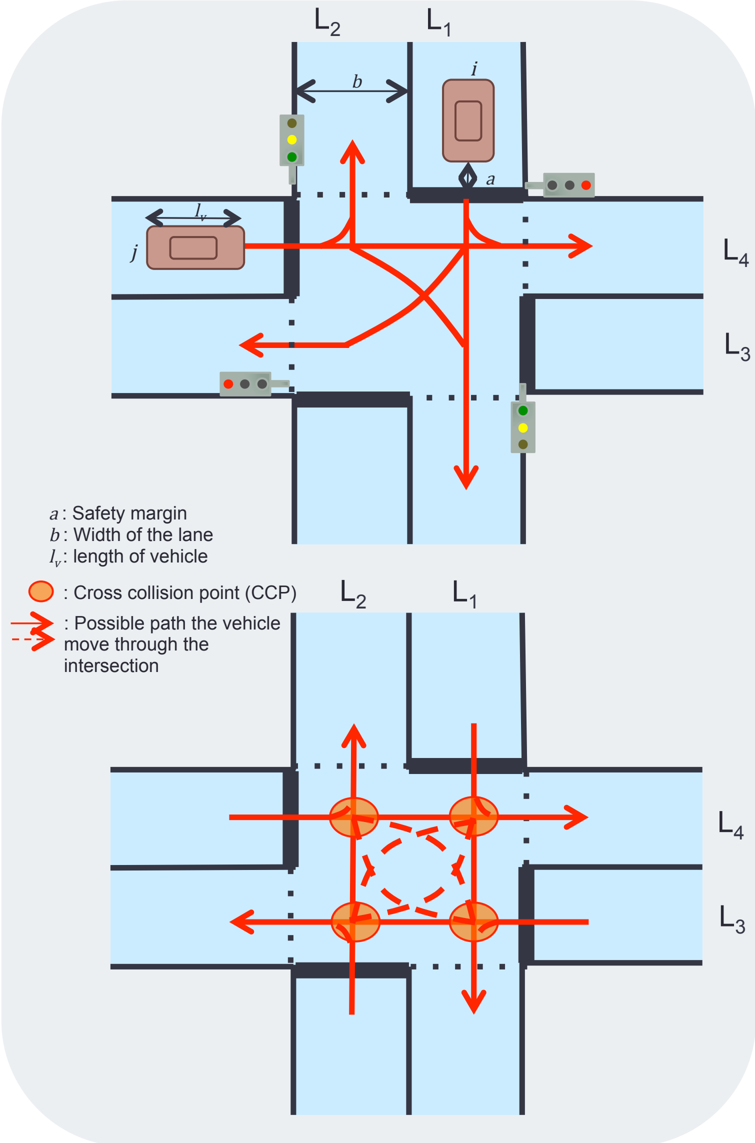


Table 1:
Changing of traffic light for each lane A, B, C and D

A	B	C	D
G	G	R	R
Y	Y	R	R
R	R	G	G
R	R	Y	Y
G	G	R	R
Y	Y	R	R
R	R	G	G

G: Green
Y: Yellow
R: Red

- Rule of the traffic light at the cross intersection
  - Vehicles allow to go straight or turn left (A→D, B→C, C→A,D→B) or turn right (A→C, B→D, C→B,D→A)
  - Green: vehicles can go straight or turn with preference speed
  - Yellow: vehicles have to slow down and stop, or go straight/turn before traffic light turn into red
  - Red: vehicles have to stop

Accident Risk Function:

$$F_{i,j}(t) = H\delta_{\phi_i,\phi_j} e^{-(\alpha_i(x_i(t)+p_{\phi_i\phi_j})^2+\alpha_j(x_j(t)+p_{\phi_i\phi_j})^2)}$$

where

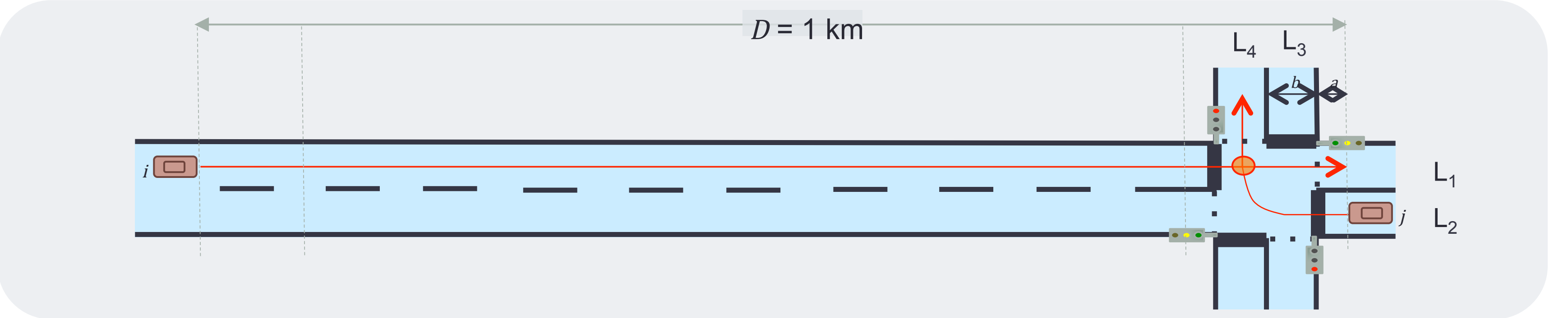
$F_{i,j}(t)$	: Risk function
H	: Highest possible risk of collision
δ_{ϕ_i,ϕ_j}	: CPP state (1: CPP, 0: otherwise)
α_i , α_j	: Positive constant
$x_i(t)$, $x_j(t)$	: Position of vehicle
$p_{\phi_i\phi_j}$, $p_{\phi_i\phi_j}$	: Distances of the CCP from the lane l_i and l_j
ϕ_i , ϕ_j	: Turning status

Accident risk between all the vehicles:

$$\sum_{i=1}^{N-1}\sum_{j=i+1}^{M} F_{i,j}(t)$$

References:
Md. Abdus Samal Kamal, et al., “ A Vehicular Coordination Scheme for Smooth Flows of Traffic Without Using Traffic Light”, IEEE Transaction on Intelligent Transportation Systems, Vol. 16, No. 3, June 2015, pp. 1136-1147.

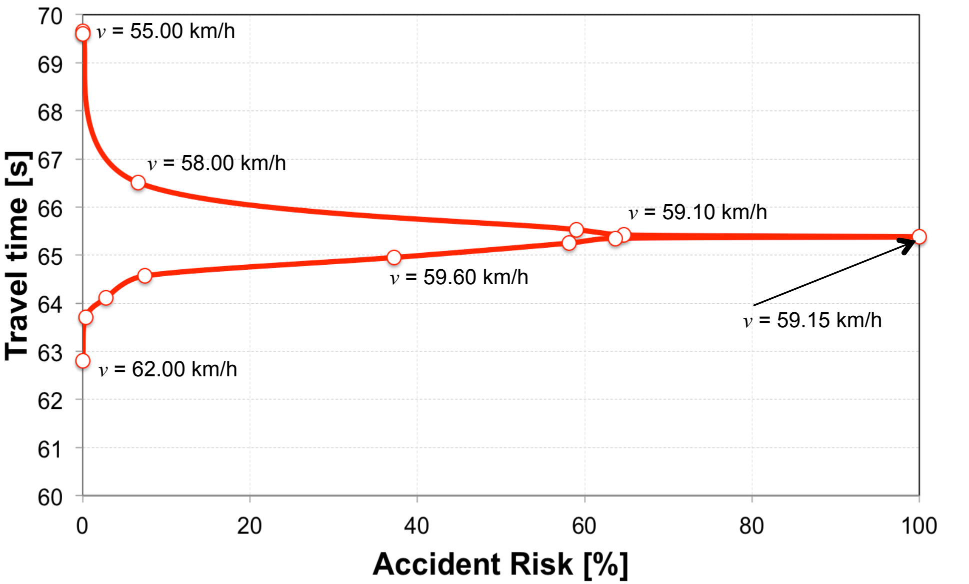
Calculation Example



Scenario

- Free-flow condition, the vehicle i move through the lane L_1 from stationary and the destination is the a m after the intersection
- At the intersection, vehicle i will go straight whereas the vehicle j will turn right from L_2 to L_4

Parameter	Value
Total travel distance, D	1000 m
Safety margin, a	2 m
Width of lane, b	3 m
Length of vehicle, l_v	5 m
H	100
α (for all vehicles)	0.005
Turning status, ϕ_i	$L_1 0$ (straight)
Turning status, ϕ_j	$L_2 2$ (turn right)
$x_j(t) = l_v/2$	2.5 m
$p_{L_1 0, L_2 2} = b/2$	1.5 m
$p_{L_2 2, L_1 0} = b\left(1/2 + \sqrt{2}\right)$	5.743 m
Average acceleration, a_{aa}	1.5 m/s[2]



Discussion & Concluding Remarks

- 2 models of objective function are introduced
  - ✓ Travel time model: To measure the travel time
  - ✓ Accident risk model: To measure the potential collision risk of a vehicle with other vehicles at the intersection
- Conflict between two objective functions: When a vehicle moves at the high speed for shortest travel time, it may poses to the highest potential collision risk with other vehicle
- Work in progress! This research is still in the initial stage
- Next, the tradeoff solutions between two objective functions will be found by applying Pareto MOO
  - ✓ Hypothesis: Speed of vehicle plays a significant role
- The models and optimum result get from the MOO can be applied to the proposed framework of efficient vehicle management

Future Work

- Short-term:
  - ✓ To apply Pareto MOO to find the tradeoffs or optimum solutions of two objective functions using evolutionary algorithm
  - ✓ To study the two objective functions for uninterrupted and interrupted traffic
- Long-term:
  - ✓ To build a simulator for the proposed efficient vehicle management framework