Analysis of the effect of road surface conditions and rutting on vehicle dynamics using CARSIM

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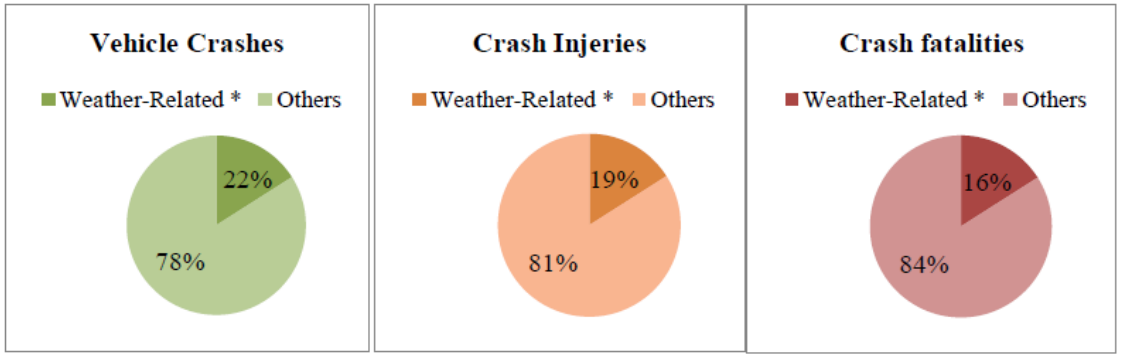
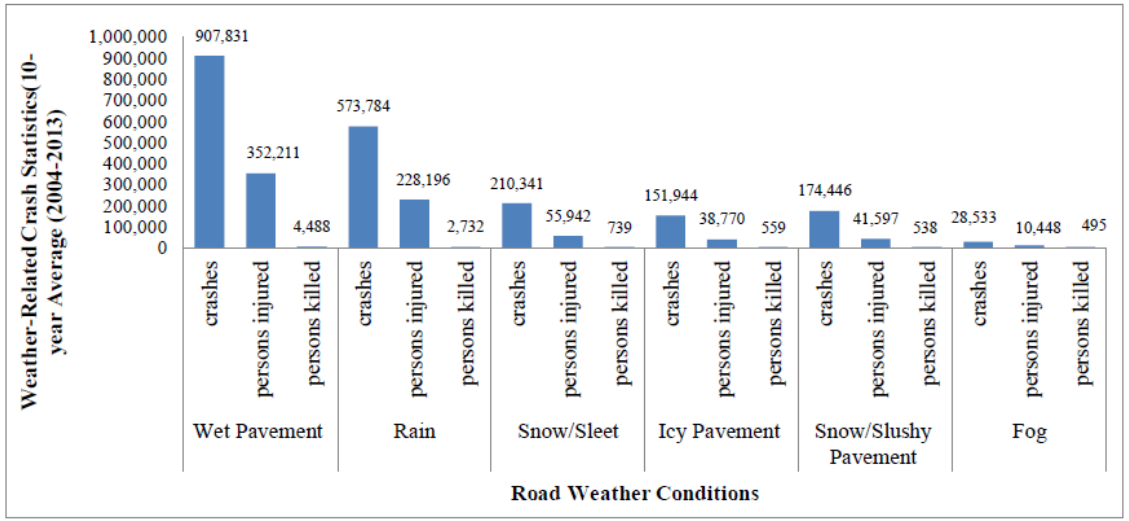
Introduction

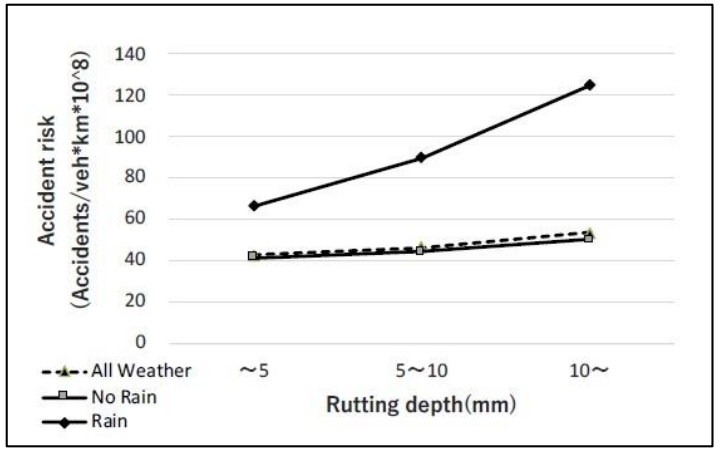


Note: "Weather-Related" crashes are those that occur in the presence of adverse weather and/or slick pavement conditions



Weather-Related Crash Statistics (10-year), USA

Kordani et. al. 2018, http://dx.doi.org/10.28991/cej-030967



Rutting depth vs. accident risk in Japan
Tsubota et al., 2019, https://doi.org/10.2208/jscejipm.75.I_1081

- Accident ratio related to bad weather and/or road surface conditions is high.

- Lane change, obstacle avoidance in rutting + wet, snow or icy road surfaces => vehicle spinning and uncontrollable driving path => may cause serious accidents.

- Understanding vehicle dynamic behaviors in such conditions is important to provide proper road design, maintenance and repair to ensure safety driving.

Objectives

This study used CARSIM, a vehicle dynamic simulation software, to model and analyze the yaw motion of a normal car and a light truck in a double-lane-change (DLC) maneuver under different road surface conditions.

Considered conditions

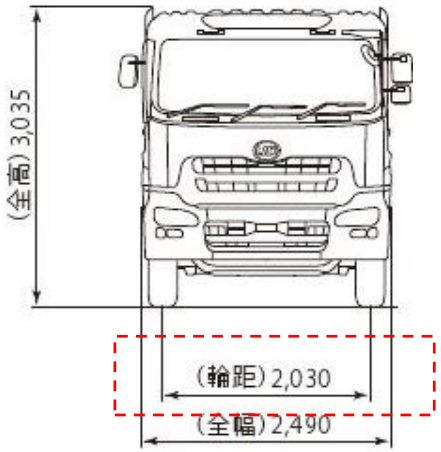
I. Rutting
   - Single rut
   - Dual rut

II. Road surface conditions
   - Pavement: Dry, Wet, Snow and Icy conditions

III. Vehicle
   - Normal car
   - Light truck

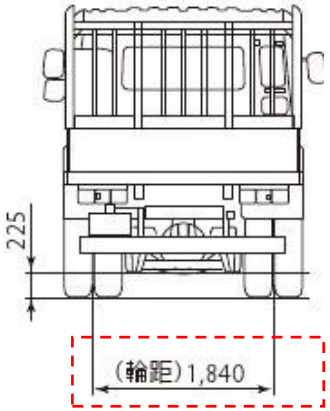
Simulated single and dual ruts

Rut widths were based on the configuration of big box trucks

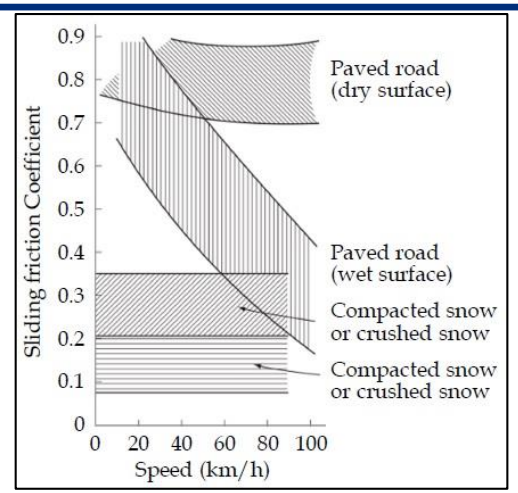


Single rut, 2030 mm

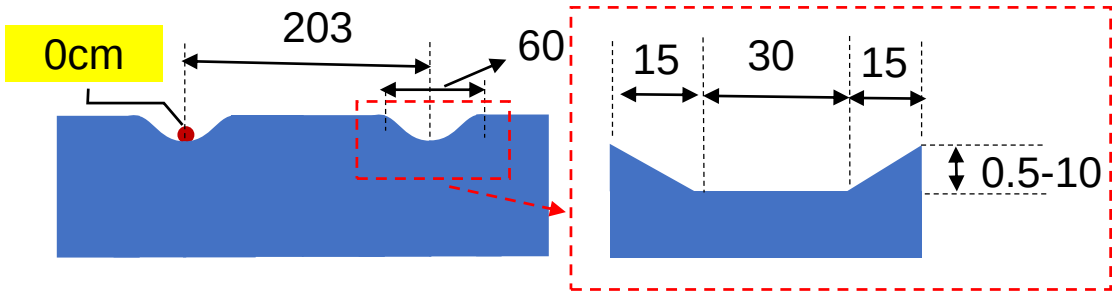
Wheel width
max = 30 cm



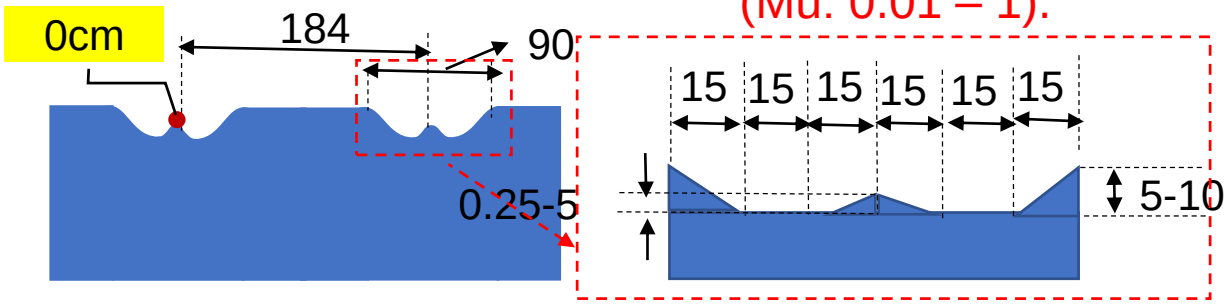
Dual rut, 1840 mm



Friction coefficients
Kageyama et. al. 2021
https://doi.org/10.3390/app12010018
(Mu: 0.01 – 1).



Single rut (cm), Wheel position (●)

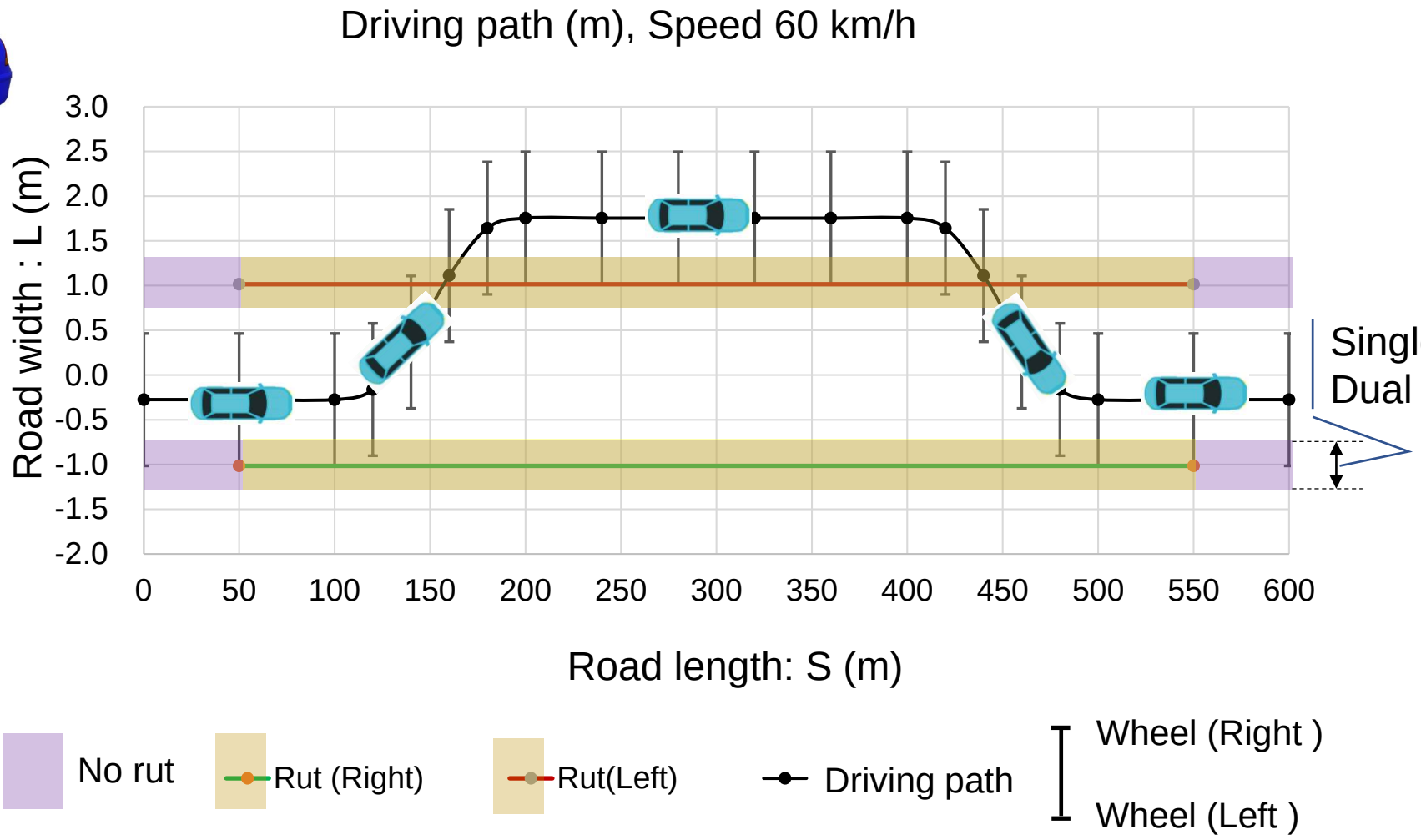


Dual rut (cm), Wheel position (●)

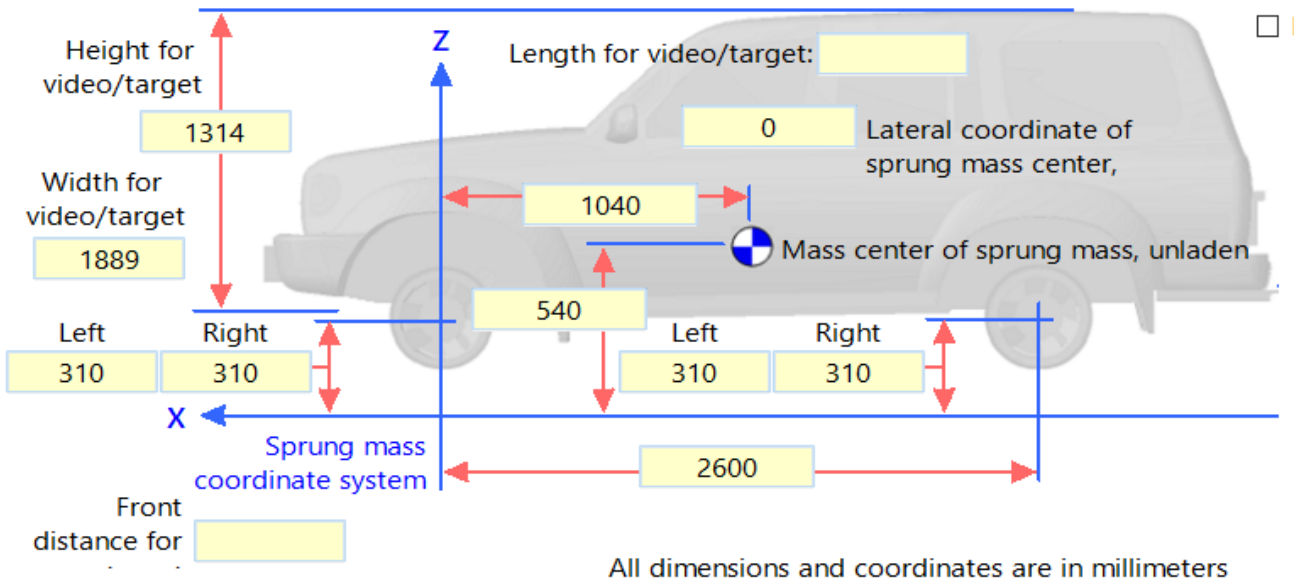
Vehicles and driving paths

Normal car

Light Truck



Normal car



Based on B-Class Hatchback (CARSIM)

The inertia properties below are all for the sprung mass, unladen

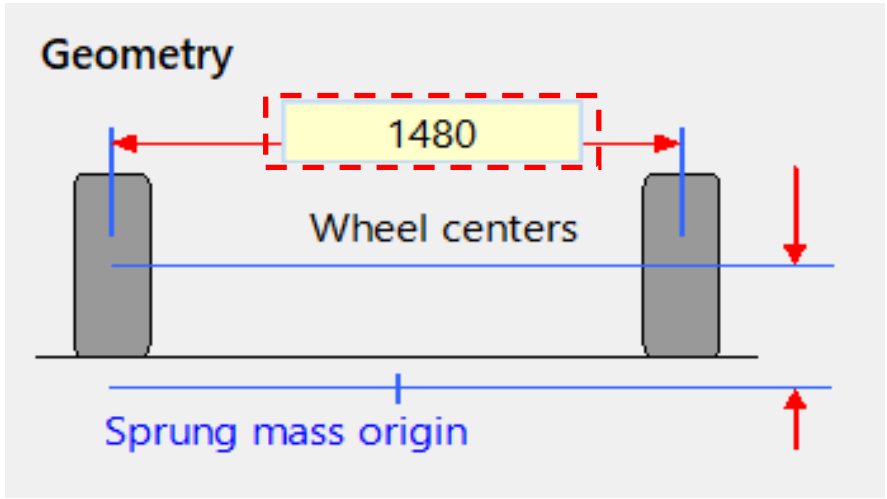
Sprung mass:	1110	kg
Roll inertia	440.6	kg-m2
Pitch inertia	1343.1	kg-m2
Yaw inertia	1343.1	kg-m2
Product (Ixy):	0	kg-m2
Product (Ixz):	0	kg-m2
Product (Iyz):	0	kg-m2

☐ Edit radii of gyration

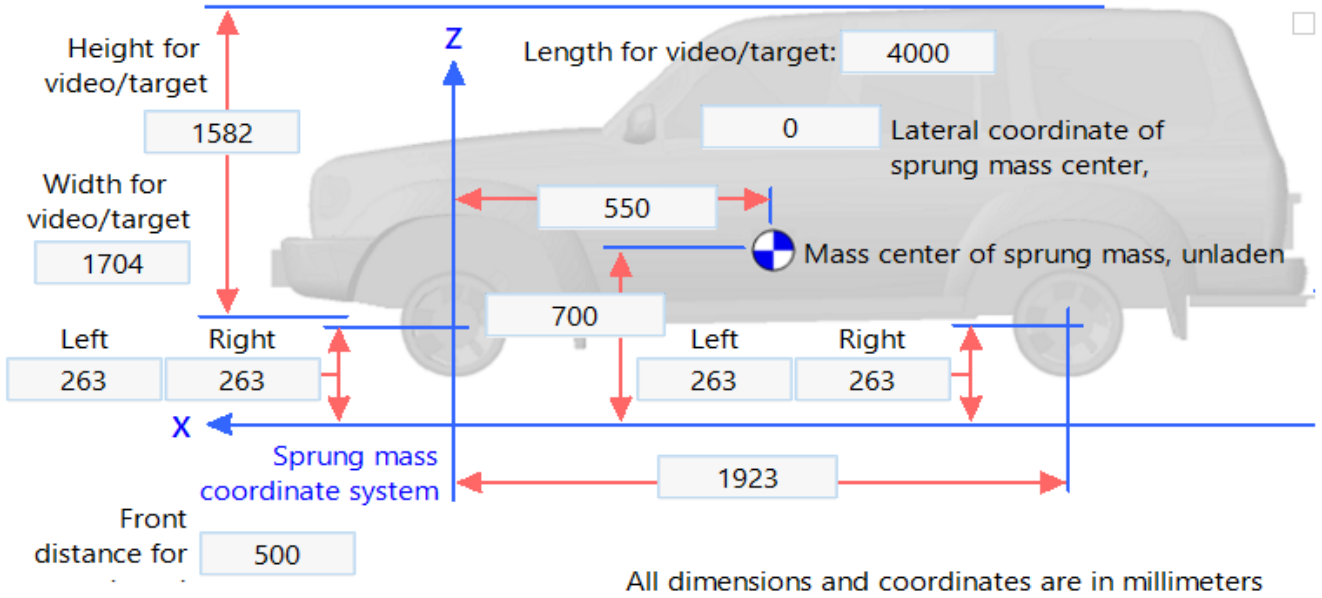
Rx:	0.630	m
Ry:	1.100	m
Rz:	1.100	m

Inertia and radius of gyration are related by the equation: I = M*R*R

Radii must be specified with numbers; formulas are not supported



Light truck



Based on Utility compact Truck (CARSIM)

The inertia properties below are all for the sprung mass, unladen

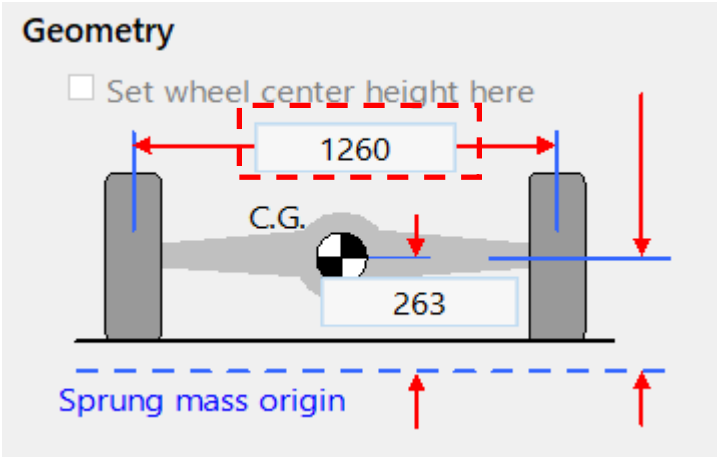
Sprung mass:	600	kg
Roll inertia	384	kg-m2
Pitch inertia	624	kg-m2
Yaw inertia	686	kg-m2
Product (Ixy):	0	kg-m2
Product (Ixz):	0	kg-m2
Product (Iyz):	0	kg-m2

Edit radii of gyration

Rx:	0.800	m
Ry:	1.020	m
Rz:	1.069	m

Inertia and radius of gyration are related by the equation: I = M*R*R

Radii must be specified with numbers; formulas are not supported



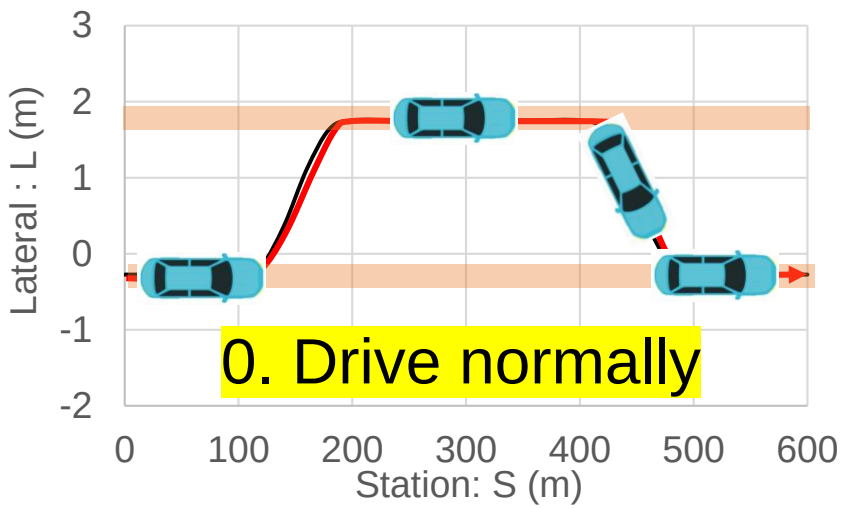
Driving behaviors

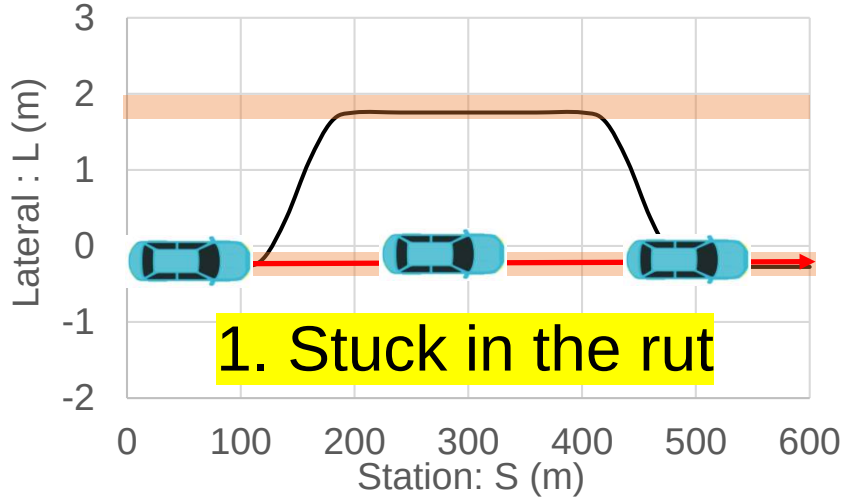
Targeted driving path

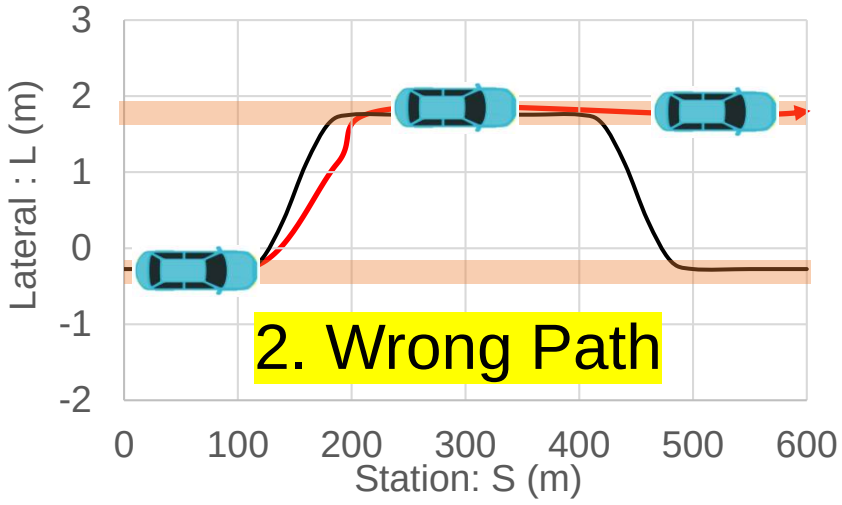
Actual driving path

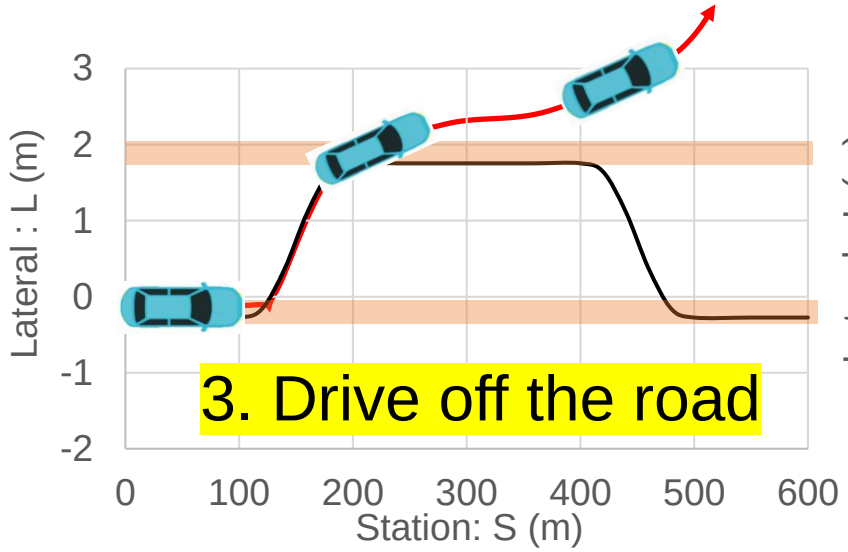
Vehicle

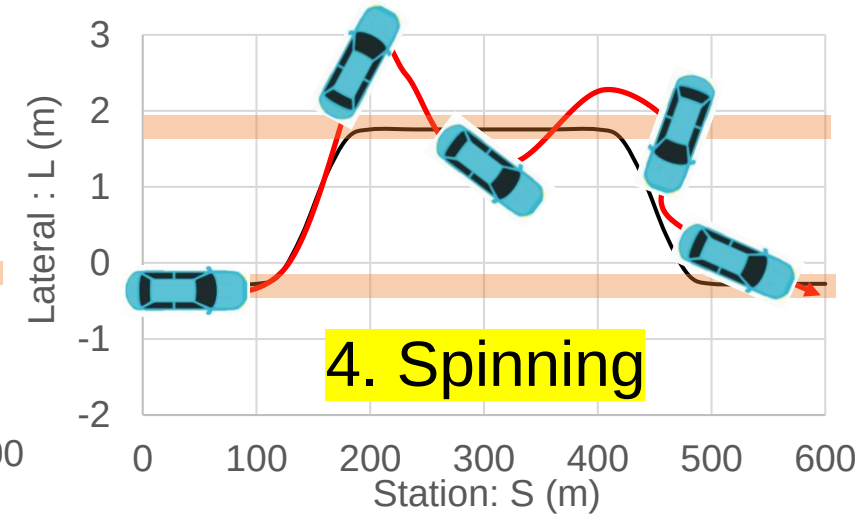
Rut





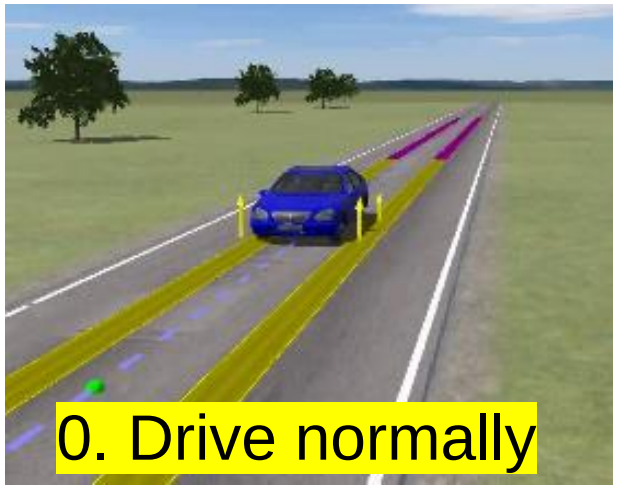


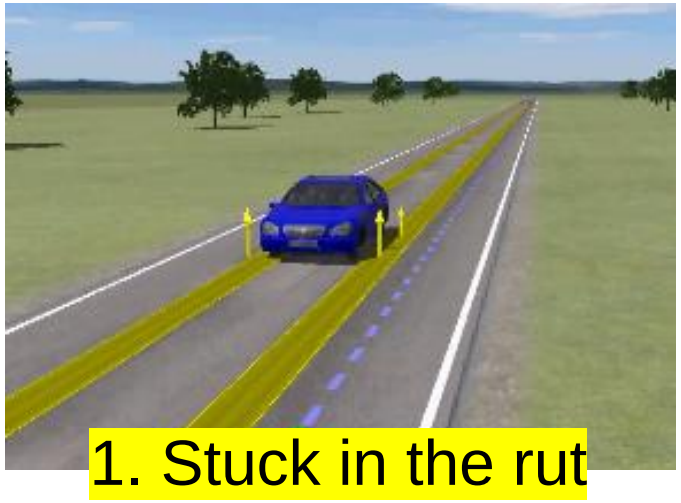




Driving behaviors

0. Drive normally
1. Stuck in the rut
2. Wrong path
3. Drive off the road
4 Spinning



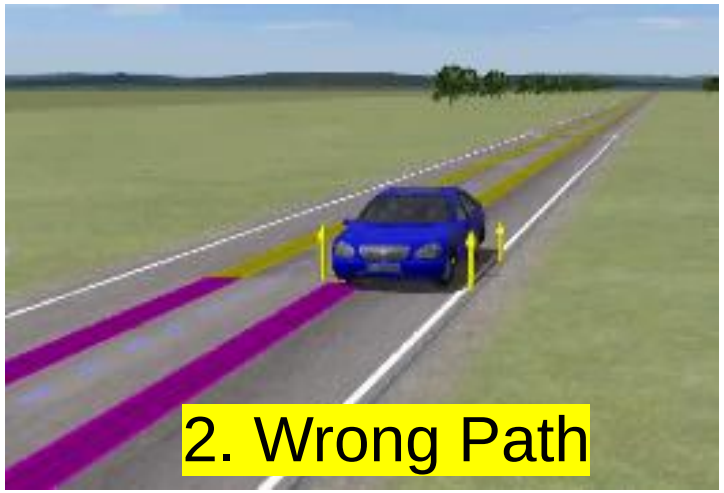


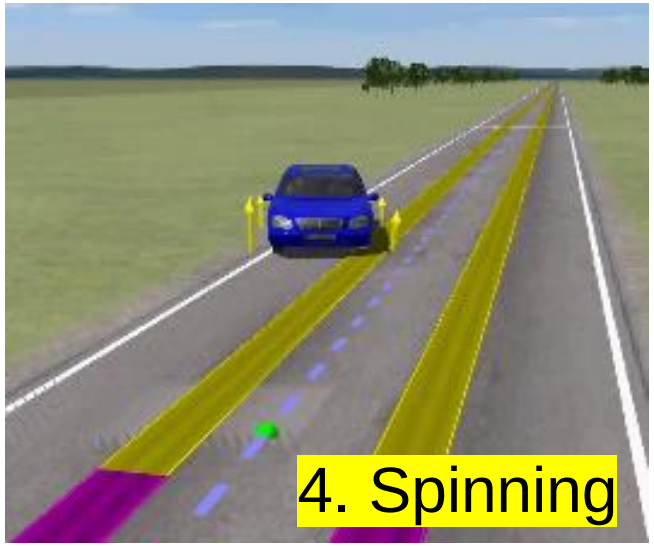
Wheel positions

No rut

Rut

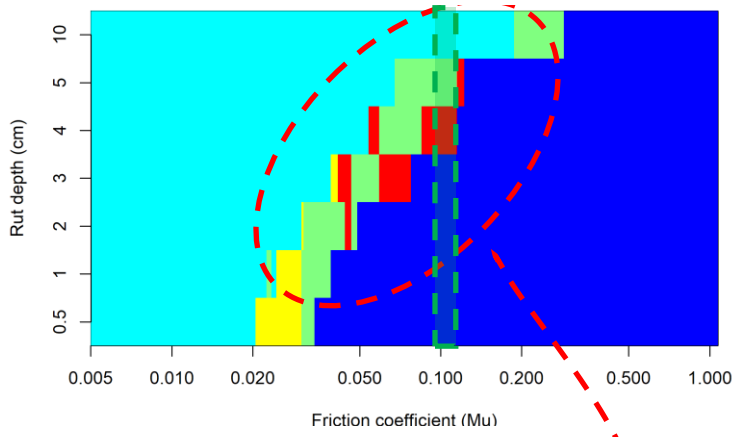
Targeted driving path



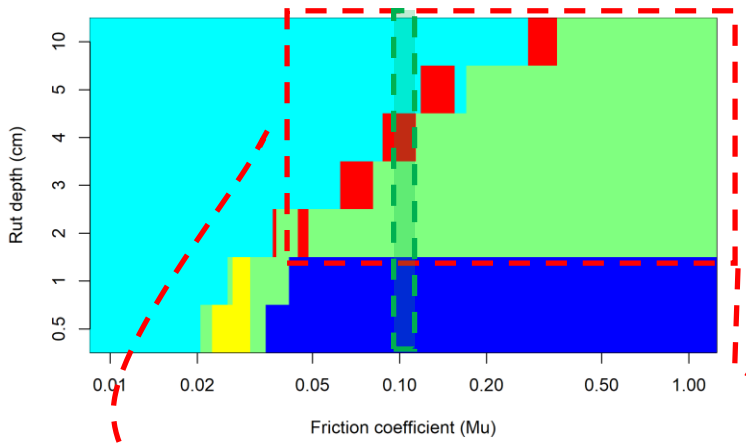


Vehicle behavior based on rut depths and road surface types

Normal car, single rut



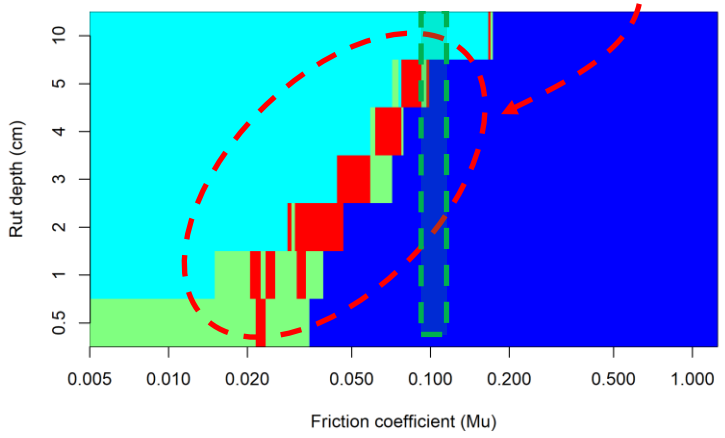
Normal car, dual rut



Danger rate

- 4 Spinning
- 3 Drive off the road
- 2 Wrong path
- 1 Stuck in the rut
- 0 Drive normally

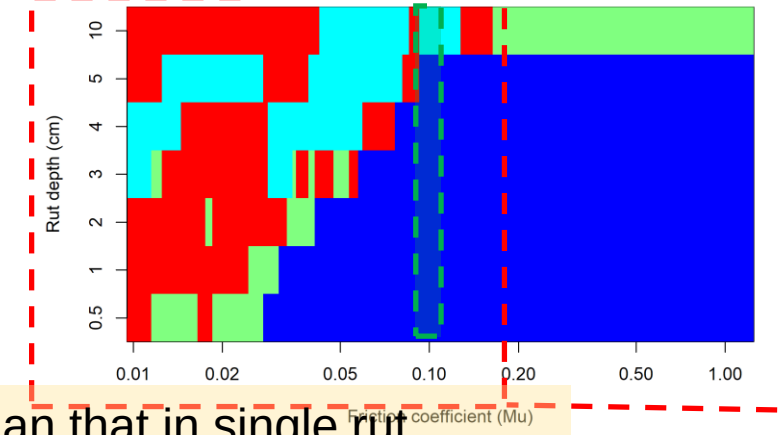
Light truck, single rut



More spin in light truck

Mu < 0.4 => risky

Light truck, dual rut



Unstable driving

Cannot drive on the targeted path most of time => unstable driving

Spin on icy road

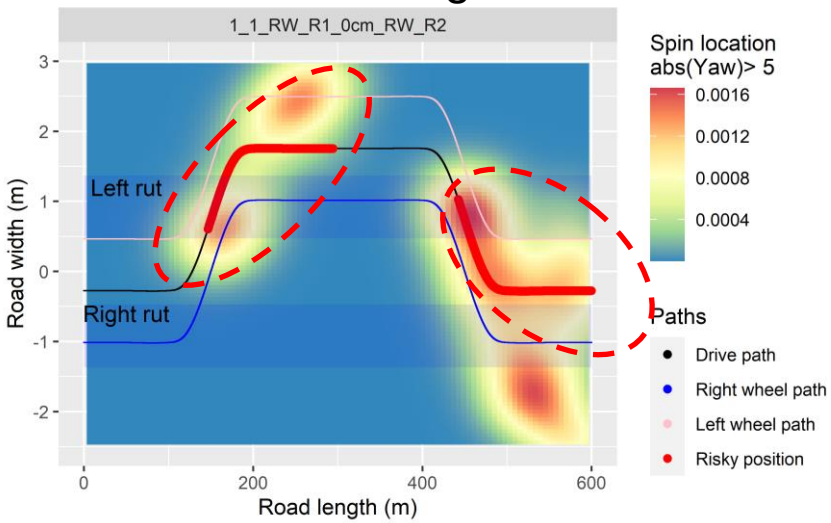
High risk of spinning on icy road

- Travelling in dual rut is more dangerous than that in single rut
- Light truck is unsafe when travelling on icy road

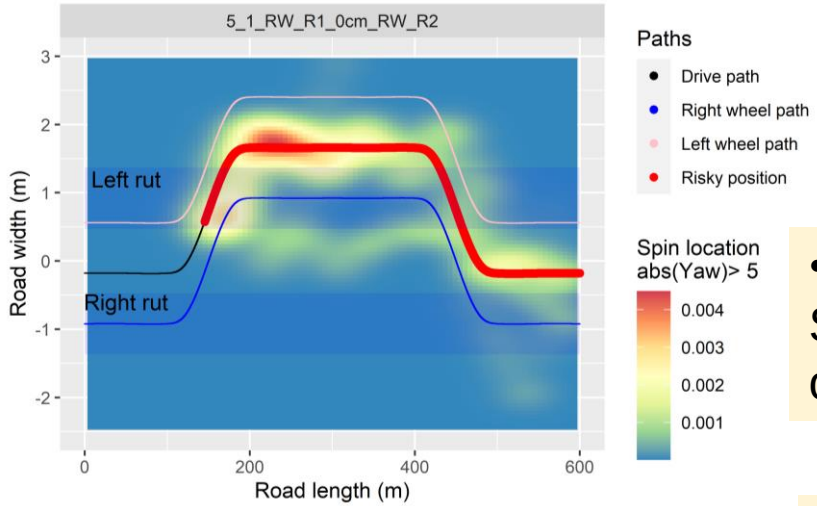
With Mu > 0.1, required RD <1 cm => safety

Danger location with Yaw angle > 5

Normal car, single rut



Normal car, dual rut

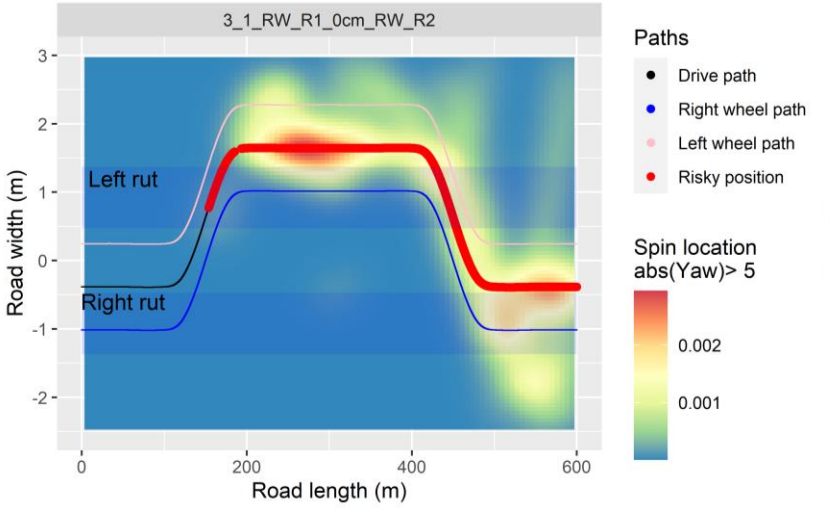


Mu 0.01-1, rut depth: 0.5-10 cm

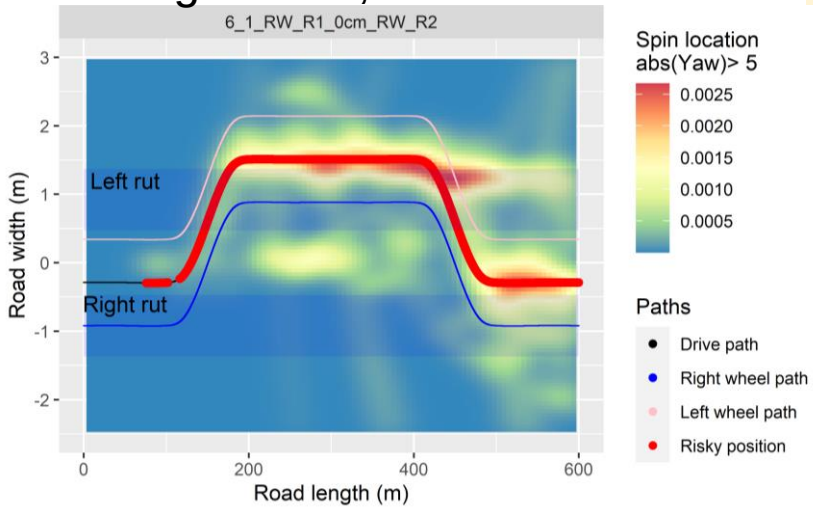
- Normal car

Spin mainly occurred at turning points on a single rut road

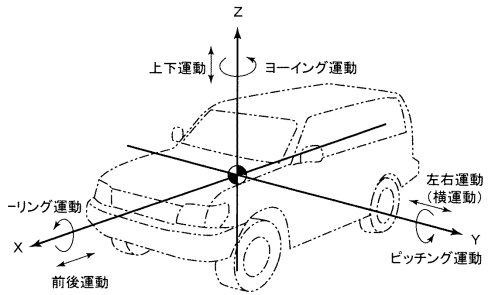
Light truck, single rut



Light truck, dual rut



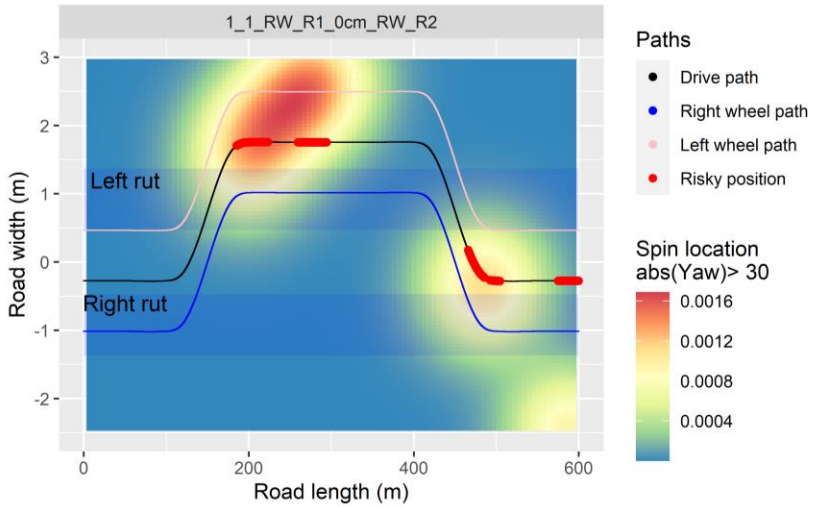
- Large spin area in a dual rut road



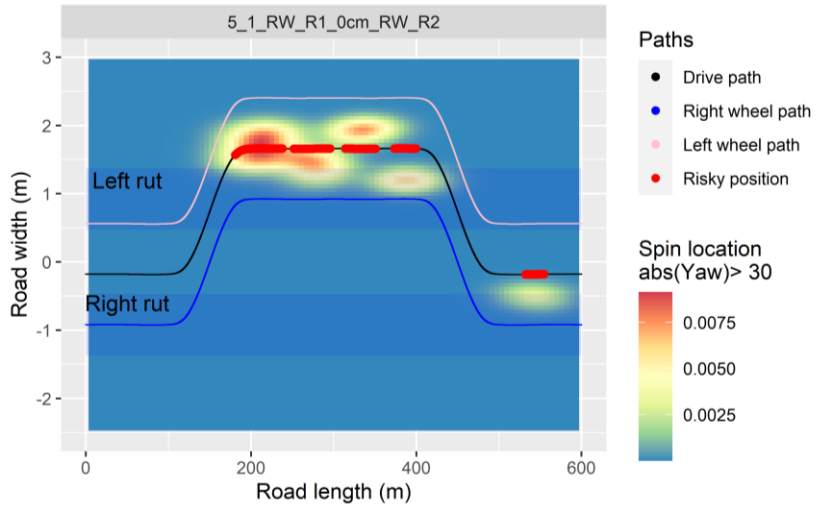
https://www.webcartop.jp/2016/10/52015/

Danger location with Yaw angle > 30

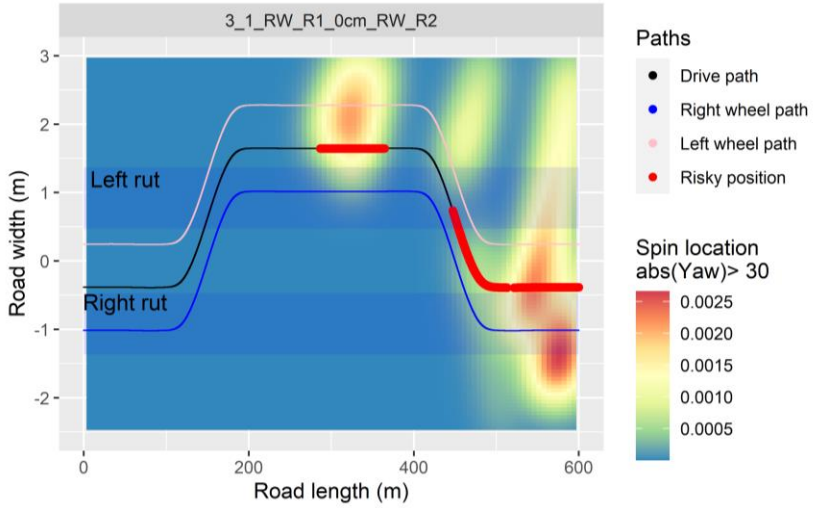
Normal car, single rut



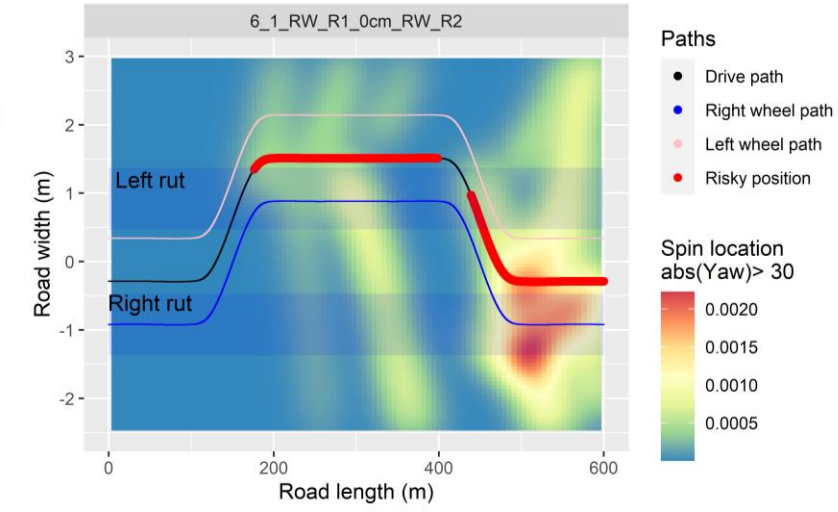
Normal car, dual rut



Light truck, single rut



Light truck, dual rut



Mu 0.01-1, rut depth: 0.5-10 cm

- Normal car:
High yaw angle mainly occurred when the car crossed the left rut

- Light truck
High yaw angle mainly occurred when the truck returned to the right rut.

Conclusions

- Wrong path driving mainly occurred at Mu < 0.4, which was likely in icy, snow or wet road surface condition.
- Driving in dual rut roads was more dangerous than that in single rut roads.
- The light truck had a higher risk of spinning on icy road surfaces than the normal car.
- Spinning mainly occurred at turning points for the normal car while it could happen at any positions in a driving path for the light truck during DLC maneuvers.
- The deeper RD caused a higher risk of spinning and required a higher Mu to ensure safe driving.
- In a typical icy road condition Mu= 0.1, RD < 1 cm is recommended for safe driving.

Thank you for your attention