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Robust Optimization of ABS Control Parameters

CarSim + MATLAB/Simulink
+
modeFRONTIER

CD-adapco JAPAN Co., Ltd.

CarSim

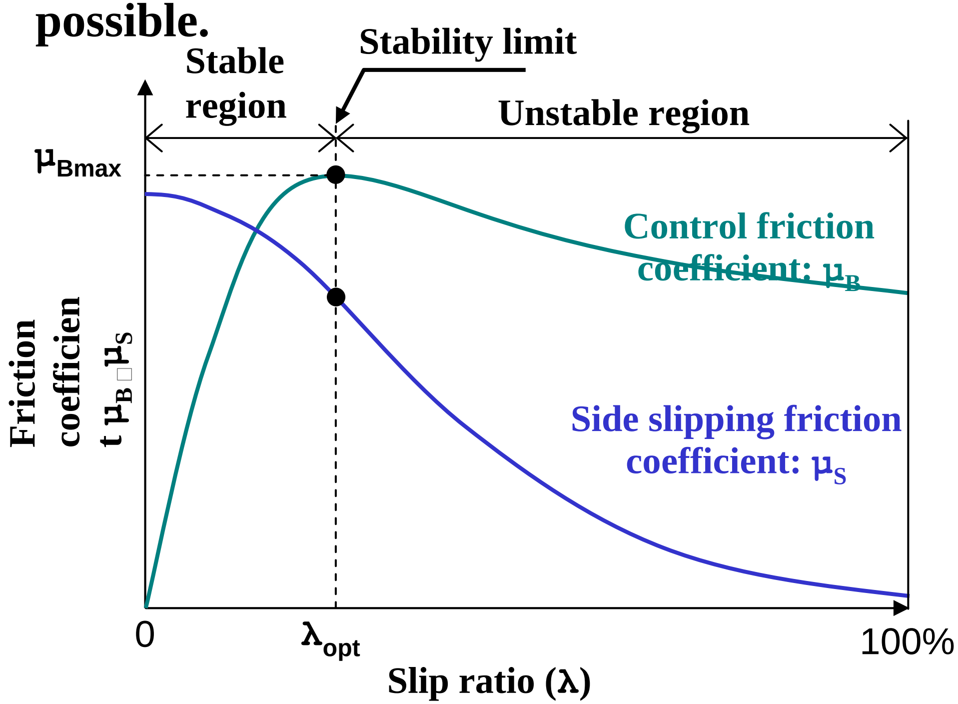
- **Vehicle dynamic simulation tool for Automobiles**
  - **Developed at UMTRI (University of a Michigan Transportation Research Institute) and commercialized by Mechanical Simulation Corporation.**
  - **Full vehicle dynamics models with 19 degree of freedom applicable for four-wheeler, RV, light-trucks, etc.**
  - **High-speed operation on Windows platform, user friendly GUI, and various examples**
  - **MATLAB/Simulink interface**
- **Domestic distributor**

Virtual Mechanics Corporation

http://www.virtualmechanics.co.jp

ABS for Automobiles

- **Anti-lock Braking System**
  - **Prevents wheel lock-up to secure steerability and controllability in emergency braking situations.**
  - **If wheel rotation exceeds the stability limit, brake pressure will be decreased to adjust the rotation to be within the stable region.**
  - **Then, brake pressure will be increased again until it exceeds the stability limit to maintain the rotation status of the stability limit region as long as possible.**

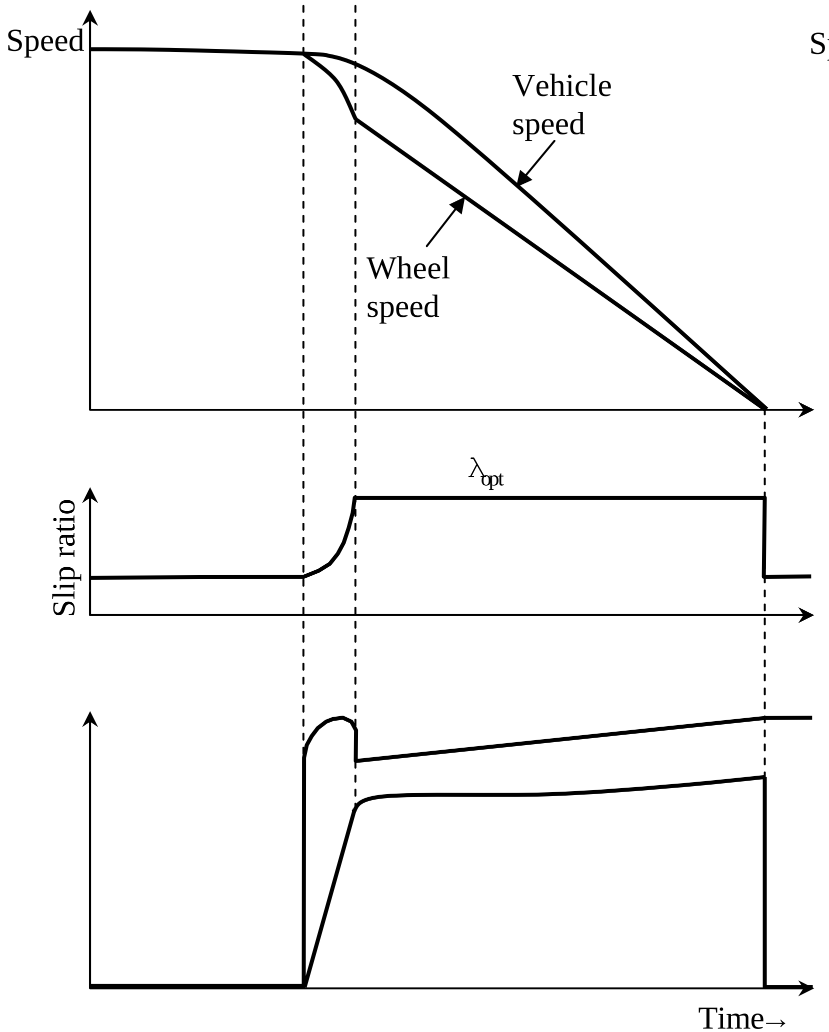


$$\lambda = \frac{V_V - V_T}{V_V} \times 100\%$$

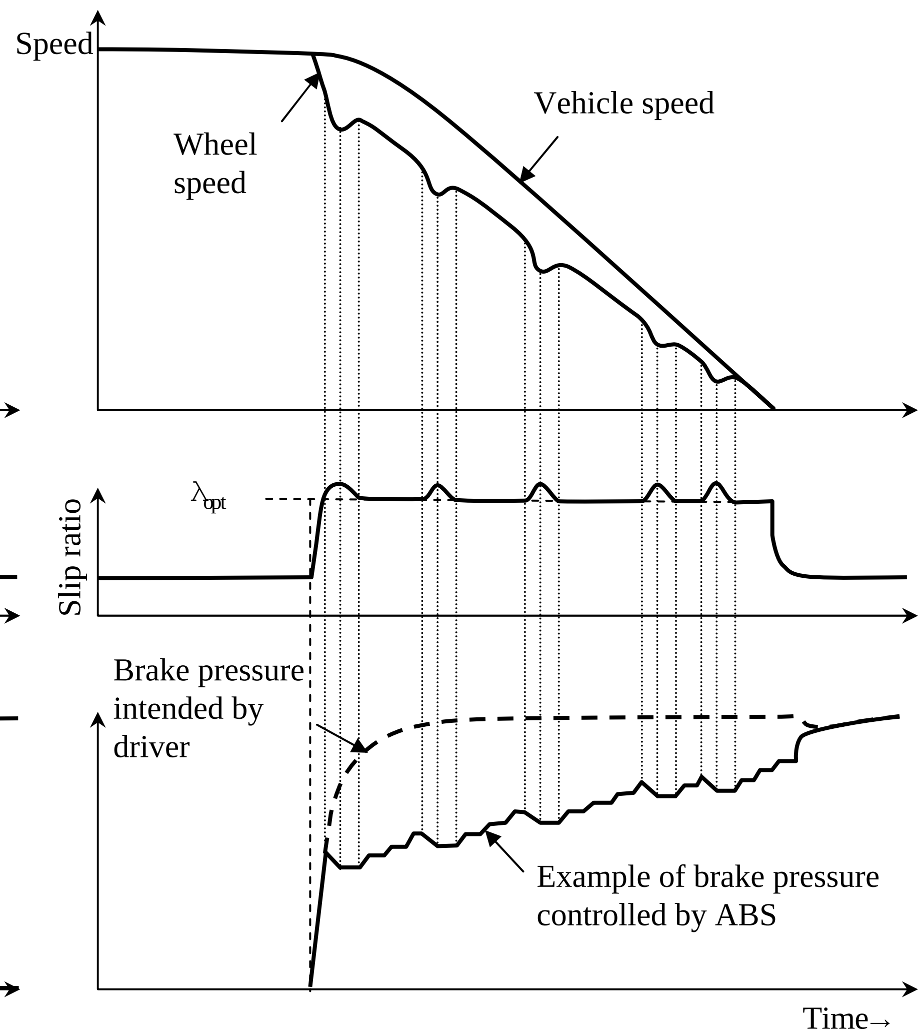
$$Control.dis = \frac{{V_{Vi}}^2}{2\mu_B \cdot g}$$

λ: Slip ratio
V_V: Vehicle speed
V_T: Wheel speed
V_{Vi}: Vehicle speed at the start of braking
μ_B: Control friction coefficient
g: Gravitational acceleration

Ideal Braking Control

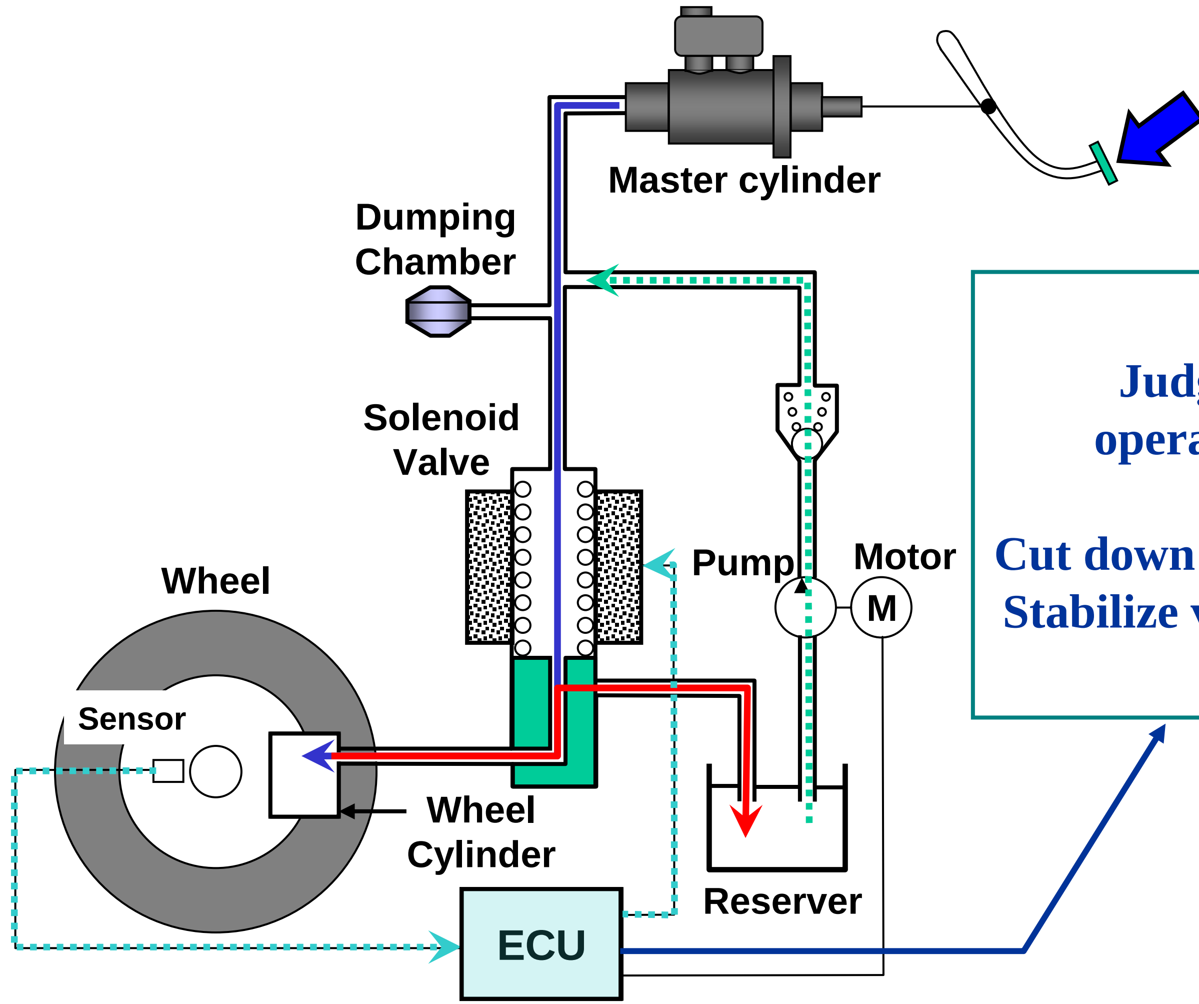


Ideal Braking Control



Ideal Braking Control with ABS

Example of ABS Configuration (Circuit System)



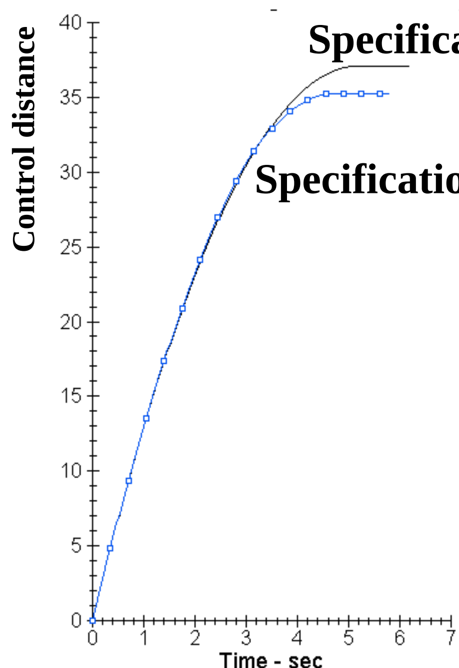
Judgement of operation switch

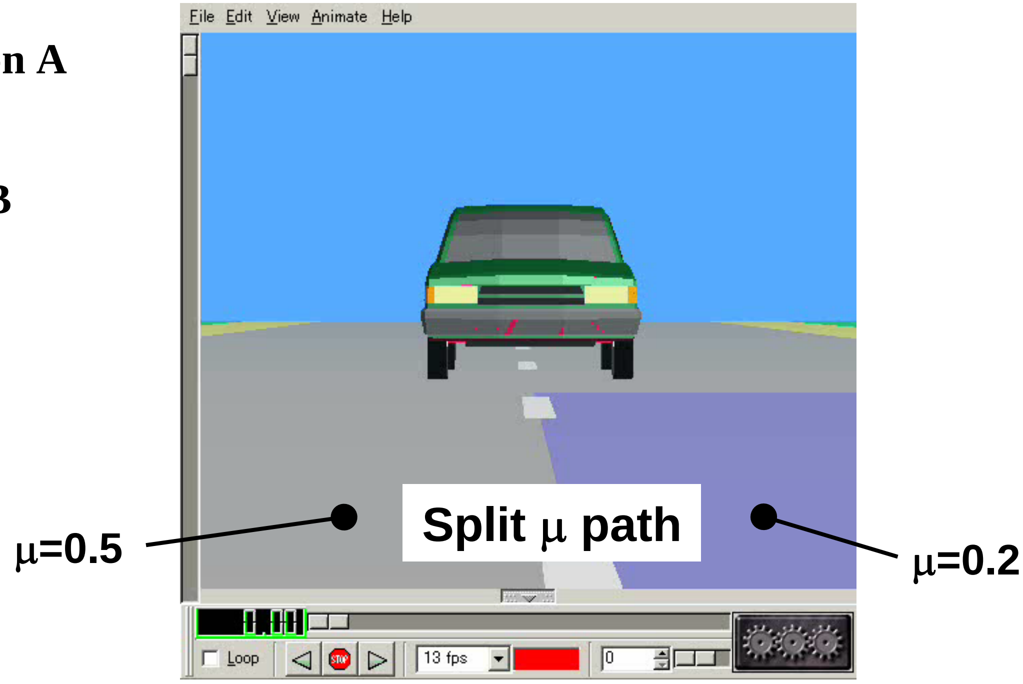
Cut down control distance
Stabilize vehicle activities

Setting ABS Control Parameters

Switching among Normal - Holding - Depressurizing Operations

- **Friction coefficients (μ) for wheel and road are not constant**
  - There are many uncertain factors (road status, etc.)
  - Robust parameters for μ are desirable
- **Secure linear movement upon sudden braking on laterally uneven μ path**
  - Both control distance and side deflection need to be minimized





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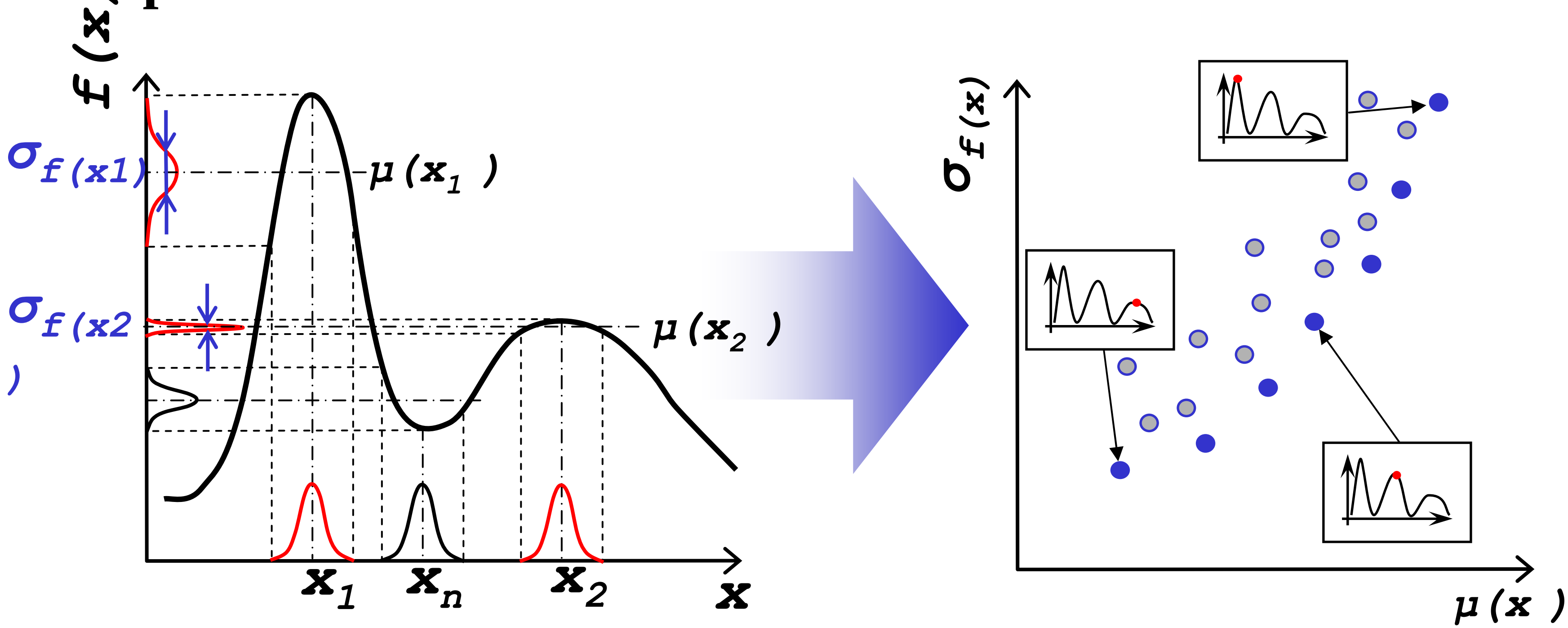
Multi Objective Robust Design Optimization

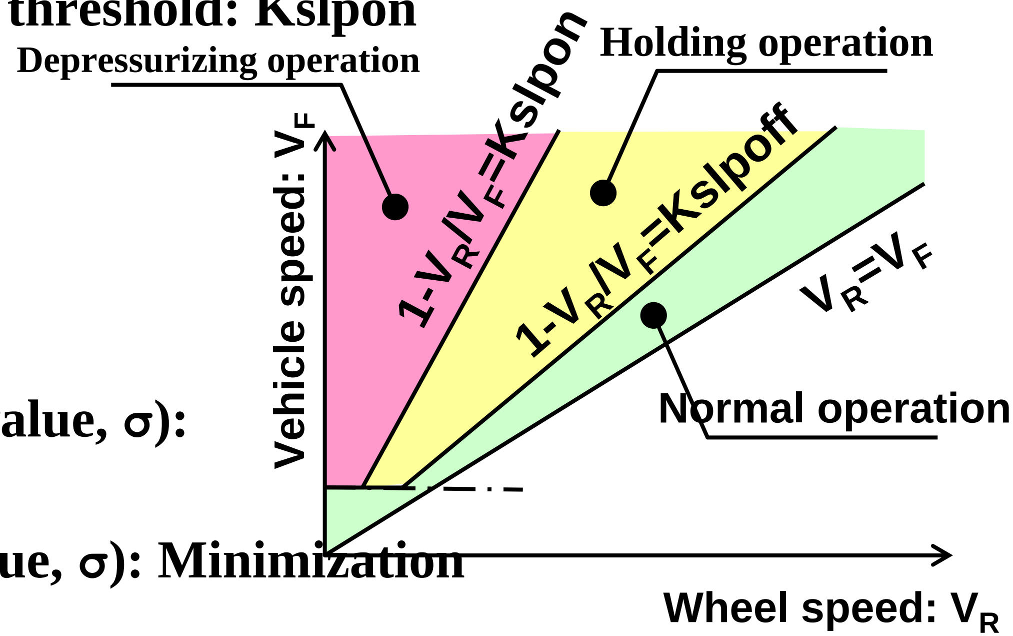
- Perform global exploration by considering the issue as multi-objective optimization problem of
    - Output average value: Maximization (minimization)
    - Output standard deviation: Minimization

  when probability distribution variation is applied to the input.



Optimization Issue (1)

- **Design parameters**
  - Normal <-> Holding threshold: Kslpoff
  - Holding <-> Depressurizing threshold: Kslpon
- **Dispersion element**
  - High μ: 0.5±0.1
  - Low μ: 0.2±0.1
- **Objectives**
  - Control distance (Average value, σ): Minimization
  - Side deflection (Average value, σ): Minimization

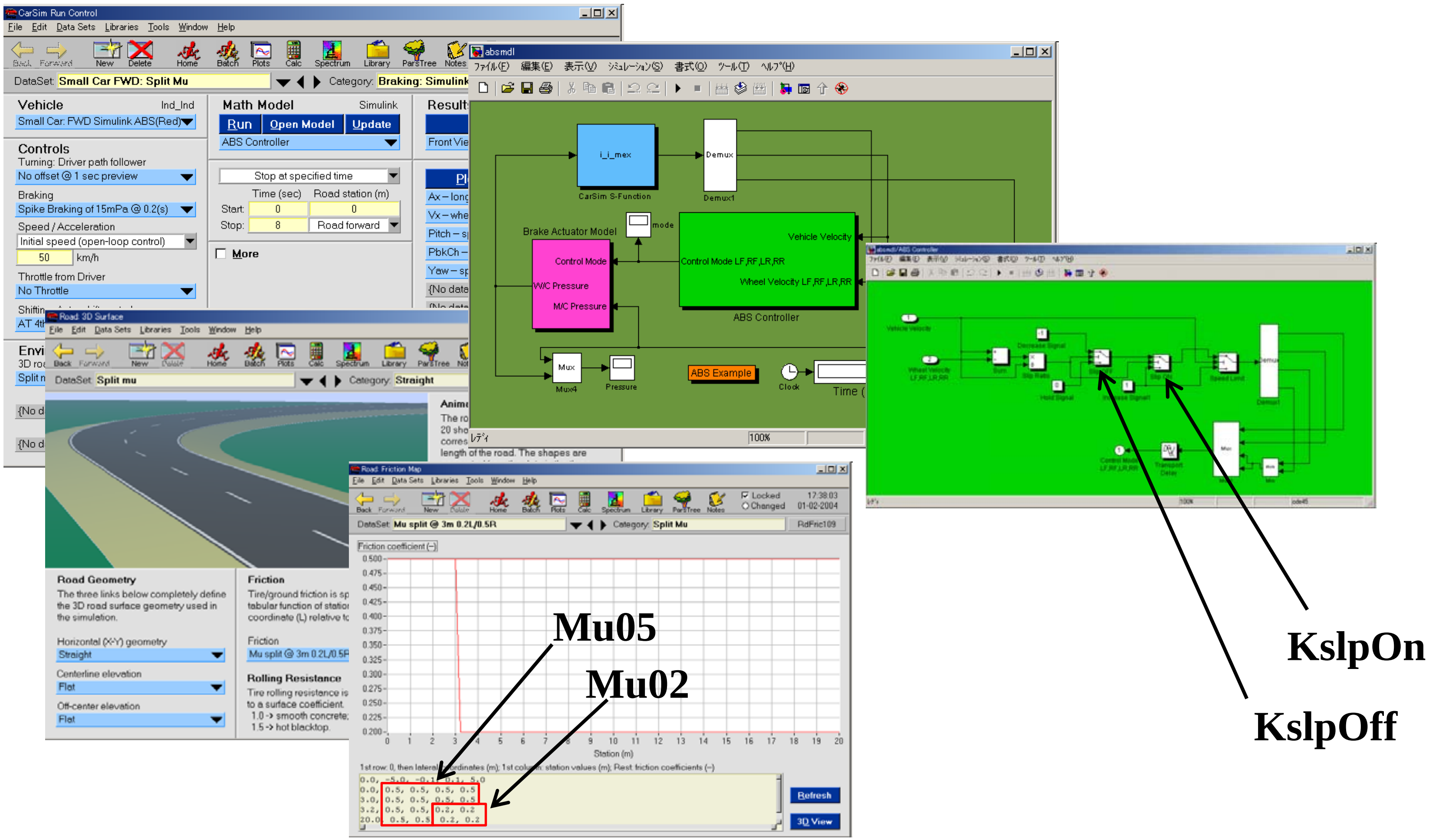


- **Constraints**
  - Relationships of design parameters: Kslpoff > Kslpon
  - Side deflection width < Vehicle width/2
  - Target value for each objective

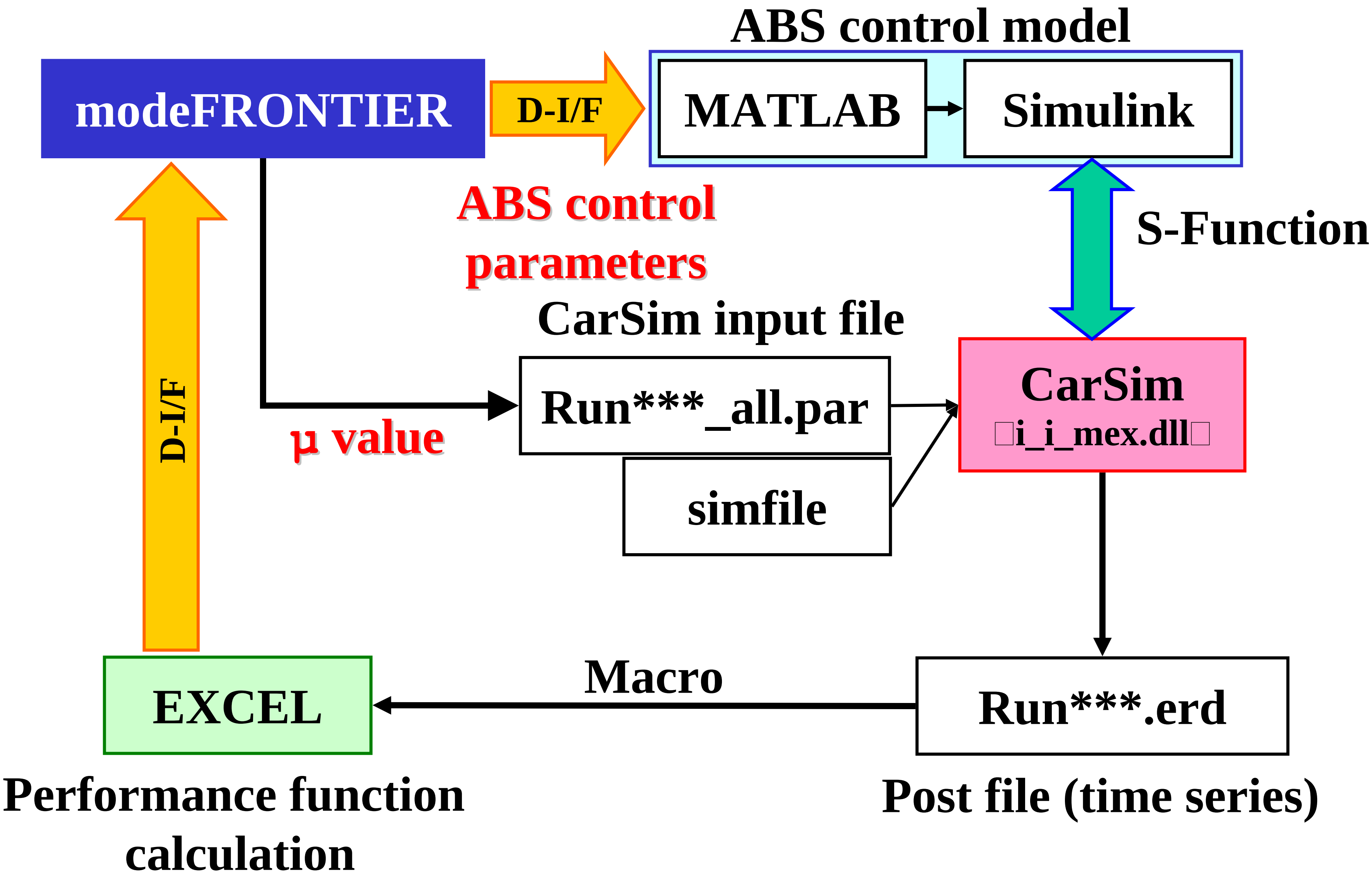
Optimization Issue (2)

■ Target optimization model

- Coupled model included in CarSim (Small Car FWD: Split Mu)



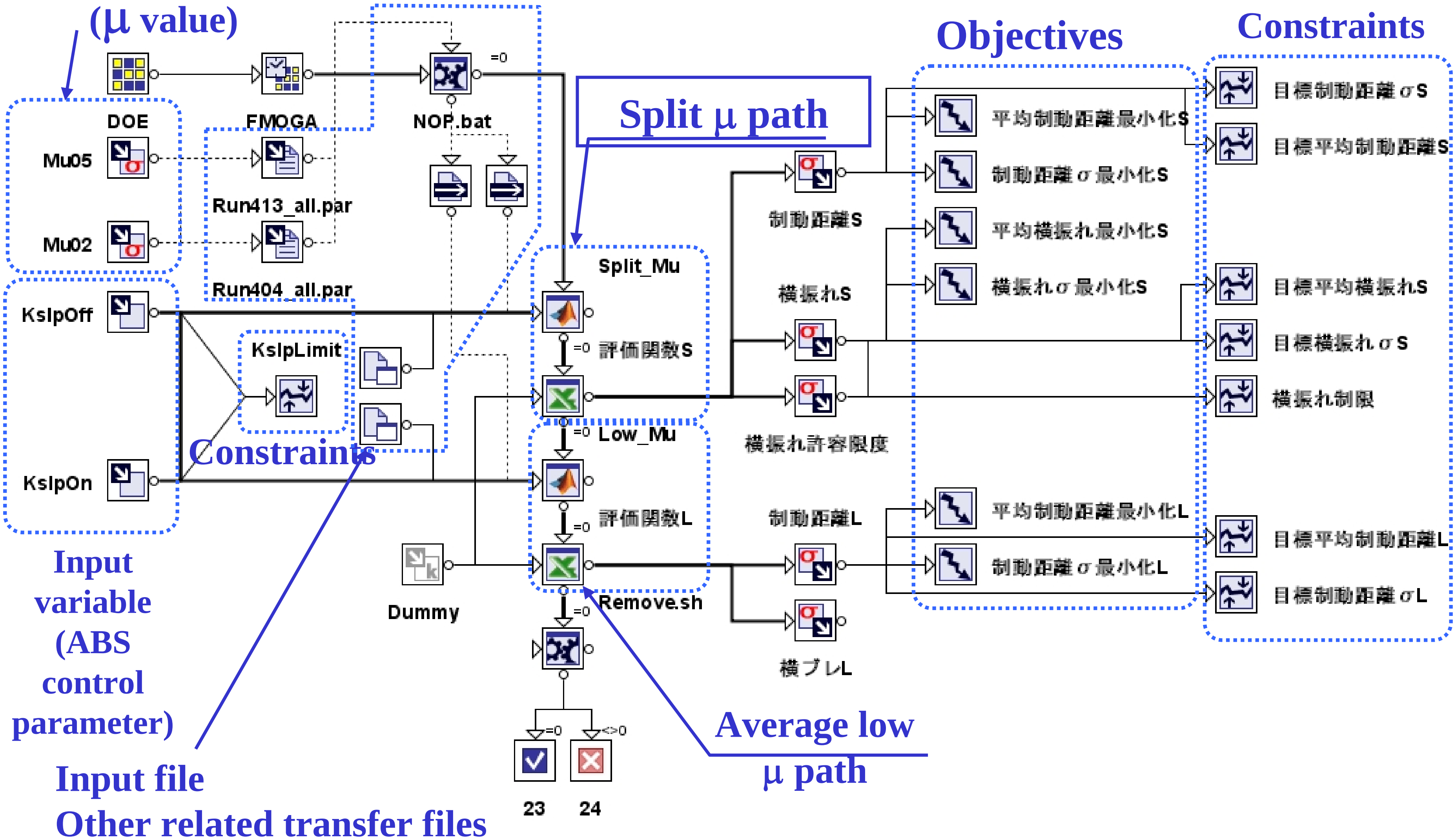
Optimization Flow



Optimization Workflow

(Multi Objective Robust Optimization)

Scattering element



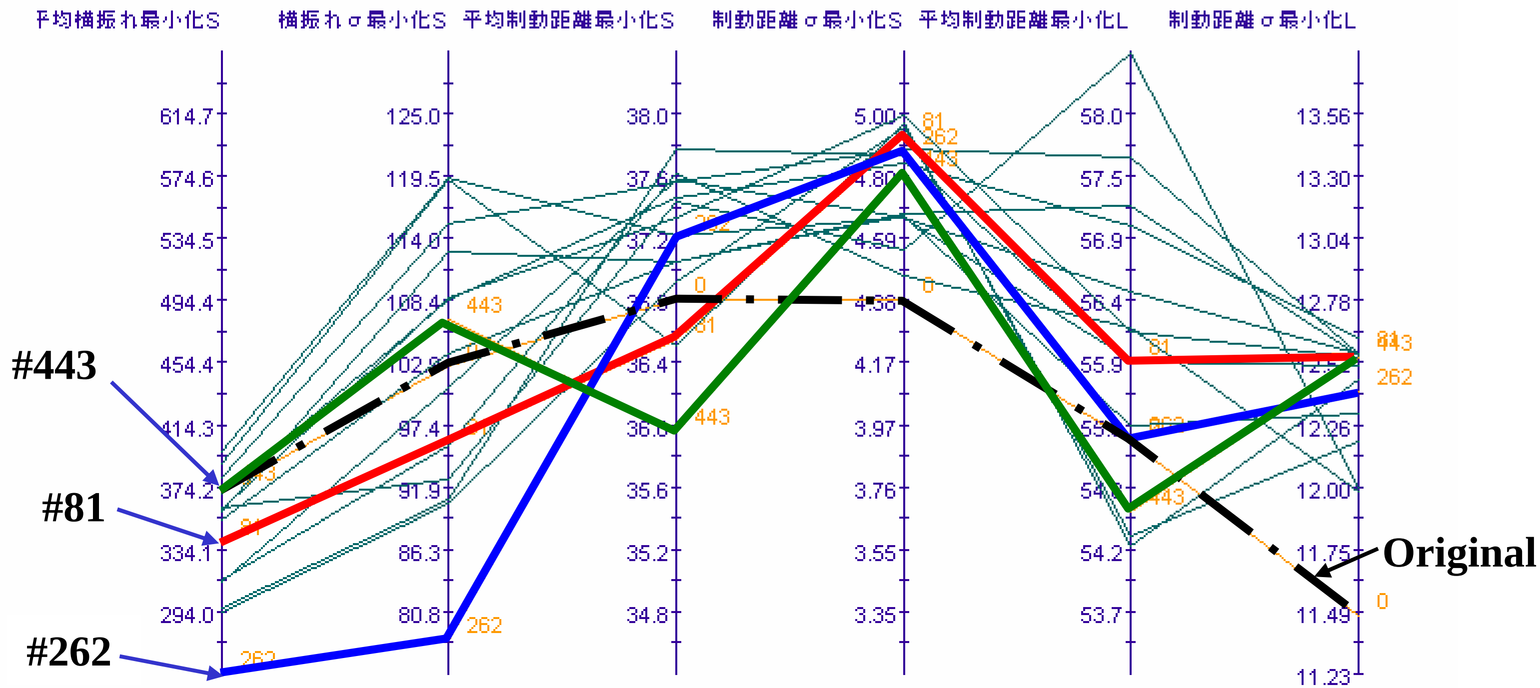
Optimization Process

- **Step1**
  - **Scheduler: FMOGA (RSM Evaluation: 0.8/Linear annealing)**
  - **First generation individuals: 25 DOE (Random)**
  - **Number of generations: 15**
  - **Number of robust sampling: 110 (Actual samples: 10, RSM: 100)**
- **Step2, 3**
  - **Scheduler: FMOGA (RSM Evaluation: 0.6/Fixed)**
  - **First generation individuals: 20 Pareto solutions for previous Step**
  - **Number of generations: 15**
  - **Number of robust sampling: 110 (Actual samples: 10, RSM: 100)**

- **CPU: Pentium 3 (1.0GHz) Dual (RAM: 780MB)**
- **Total calculation time: Approximately 25 hours**

Optimization Results (1)

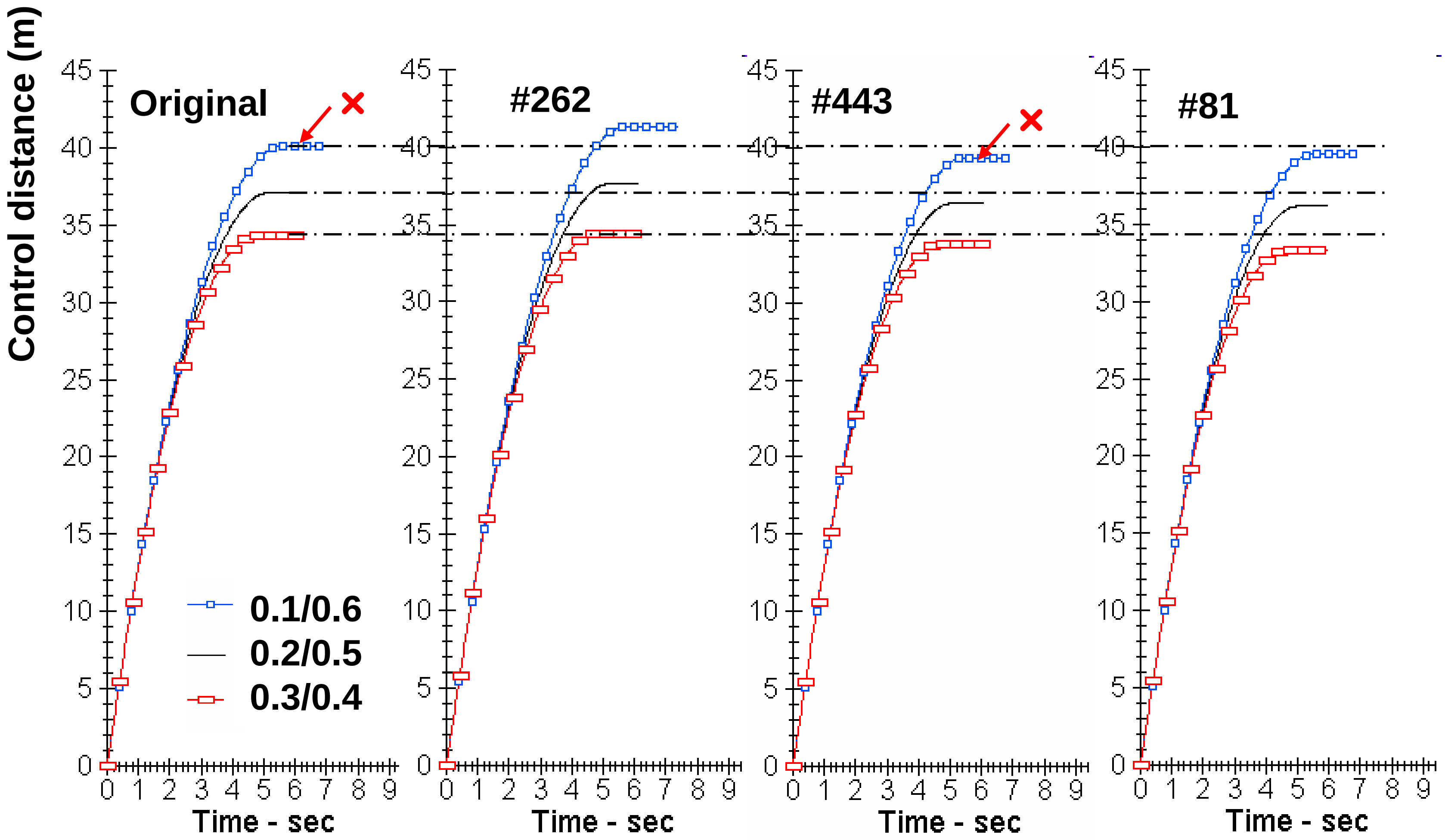
(Only Pareto solutions displayed)



Design	Kslpoff	Kslpon	Split μ path (m)				Average low μ path (m)	
			Average control distance	Control distance σ	Average side deflection	Side deflection σ	Average control distance	Control distance σ
Original	0.2	0.05	36.81	4.38	0.37	0.10	55.17	14.46
#81	0.143	0.059	36.55	4.93	0.34	0.10	55.87	12.56
#262	0.136	0.010	37.21	4.87	0.25	0.08	55.19	12.41
#443	0.167	0.067	35.96	4.81	0.37	0.11	54.57	12.54

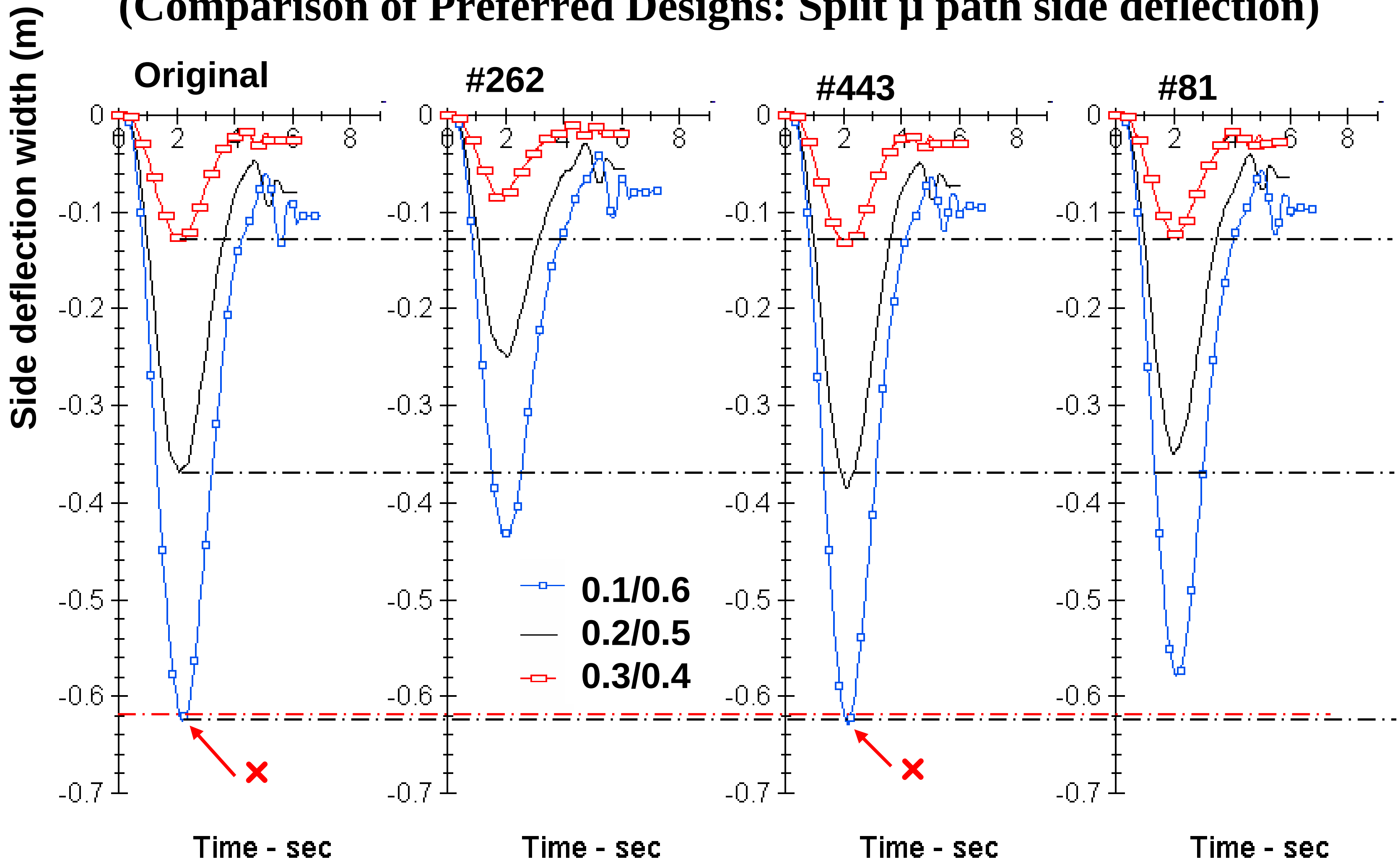
Optimization Result (2)

(Comparison of Preferred Designs: Split μ path control distance)



Optimization Result (3)

(Comparison of Preferred Designs: Split μ path side deflection)



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Conclusion

- **Conducted multi-objective robust optimization of ABS control parameters using CarSim + Simulink coupled simulation model**
- **Performed exploration of robust ABS control parameters for dispersions of μ values on split μ path**
- **Completed optimization by using FMOGA scheduler**
  - **Total number of design: 452**
  - **Total number of calculations:4529 (Robust evaluation sampling included)**
  - **Total calculation time: Approximately 25 hours**
    - **Number of parallel executions:1**
    - **CPU: Pentium 3 (1.0GHz) Dual**

Acknowledgement

Many thanks for Virtual Mechanics Corporatoin for lending us CarSim.