Verification of model connection by FMI using acausal modeling tools ~ JSAE WG Activities ~

Society of Automotive Engineers of Japan (JSAE)
Committee of Automotive Control and Model
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1. Purpose and outline of this WG's activity

[Background]

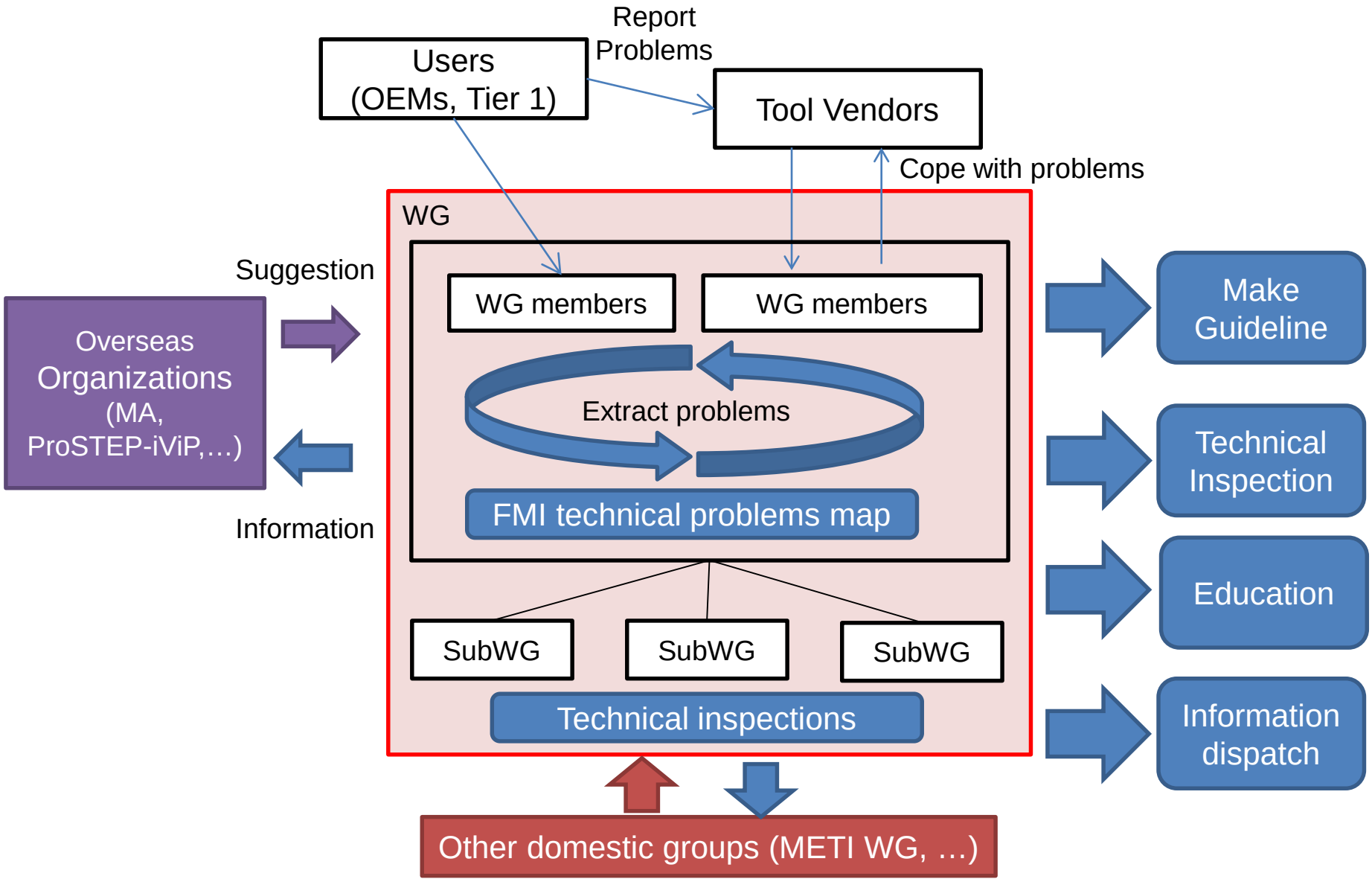
- Expectation to FMI for model connection and interchange is glowing.
- FMI is still not well-known and it's often hard to apply FMI for model connection in Japan.

[Purpose of the WG]

1. Investigate ways to utilize FMI for model connection and make a guideline.
2. Inspect technical problems about applying FMI for actual model connection.
3. Inform and educate users about above knowledge.
4. Collaborate with other groups for improving the situation.

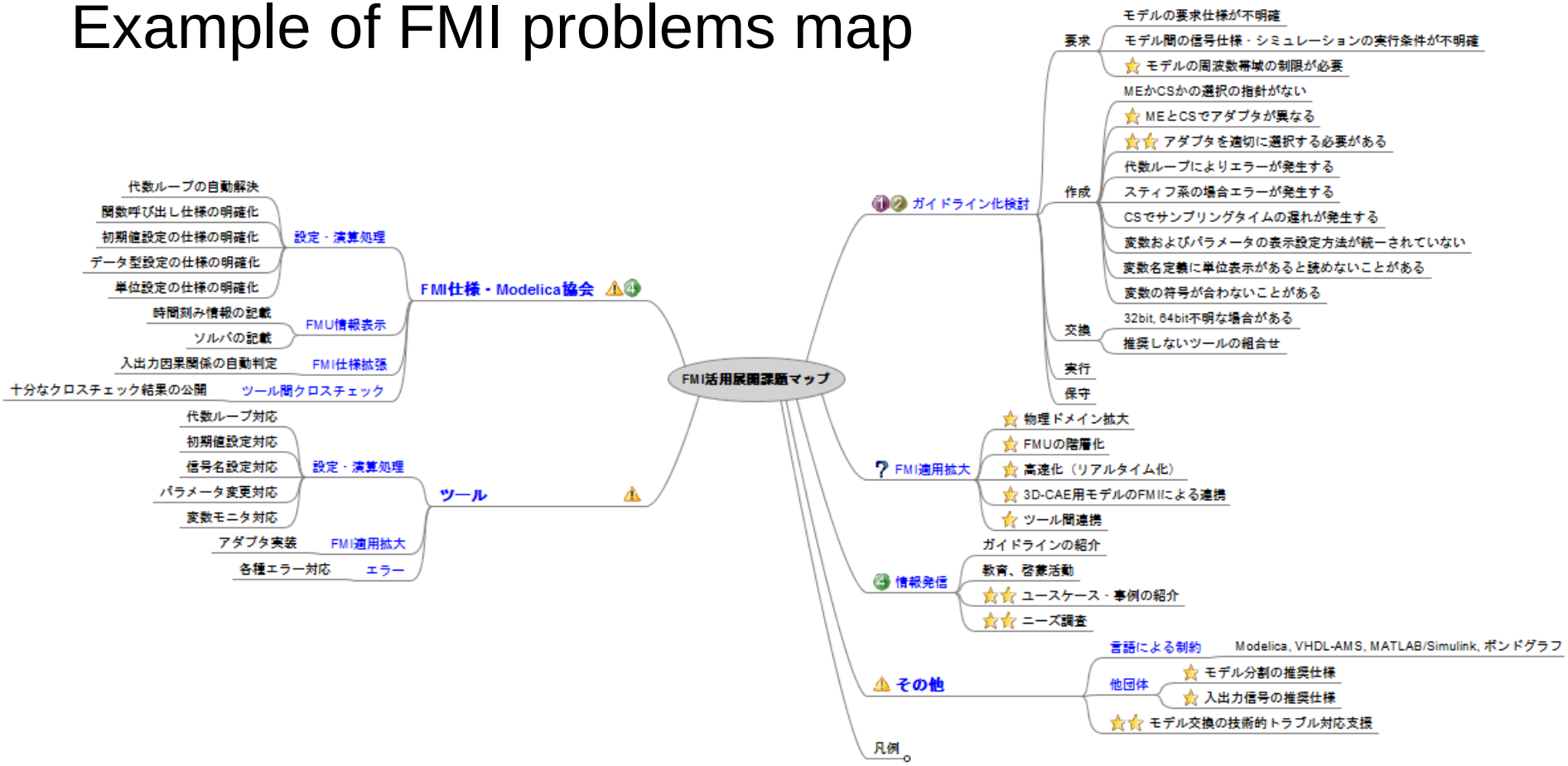
1. Purpose and outline of this WG's activity

[Organizations]



1. Purpose and outline of this WG's activity

Example of FMI problems map



[Outputs]

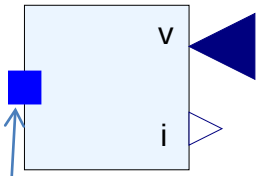
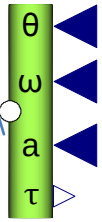
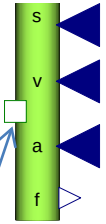
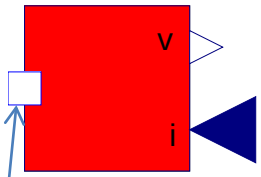
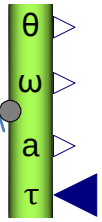
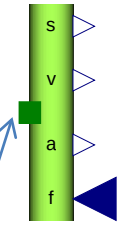
- WG meeting: 1 time / 1 month
- JSAE Organized Session: 1 time / 1 year

2. JSAE Guideline for using adaptor

[Basic Idea]

- Connect causal FMUs in acausal modeling environment to make use of following merits of acausal modeling.
  - Automatic regulation of causality.
  - Symbolic manipulation of equations when solving the total system of the model.

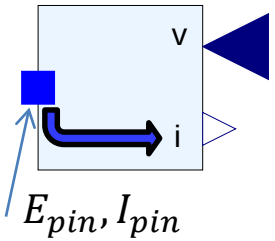
Adaptors between causal and acausal terminal

Electronics	Rotational mechanics	Translational mechanics
Current signal output  $E_{pin} = v$ $I_{pin} = i$ E_{pin}, I_{pin}	**Torque signal output**  $\Theta_{flange} = \theta$ $\Omega_{flange} = \omega$ $A_{flange} = a$ $T_{flange} = \tau$ $\Theta_{flange}, \Omega_{flange}, A_{flange}, T_{flange}$	**Force signal output**  $S_{trfln} = s$ $V_{trfln} = v$ $A_{trfln} = a$ $F_{trfln} = f$ $S_{trfln}, V_{trfln}, A_{trfln}, F_{trfln}$
Voltage signal output  $E_{pin} = v$ $I_{pin} = -i$ E_{pin}, I_{pin}	**Angle signals output**  $\Theta_{flange} = \theta$ $\Omega_{flange} = \omega$ $A_{flange} = a$ $T_{flange} = -\tau$ $\Theta_{flange}, \Omega_{flange}, A_{flange}, T_{flange}$	**Position signals output**  $S_{trfln} = s$ $V_{trfln} = v$ $A_{trfln} = a$ $F_{trfln} = -f$ $S_{trfln}, V_{trfln}, A_{trfln}, F_{trfln}$

Sign of flow variables of the model is important!

Rule of defining sign of flow variables

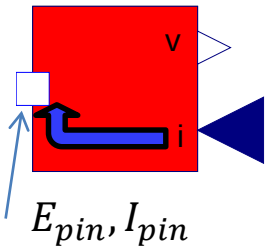
- For flow variable(s) coming into the component at acausal connector, the sign should be plus.



$E_{pin} = v$

$I_{pin} = i$

- For flow variable(s) going out of the component at acausal connector, the sign should be minus.

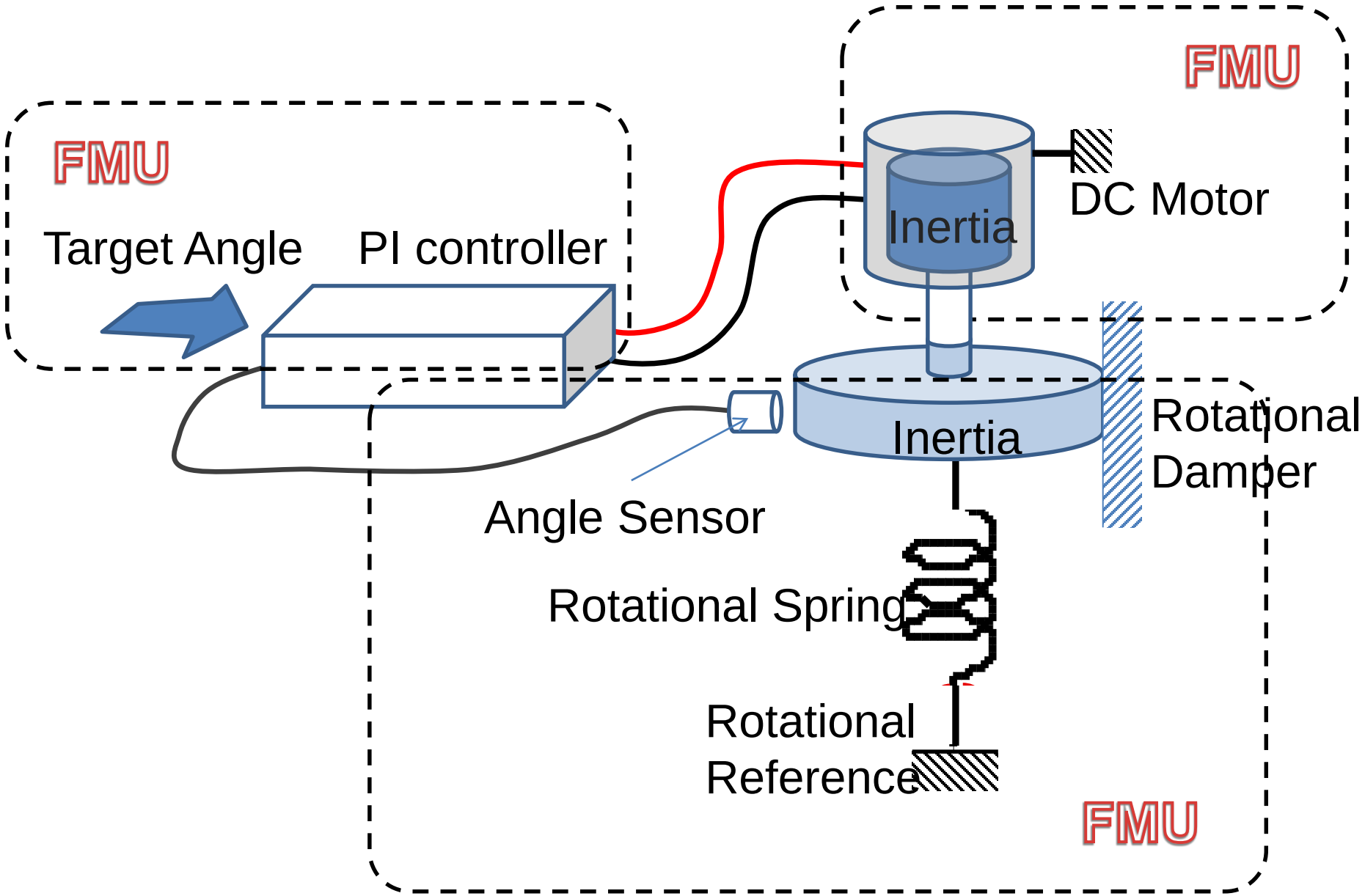


$E_{pin} = v$

$I_{pin} = \ominus i$

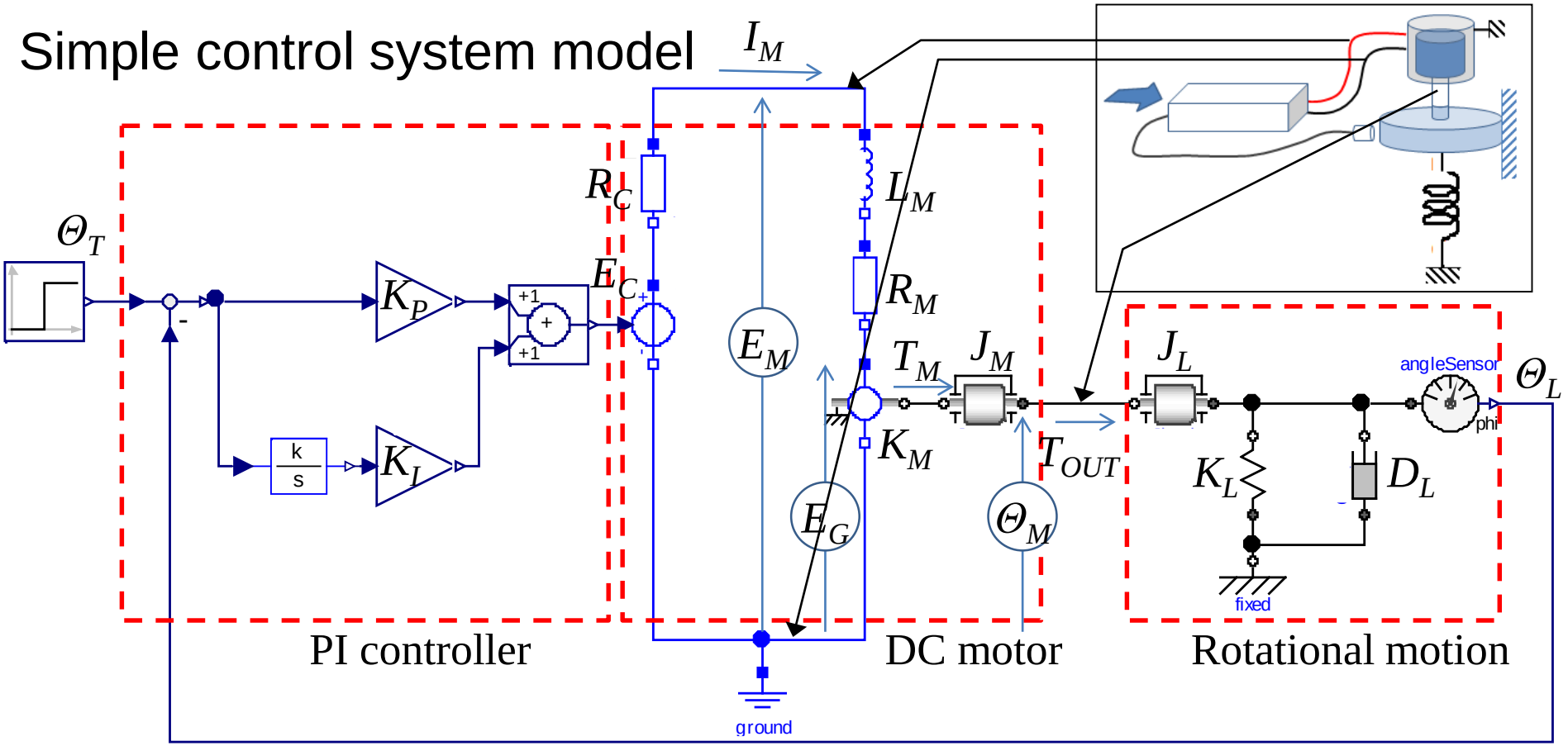
Definition of Modelica Standard Libraries:
Sign of flow variables is plus when they come into the component.

3. Confirmation by Benchmark model for ME



Acausal model of benchmark system

Simple control system model



PI controller parameter

K_P=1;	Proportional gain
K_I=100;	Integral gain
R_C=0.1;	Internal resistance of PI controller [Ω]

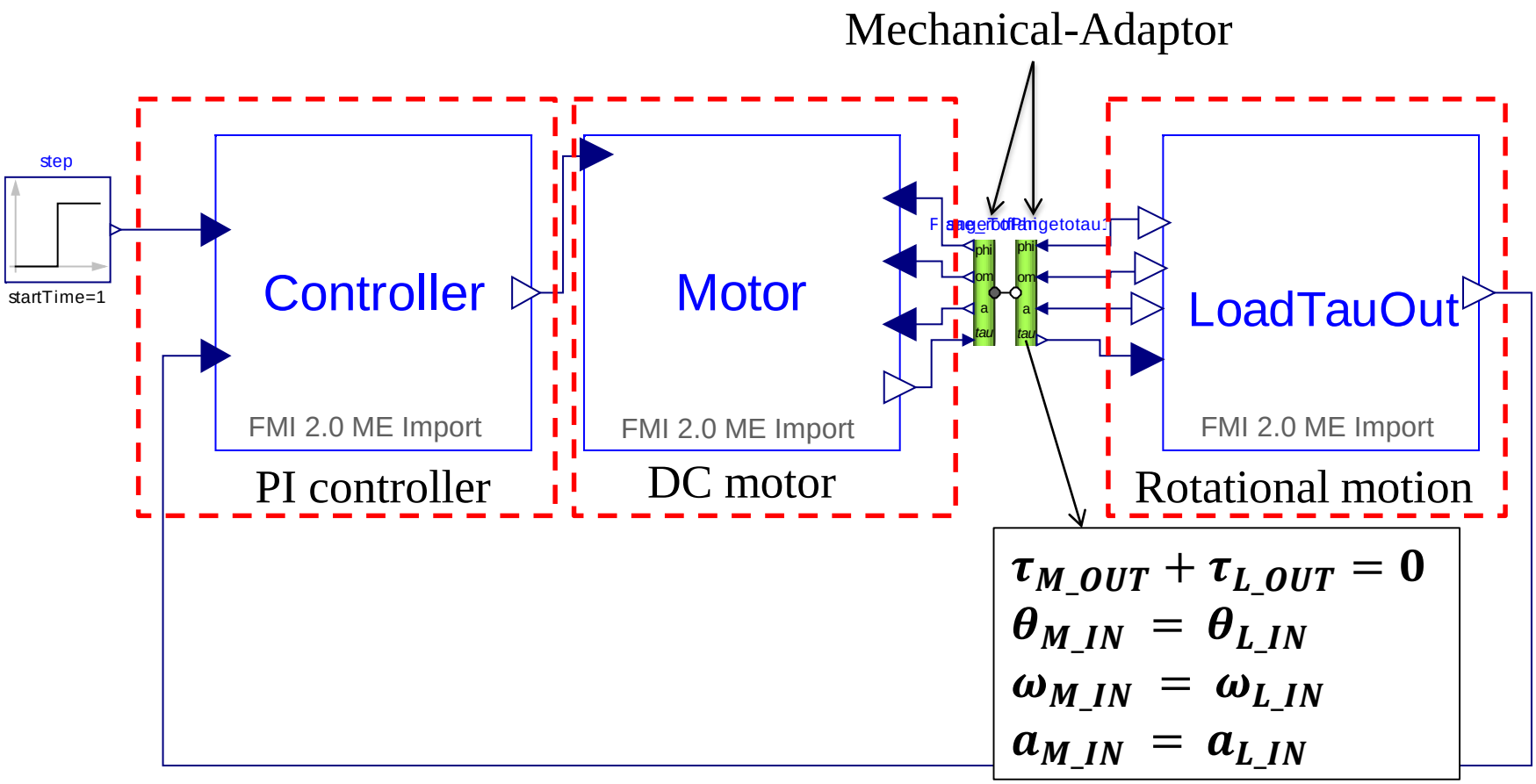
DC motor parameter

L_M=1e-6;	Motor inductance [H]
R_M=0.9;	Motor resistance [Ω]
K_M=0.1;	Torque const. [N・m/A] Back-emf const.[V/(rad/sec)]
J_M=0.001;	Motor inertia [kg・m^2]

Rotational motion parameter

J_L=0.009;	Load inertia [kg・m^2]
D_L=0.001;	Load damper [N・m/(rad/sec)]
K_L=10;	Load spring [N・m/rad]

System model using 3 FMUs



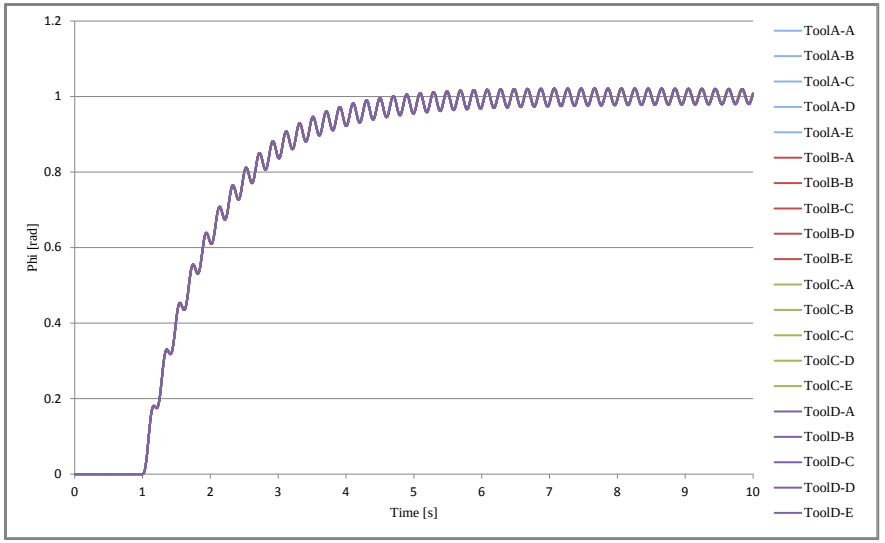
Simulator solves the simultaneous equations that is depending on the connections.

Simulation results (Various combination of tools)

Combination of the FMU export tools and FMU import tools

		FMU Create	Adapter	Running Tool			
				ToolA	ToolB	ToolC	ToolD
				Run	Run	Run	Run
System 1 FMU	ToolA	○	△	○ 6.45	○ 22.22	○ 8.00	△ 18.62
	ToolB	○	△	○ 7.82	○ 22.22	○ 5.00	△ 2.25
	ToolC	○	△	○ 505.36	○ 18.22	○ 5.00	△ 2.84
	ToolD	○	×	○ 8.55	○ 68.89	○ 5.00	△ 2.90
	ToolE	○	△	○ 2428.57	○ 35.56	○ 36.00	△ 2.08

Step response result with each tool



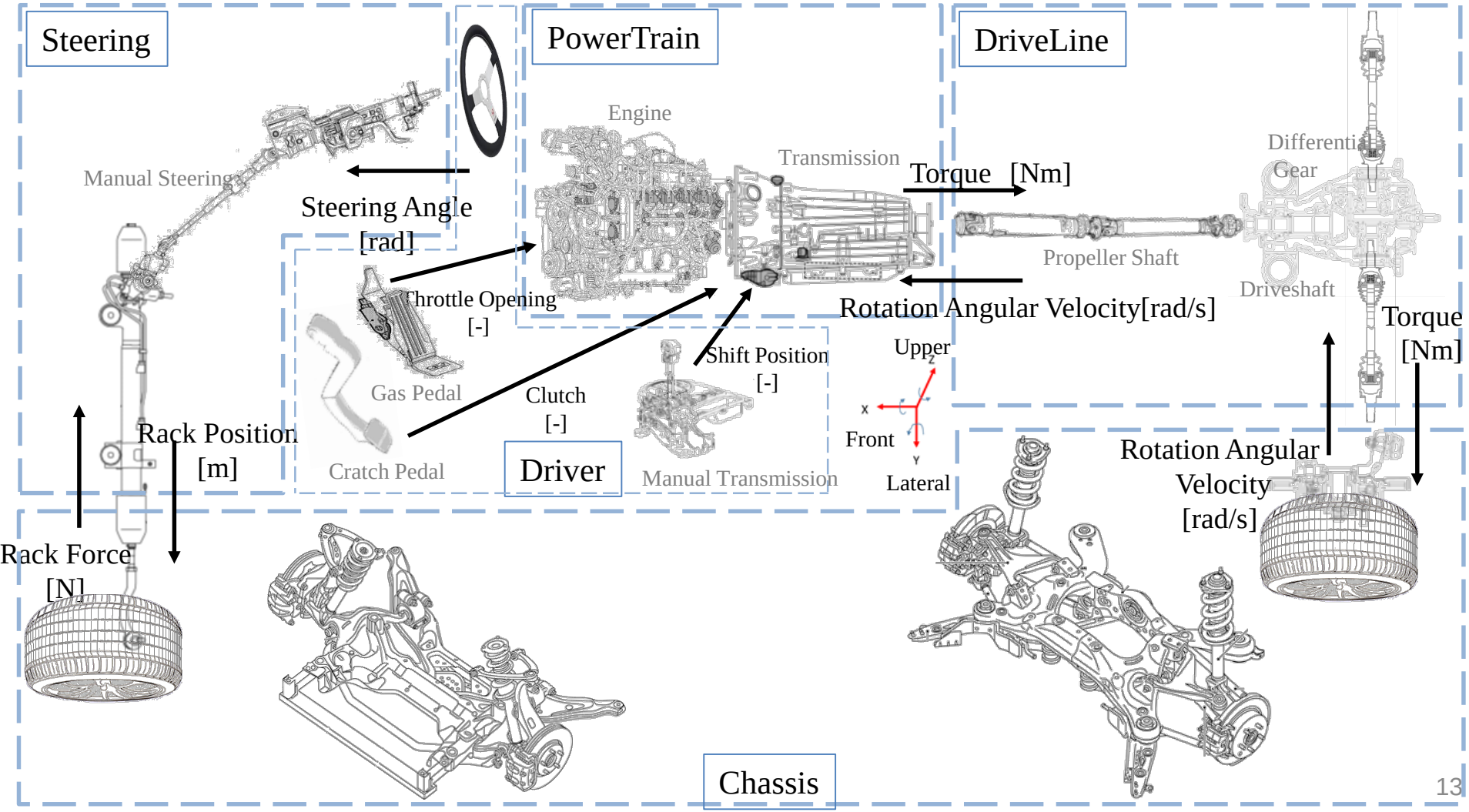
・Adapter : △ - Contains only adapters for some physical domains
× - Can not create adapters
・Run : △ - Do not use adapters and connect directly
・Number : Run time (Ratio to original model run time)

Same simulation results for all combinations

Execution time varies according to combination of tools

4. Confirmation by Full-vehicle model for CS

[Full vehicle model]



Cross-check by Amesim

		Driver	PowerTrain	Driveline	Chassis	Steering	CPU time (ratio vs RT)
Original 1	Model	Amesim original model					39.1
	Solver	LSODA					
	Interval	-					
Original 2	Model	Amesim original model					6.6
	Solver	RK4 5e-5					
	Interval	5E-05					
Case A	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	1.9
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 1e-3	RK4 1e-3	
	Interval	5E-05	5E-05	5E-05	1E-03	1E-03	
Case B	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	1.9
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 1e-3	RK4 5e-5	
	Interval	5E-05	5E-05	5E-05	1E-03	5E-05	
Case C	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	6.1
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 5e-5	
	Interval	5E-05	5E-05	5E-05	5E-05	5E-05	
Case D	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	2.0
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 1e-3	LSODA	
	Interval	5E-05	5E-05	5E-05	1E-03	1E-03	
Case E	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	2.1
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 1e-3	LSODA	
	Interval	5E-05	5E-05	5E-05	1E-03	5E-05	
Case F	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	3.8
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	LSODA	LSODA	
	Interval	5E-05	5E-05	5E-05	1E-03	5E-05	
Case G	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	21.7
	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	LSODA	LSODA	
	Interval	5E-05	5E-05	5E-05	5E-05	5E-05	
Case H	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	18.7
	Solver	LSODA	LSODA	LSODA	LSODA	LSODA	
	Interval	5E-05	5E-05	5E-05	1E-03	5E-03	
Case I	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	15.8
	Solver	LSODA	LSODA	LSODA	RK4 1e-3	RK4 5e-5	
	Interval	5E-05	5E-05	5E-05	1E-03	5E-05	
Case J	Model	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	Amesim FMU	38.3
	Solver	LSODA	LSODA	LSODA	LSODA	LSODA	
	Interval	5E-05	5E-05	5E-05	5E-05	5E-05	

Fixed Time Step Solver

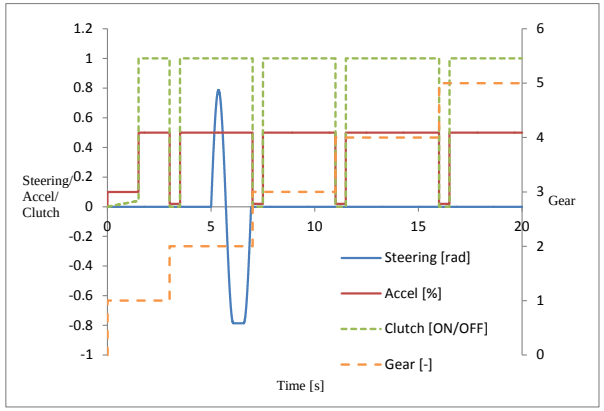
Variable Time Step Solver

FMU from different tools

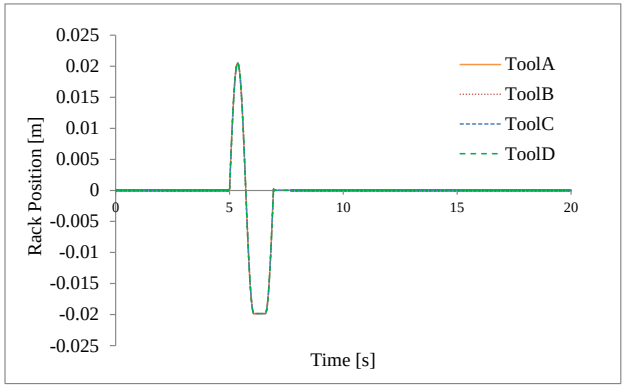
							Host Tool CPU time (ratio vs RT)			
							Amesim	SimulationX	Dymola	Simulink +Modelon
				Fixed Time Step Solver			DEV.15.0.1	3.7	2017fd	2015b
				Variable Time Step Solver			Win64	Win64	Win64	Win64
	Model	Amesim FMU	Amesim FMU	Simulink FMU	Dymola FMU	SimulationX FMU	Rk4, 5e-5	Euler1, 5e-5	Rk4, 5e-5	Rk4, 5e-5
		Driver	**Power Train**	**Driveline**	**Chassis**	**Steering**	Chassis FMI1.0	Chassis FMI1.0	Chassis FMI1.0	Chassis FMI1.0
Case 1	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 1e-3	CVODE	6.2	7.0	7.3	6.9
	Interval	5E-05	5E-05	5E-05	1E-03	1E-03				
Case 2-1	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 5e-5	CVODE	42.5	43.8	44.1	46.1
	Interval	5E-05	5E-05	5E-05	1E-03	1E-03				
Case 2-2	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 5e-5	CVODE	44.6	45.5	46.2	47.5
	Interval	5E-05	5E-05	5E-05	5E-04	5E-04				
Case 2-3-1	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	RK4 5e-5	CVODE	86.4	81.8	84.0	88.0
	Interval	5E-05	5E-05	5E-05	5E-05	5E-05				
Case 3-1	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	DASSL	CVODE	129.7	126.2	128.5	134.1
	Interval	5E-05	5E-05	5E-05	1E-03	1E-03				
Case 3-2	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	DASSL	CVODE	264	264	266.0	280.7
	Interval	5E-05	5E-05	5E-05	5E-04	5E-04				
Case 3-3	Solver	RK4 5e-5	RK4 5e-5	RK4 5e-5	DASSL	CVODE	2716	2704	2715	2852
	Interval	5E-05	5E-05	5E-05	5E-05	5E-05				

Simulation results (Case3-3)

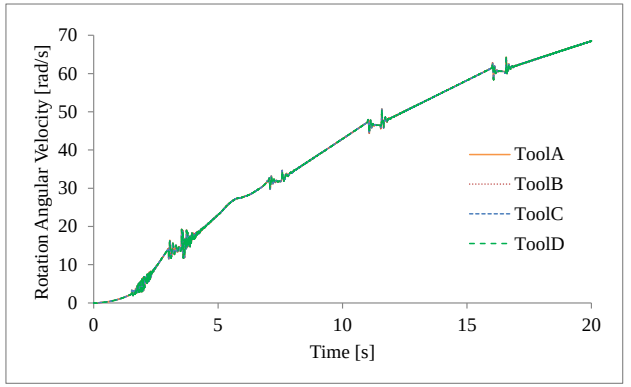
Results of connection signals of each part



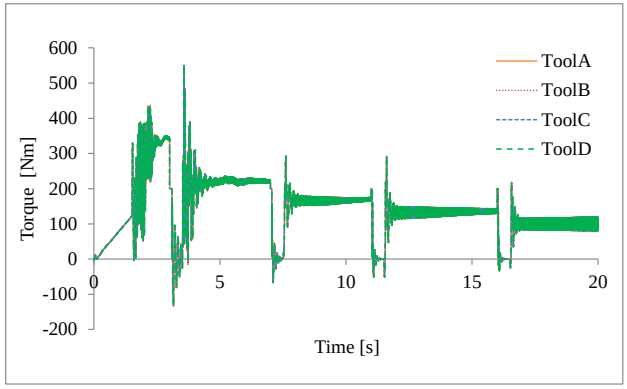
Input Signals
(Driver)



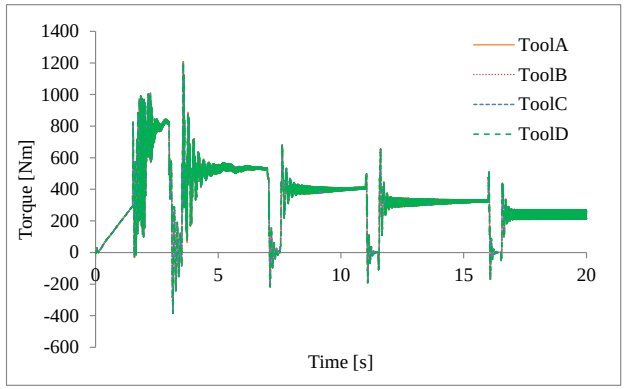
Rack Position
(Steering)



Rear Left Wheel Rotation Angular Velocity
(Chassis)



Transmission Output Torque
(PowerTrain)



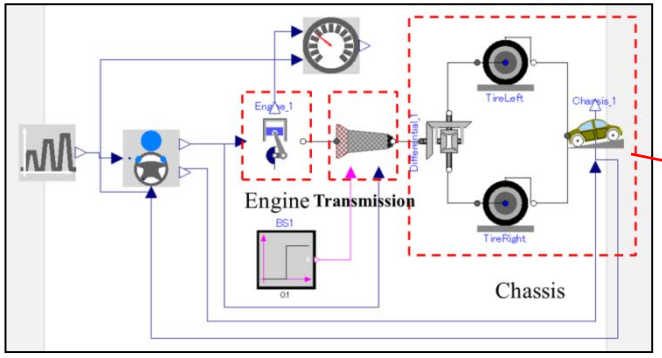
Rear Left Driveshaft Torque
(DriveLine)

Identical simulation results with 4 host tools (Same in other cases)

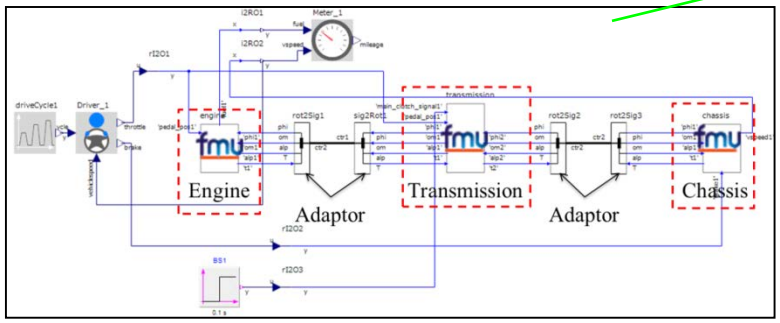
5. Clarified problems (FMI implementation)

[Model for ME]

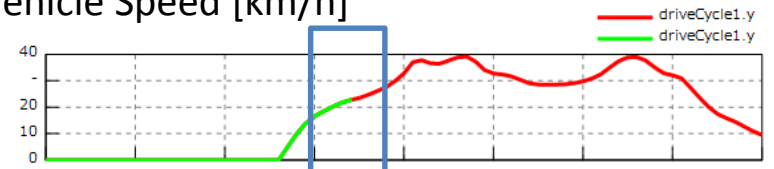
Original



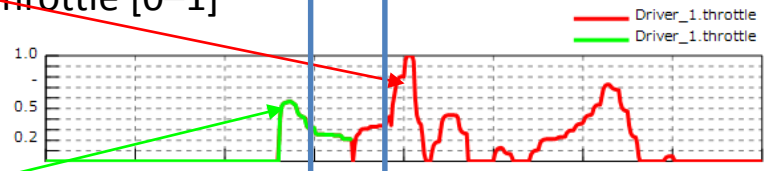
Model Exchanged



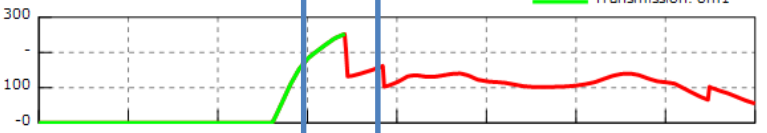
Vehicle Speed [km/h]



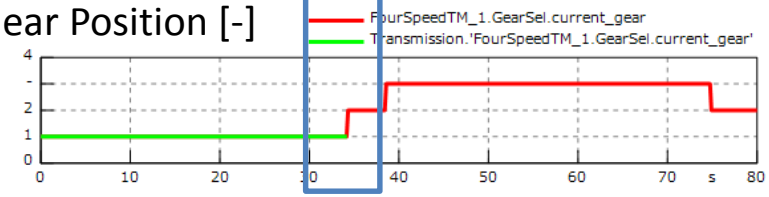
Throttle [0–1]



Engine Speed [rad/s]



Gear Position [-]



When a discontinuity (gear changing) occurs, sometimes calculation became impossible. (For some combinations of the tools.)

It is desirable that the cross-checker by MA will include the cases of discontinuity.

5. Clarified problems (FMI implementation)

[Model for CS]

- The initial value of the FMU should be set correctly.
  - Difficult to derive the correct initial value.
  - Set the initial speed of all models to 0 km/h and the initial value to 0.

(In this case, the initial value of the chassis was changed from 10 km/h to 0 km/h, and the FMU was recreated.)

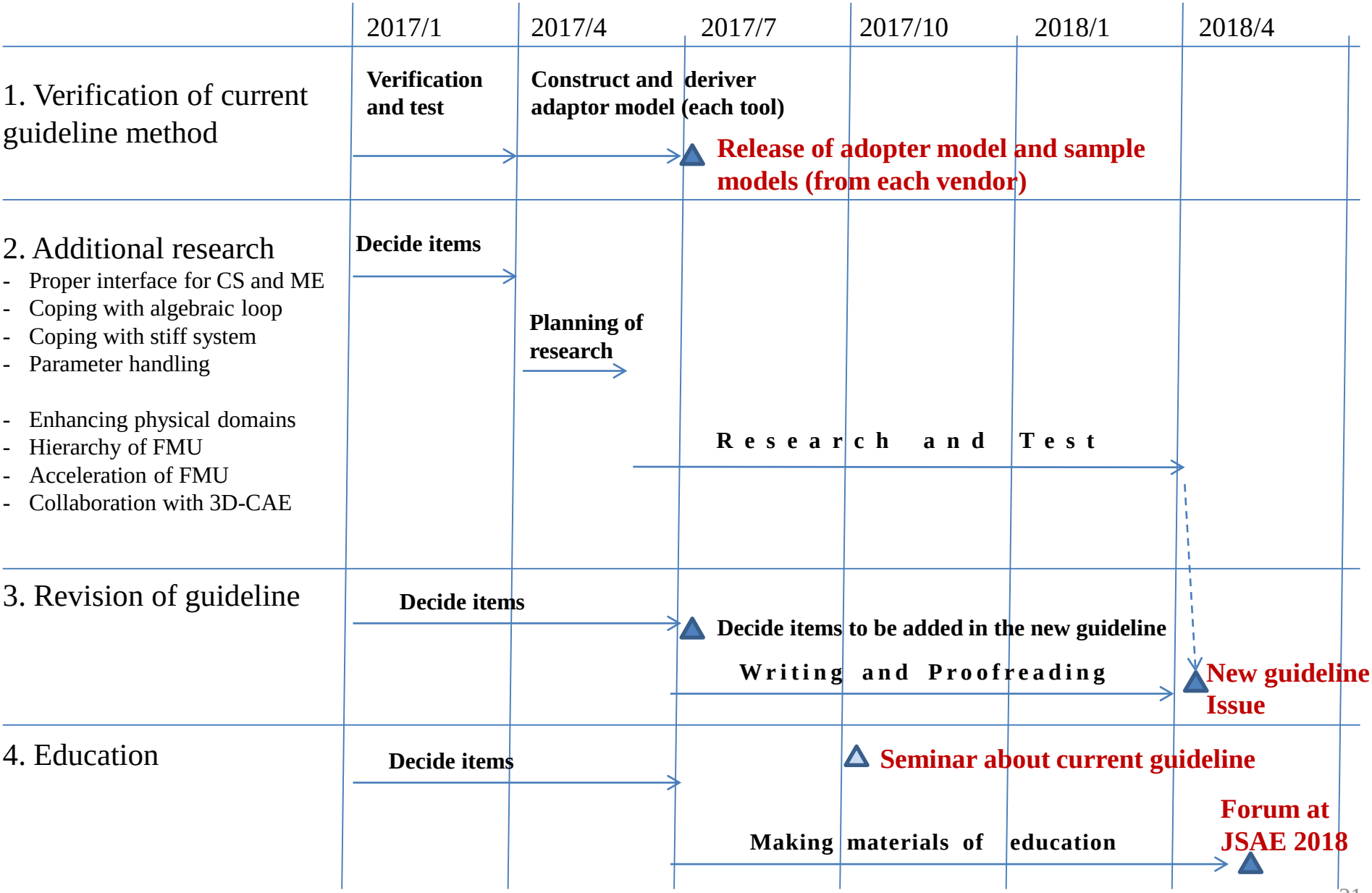
6. Requests for additional functions

No.	Problems	Factors
1	Proper guideline of CS and ME is not shown.	Some selection of flow variables sometimes cause problem. (Different for CS and ME.)
2	Algebraic loops are not handled automatically	Need to analyze closed loop gain of the algebraic loop.
3	Combining stiff FMUs causes problem.	Need to analyze time constants of the sub-systems before connecting FMUs.
4	Handling of parameters / variables between FMUs is not established.	Interconnecting parameters and proper initialization of variables are necessary.

6. Additional problems (Low priority)

No.	Problems	Factors
5	Enhancing physical domains of the adopter model.	Currently only electrical and mechanical (1D) domains available.
6	Coping with hierarchy of FMUs	
7	Coping with acceleration of FMUs (for HILS)	
8	Collaboration with 3D-CAE tools	

7. Future plan of the WG activities



Thank you for your attention.