



Enhancing Human Factors Analysis with STPA

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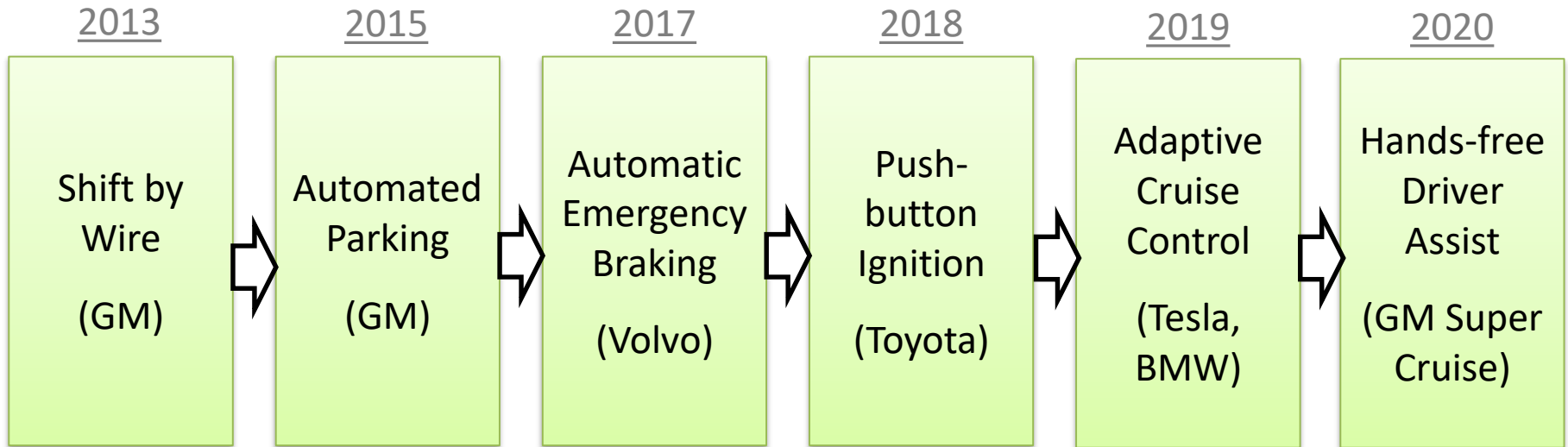


Tutorial Objective

- These short tutorials are **not training classes**
- We cannot cover everything in these tutorial sessions. The objective is just to introduce some of the core concepts and help new attendees follow the presentations to come. These short tutorials are subsets of larger training classes.
- As with most techniques, training and practice with a qualified instructor are needed to apply these techniques and become proficient.

STPA-HF Development

Previous STPA-HF development based on existing test-bed applications:



Acknowledgements

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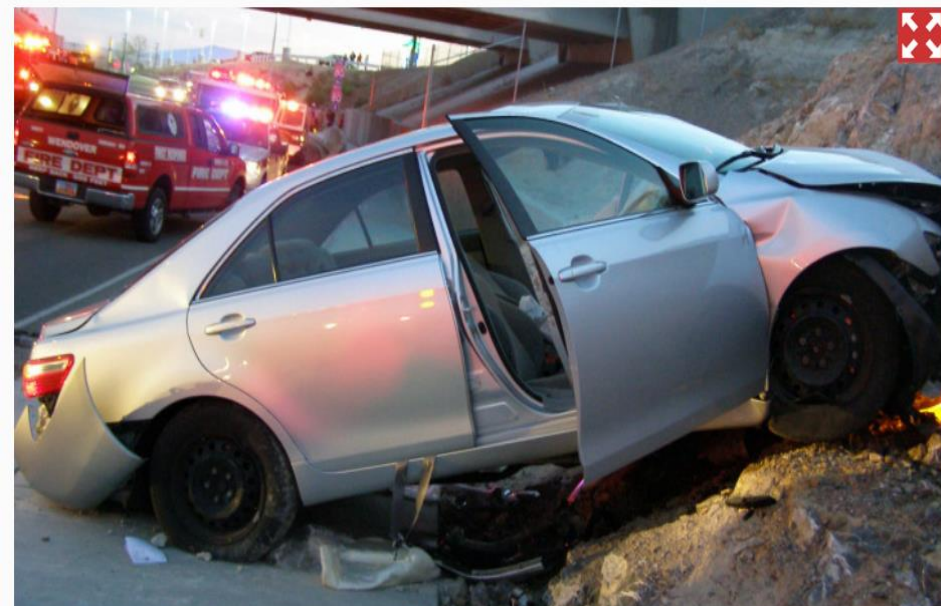
Unintended Acceleration



Toyota to pay \$1.2B settlement in vehicle acceleration lawsuit

By Bob Fredericks and Post Wires

March 19, 2014 | 9:19am



**All components operated exactly as designed!
Human and Software considerations cannot be isolated!**

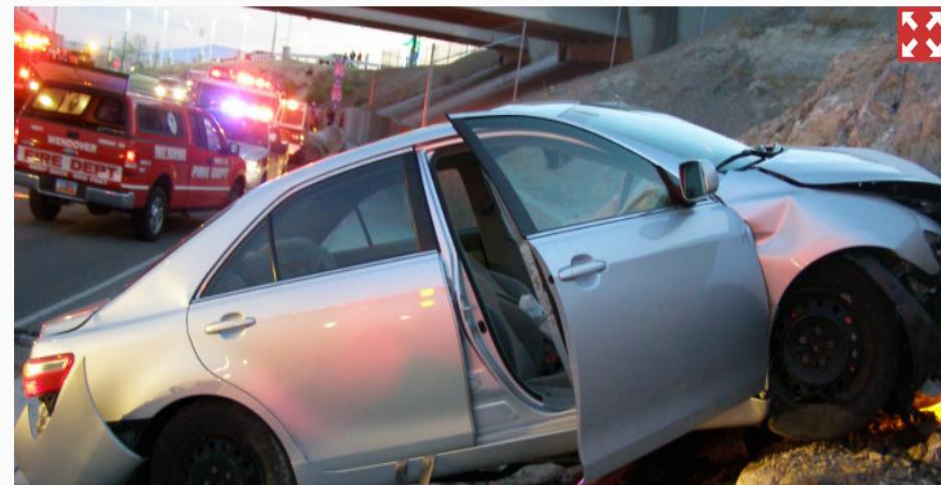
Unintended Acceleration



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Component View: Just simple driver error. Didn't follow defined procedures.

Systems View: Human error was influenced by system & software design choices.
A better system/software strategy would prevent this human error!

Which of these views is more helpful & effective?

STAMP / STPA View

(and the HF Engineering view)

- Human error is a symptom, not a cause
- All human behavior affected by context (system) in which it occurs
 - To understand human error, look at the system
 - System designs can make human error inevitable
 - **When bad systems cause operator error, can we really blame the operators rather than designers?**
- To do something about operator error, look at:
 - Unintuitive automation, SW design, system design, etc.
 - Usefulness of procedures (not just compliance)
 - Existence of goal conflicts and production pressures
 - Etc.

Human error is a symptom of a system that was designed poorly!

Asiana 214 Crash



NTSB Probable Causes:

- The flight crew's mismanagement ...
- The pilot flying's unintended deactivation ...
- The flight crew's inadequate monitoring
- The flight crew's delayed
- The flight crew's nonstandard ...
- The pilot flying's inadequate training
- The pilot monitoring [...] inadequate ...
- Flight crew fatigue
- Etc.

Air France 447 Crash

Air France crash blamed on pilot error

Pilots could have saved plane after it lost speed readings according to French air investigation report into 2009 accident



Press / Rex Features

Força Aérea Brasileira

Are these really just simply pilot errors?
Are there no lessons for software & system engineers to learn from this?
What about the automation and the system design choices that made recovery easy/hard?

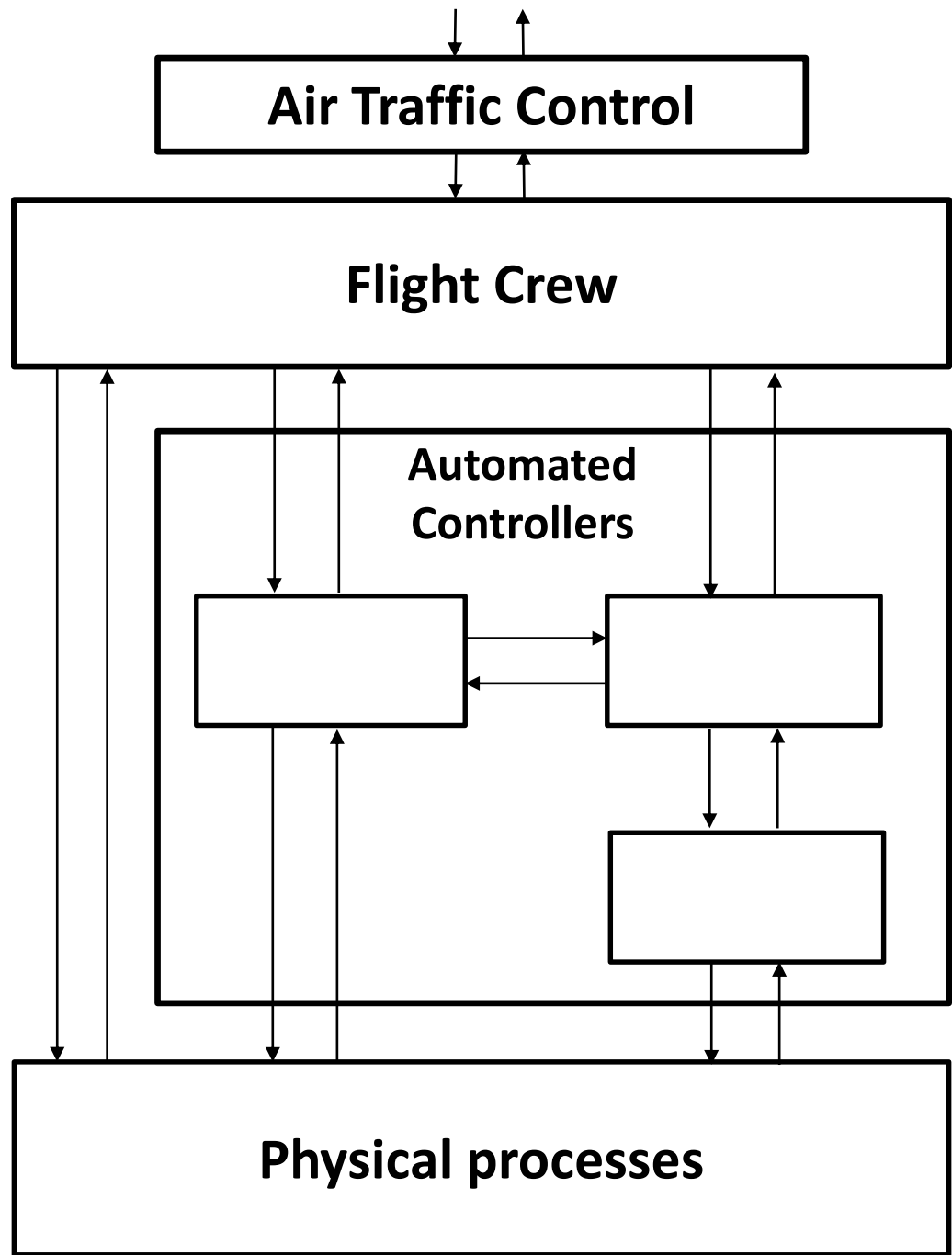
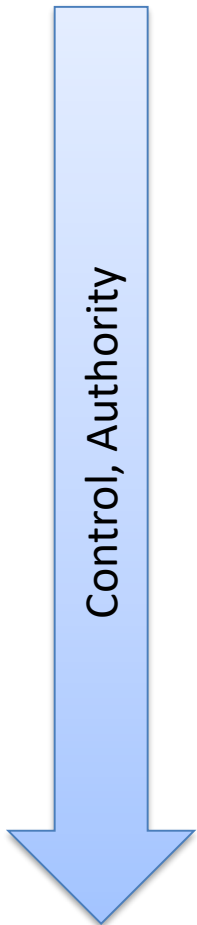
A/T will remain in HOLD mode until one of the following conditions is met:

[...]

5) The A/P is disconnected, and both F/D switches are turned off

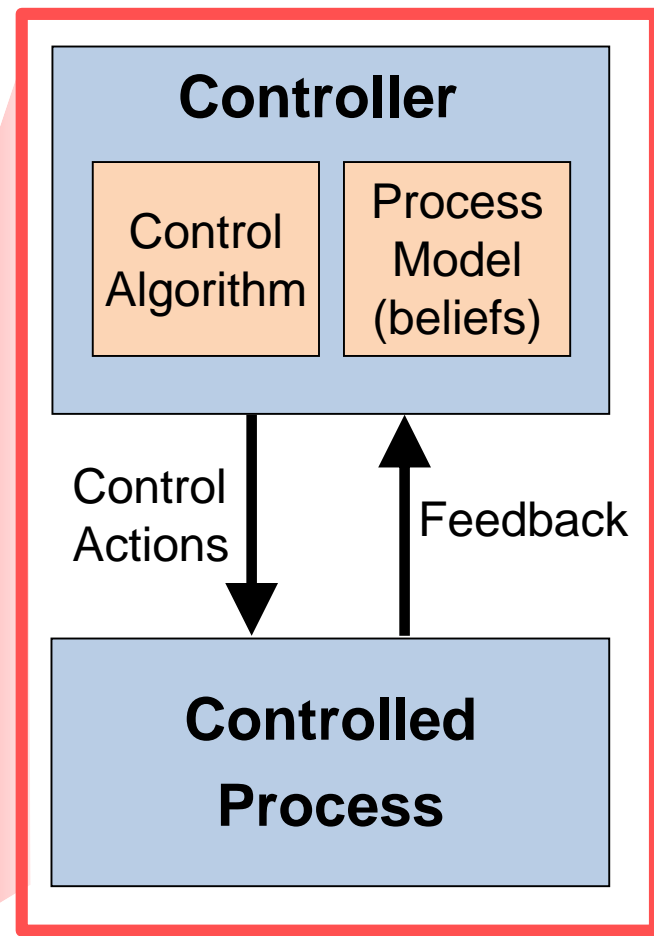
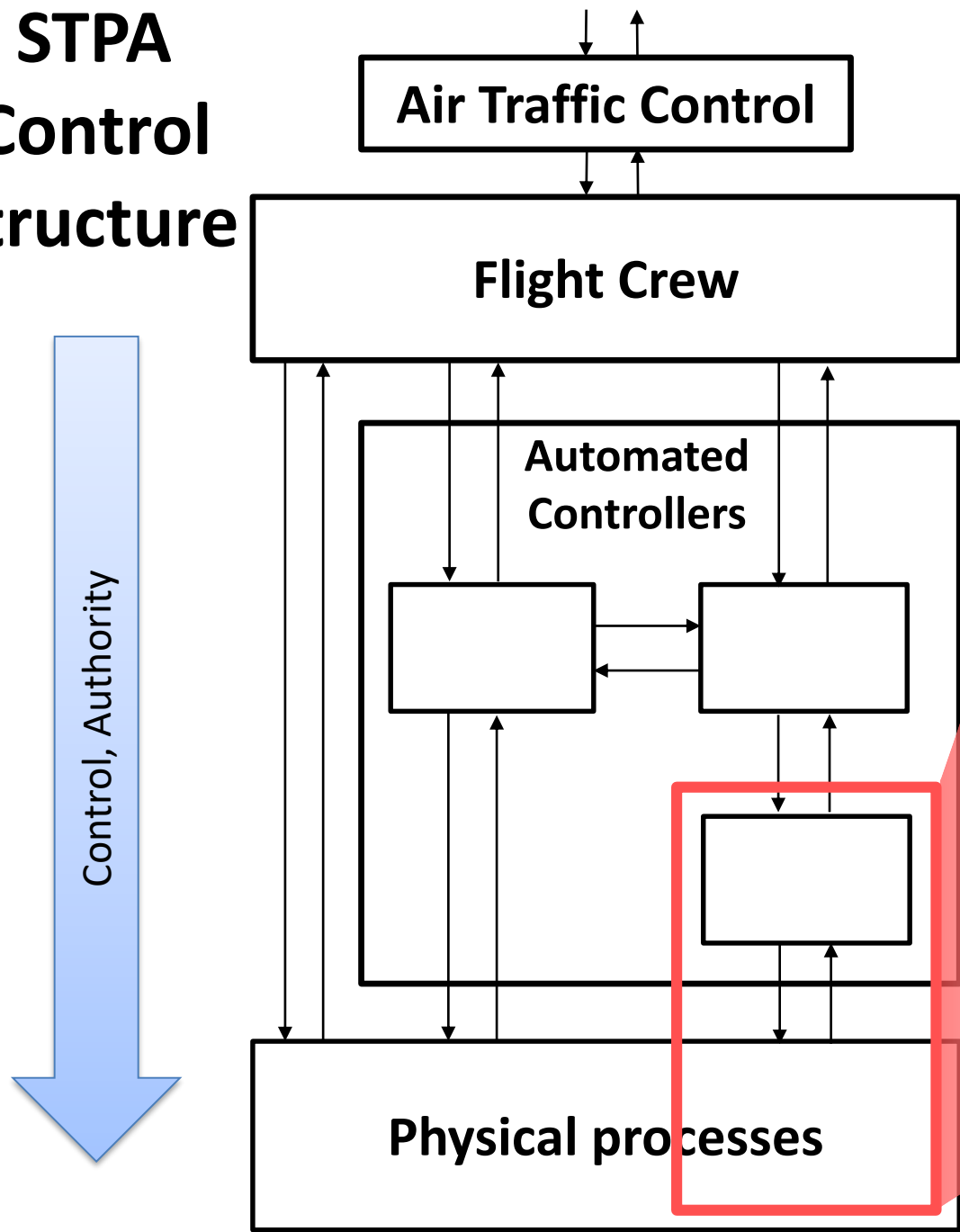


STPA Control structure

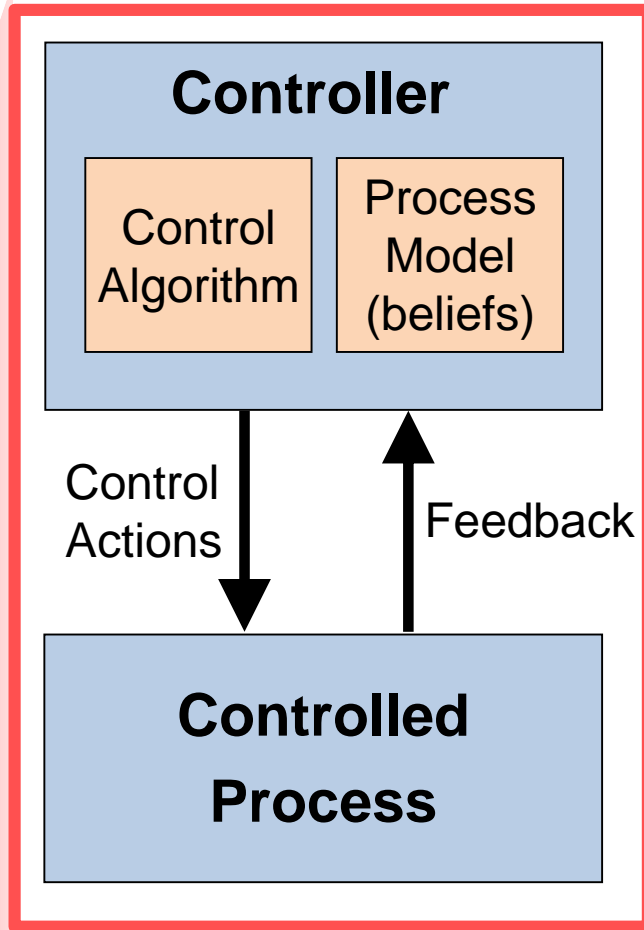
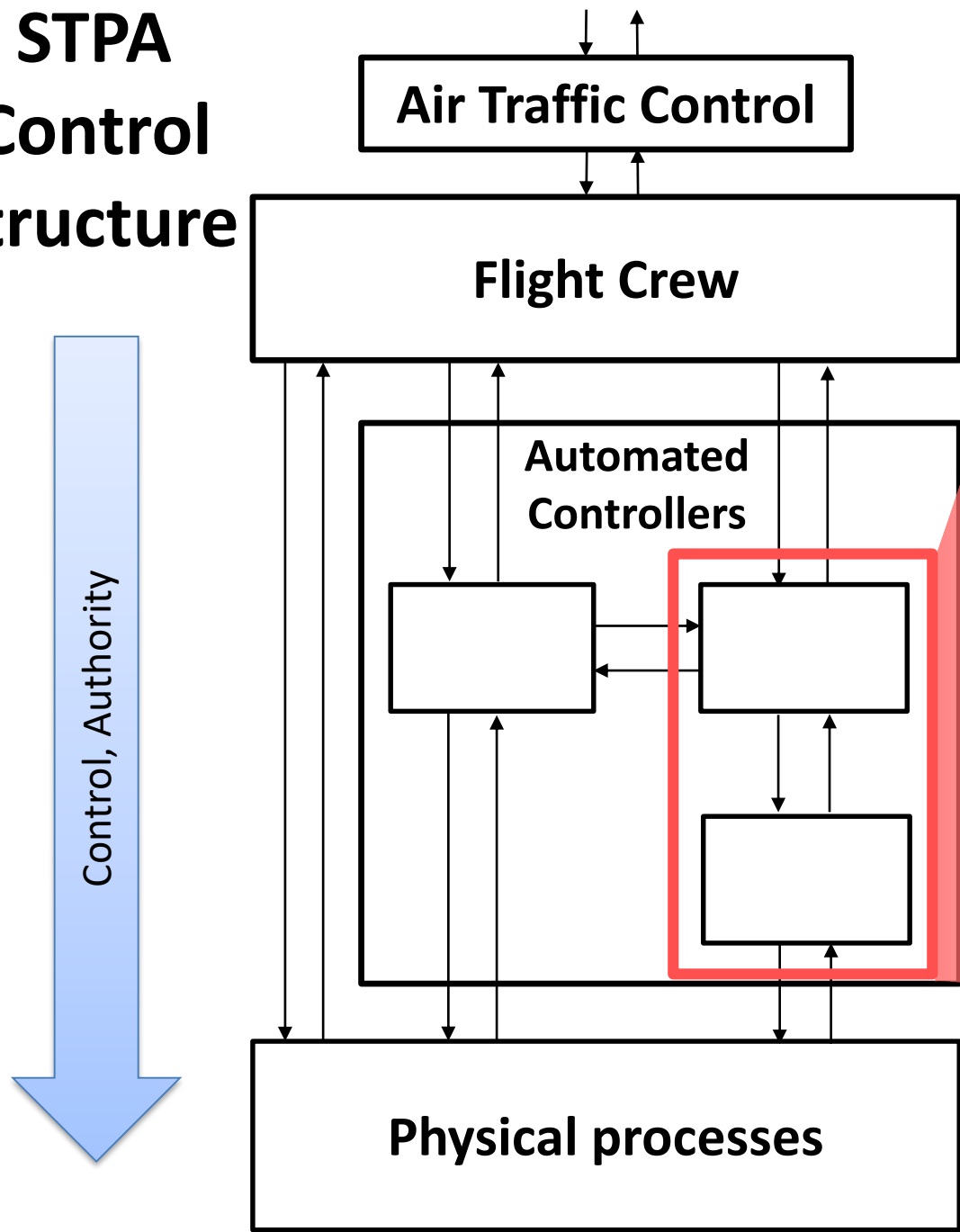


(Thomas, 2017)

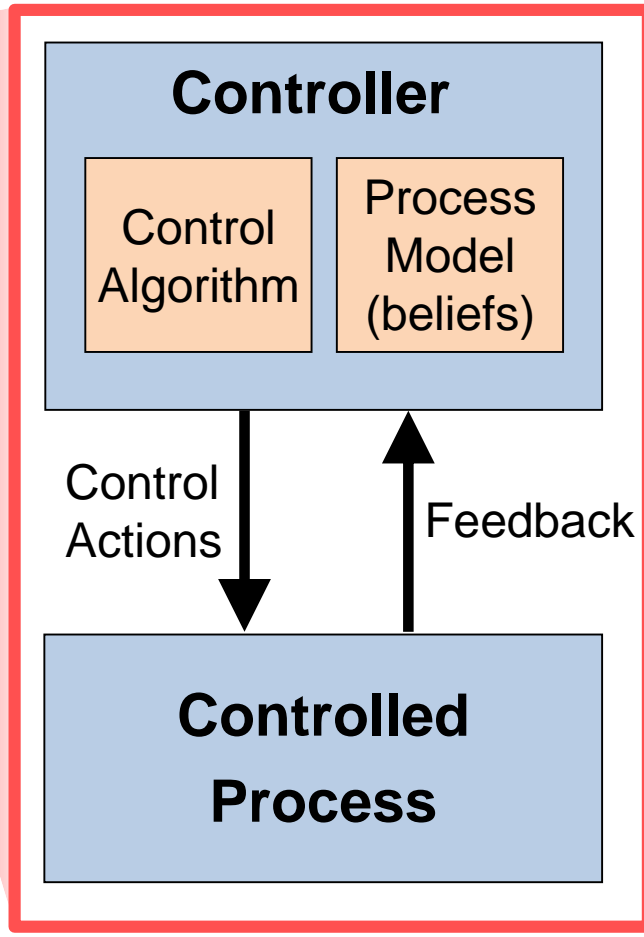
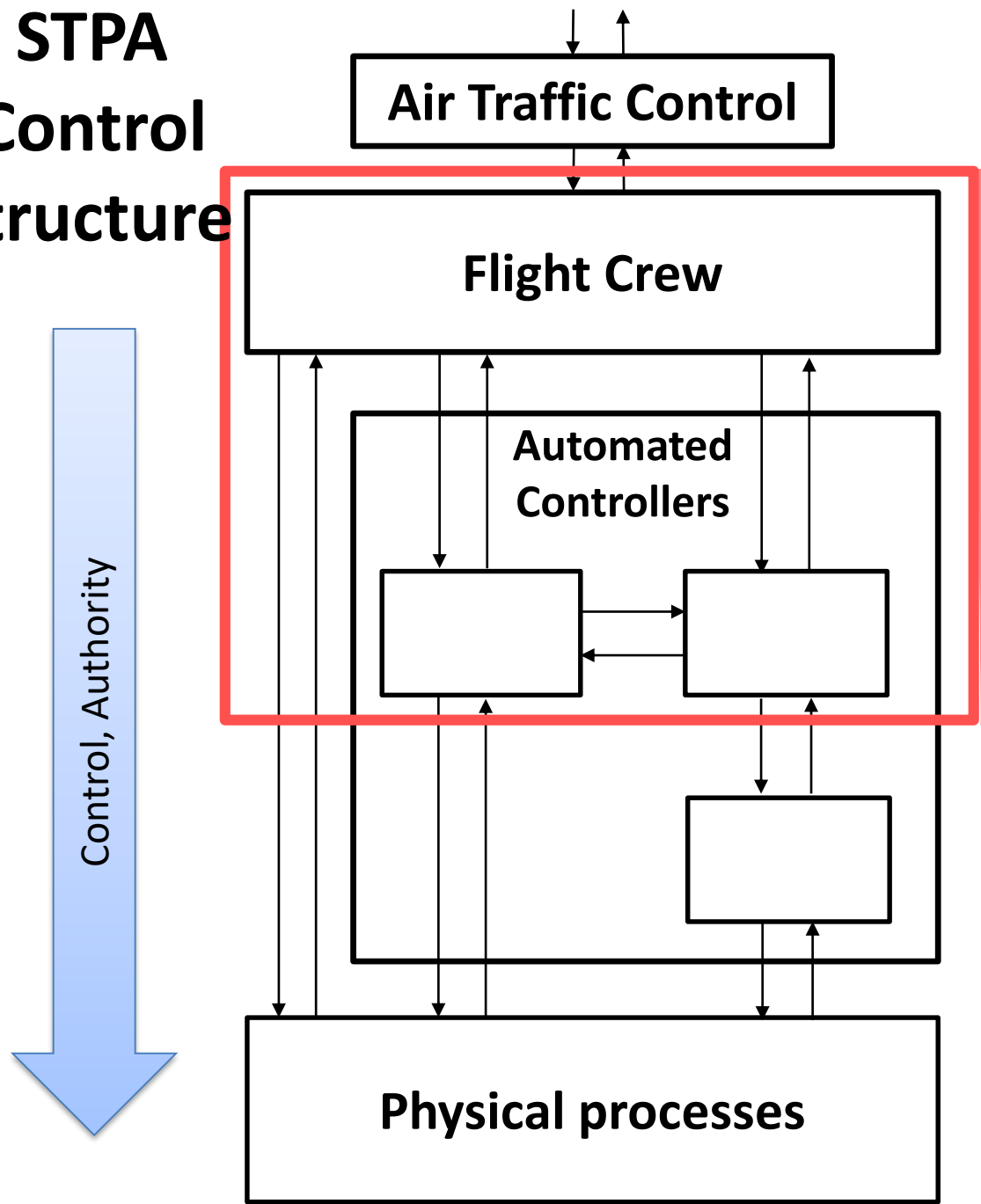
STPA Control structure



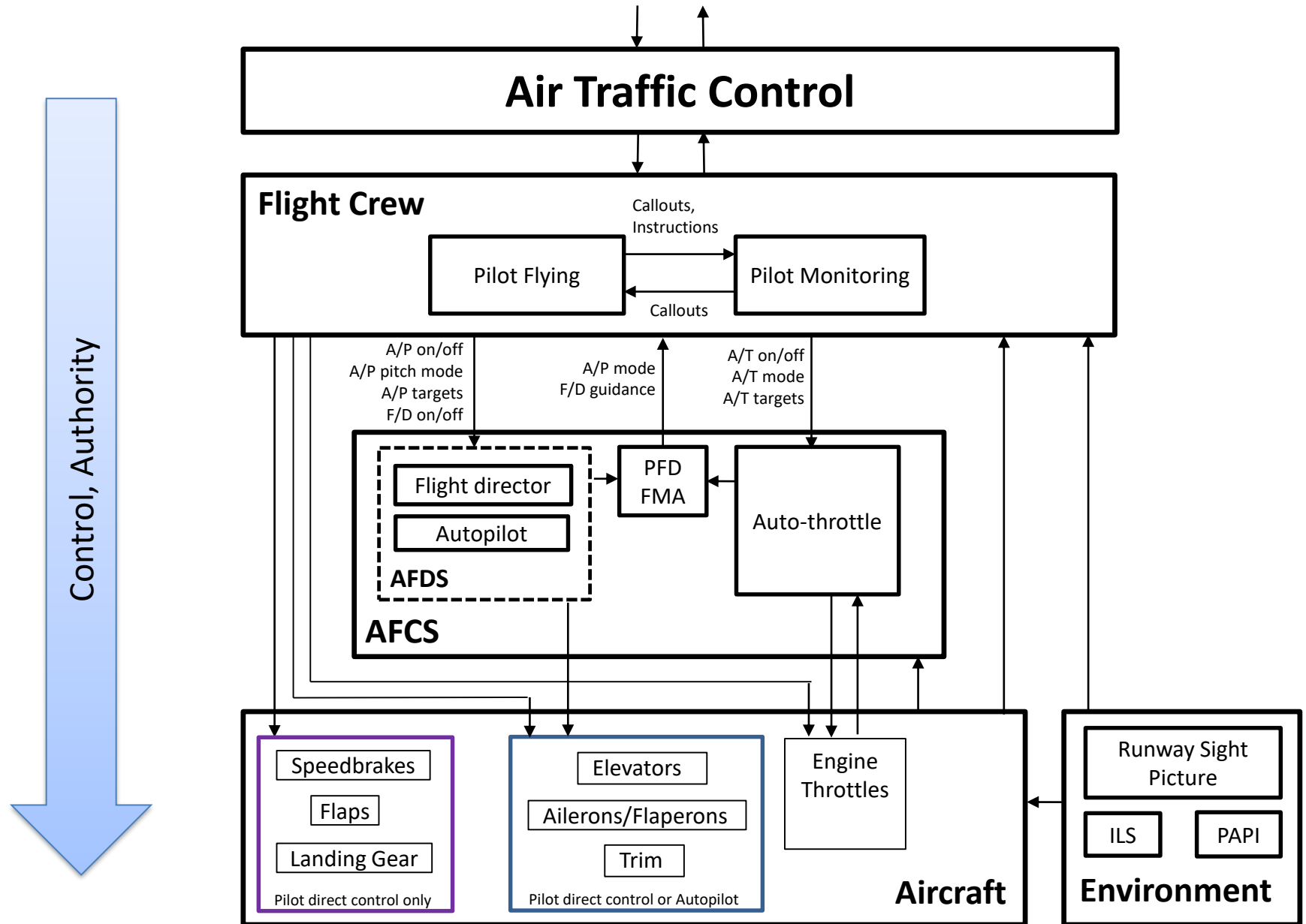
STPA Control structure



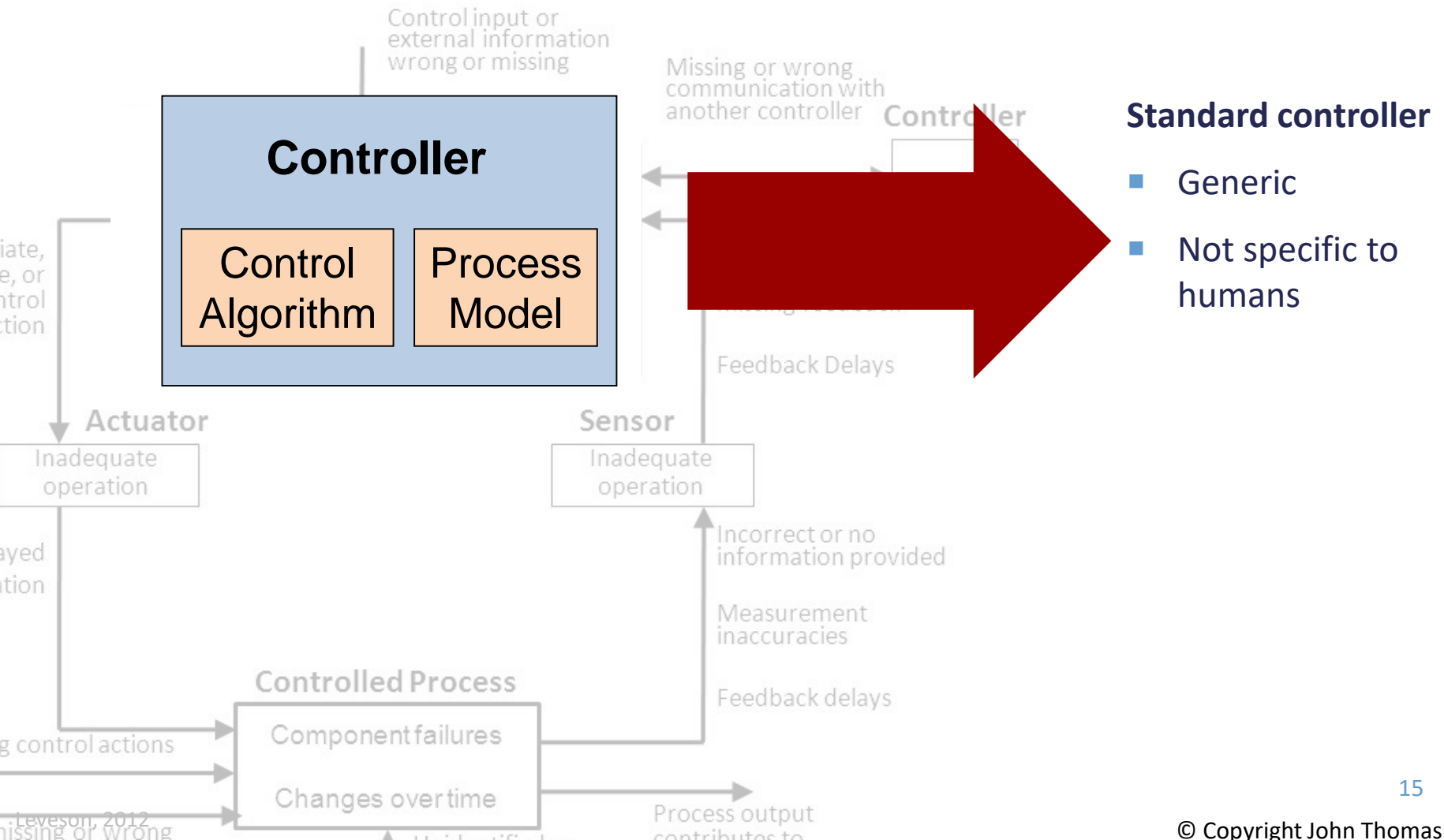
STPA Control structure



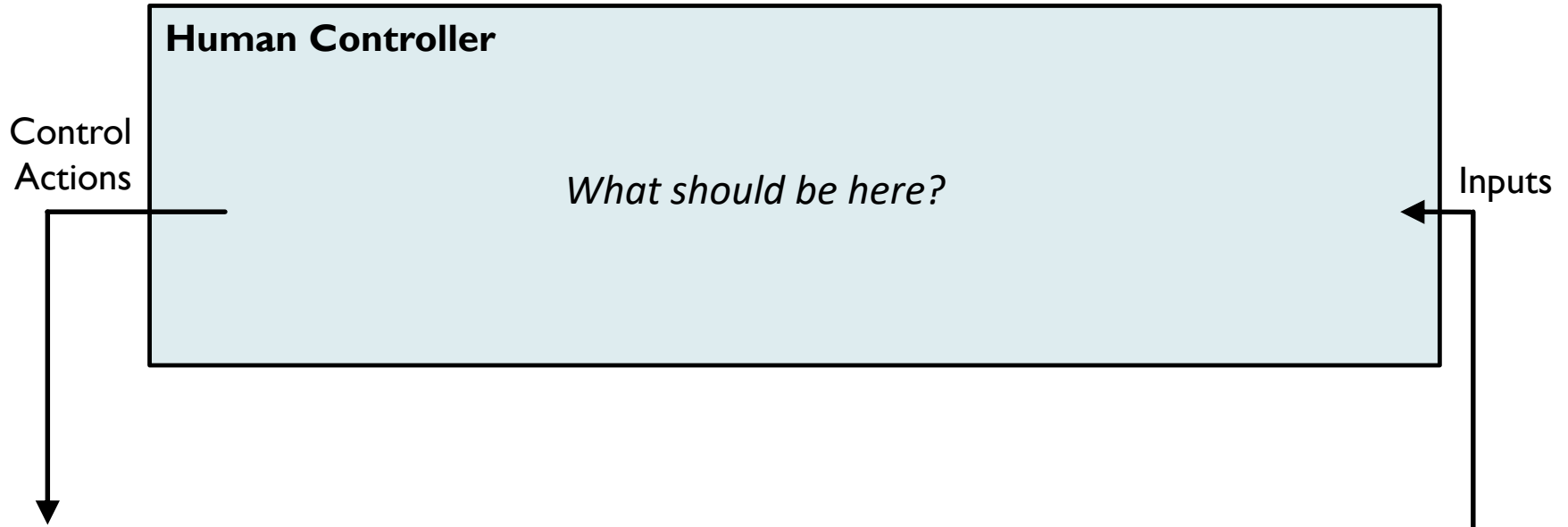
STPA Control Structure



Standard STAMP / STPA Controller model



STPA-HF: IMPROVING THE HUMAN CONTROL MODEL



EXISTING HUMAN FACTORS MODELS

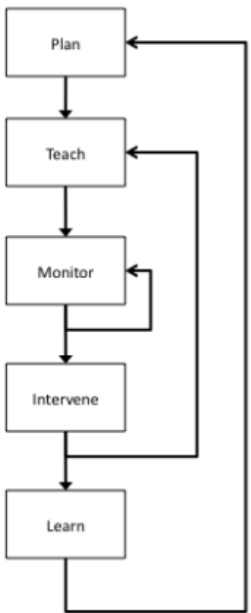


Figure 3. Sheridan's (1992) Supervisory Control Model.

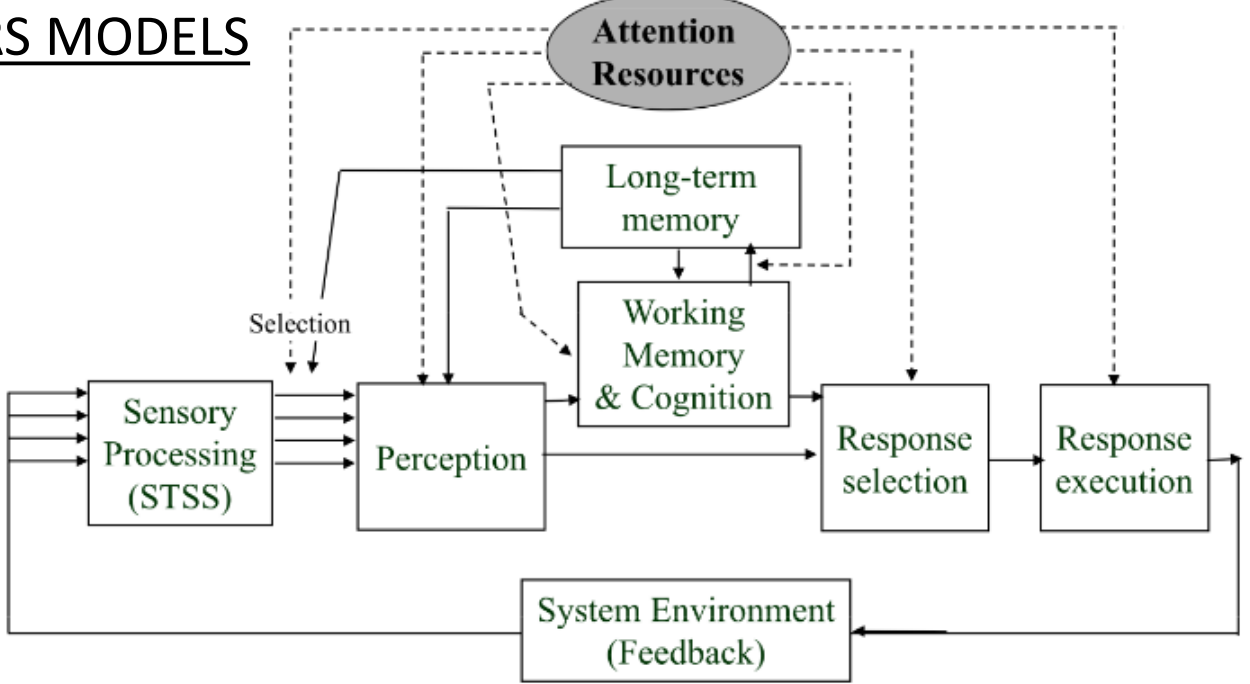


Figure 2. Modified from Wickens and Hollands (2000, p.11).

MENTAL FUNCTION REQUIRED	OBSERVATION	IDENTIFICATION	INTERPRETATION	DEFINE TASK	FORM. PROCEDURE		
	READ	DIAGNOSIS	PREDICTION	EVALUATION	DECISION	PLAN PROCEDURE	KNOWLEDGE-BASED
INFORMATION PROCESSES	SEE	CLASSIFICATION		CHOICE ASSOCIATION	RECALL PROCEDURE		RULE-BASED
		CHECK		RECALL CONDITIONS			
	LOOK	FEATURE MATCH			STORED ROUTINES		SKILL-BASED
	INPUT INFORMATION			SCHEDULE ORDER INPUT		OUTPUT ACTIONS	

Fig. 3. The diagram illustrates how the same required mental function can be served by different information processes - each with particular error mechanisms.

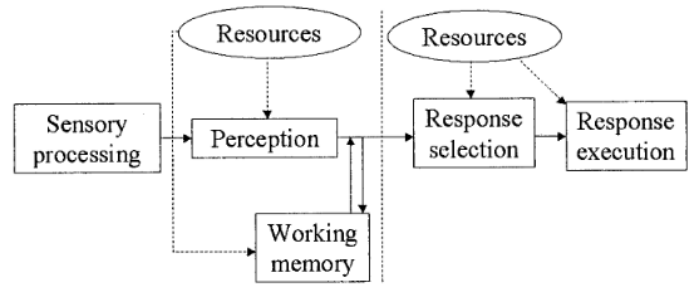
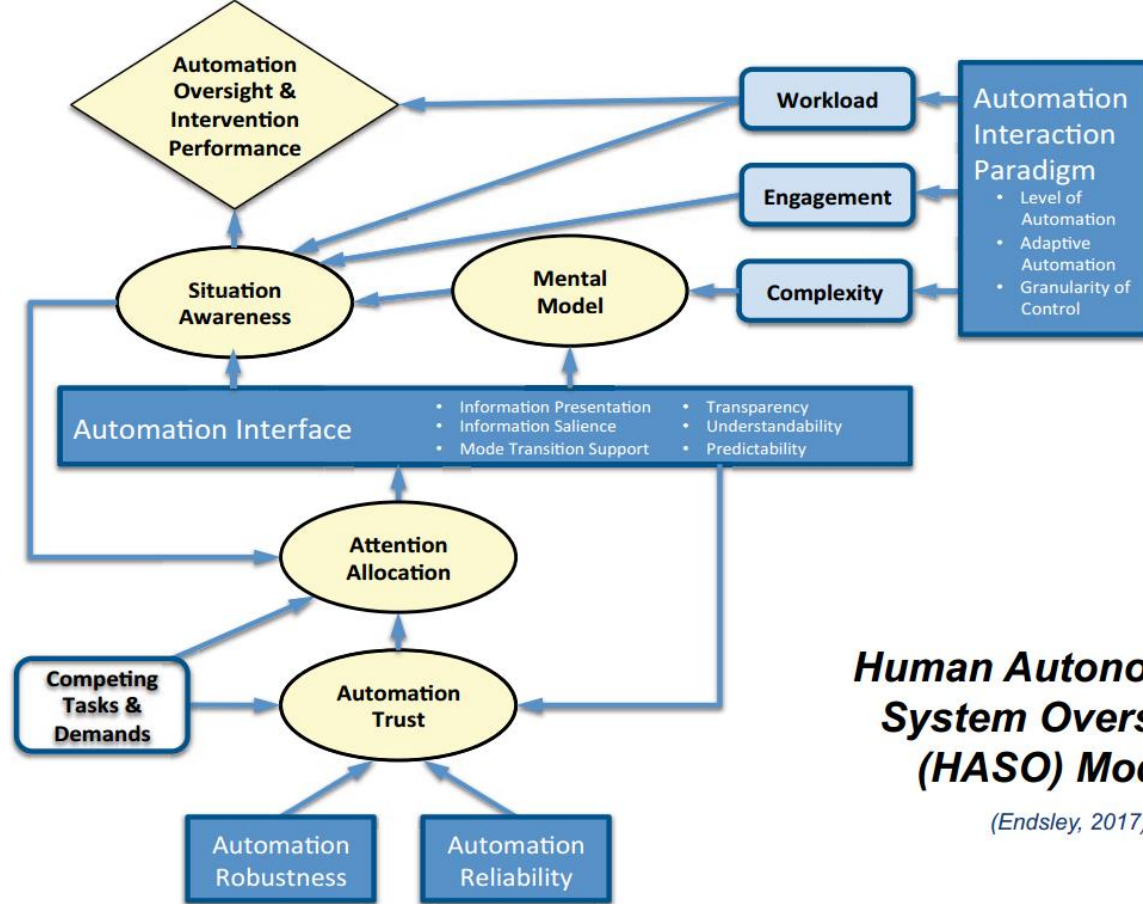


Figure 2. Representation of two resources, supplying the different stages of information processing. Sensory processing, the operation of the peripheral visual and auditory systems, is assumed to be relatively resource-free (after Wickens and Hollands 2000).



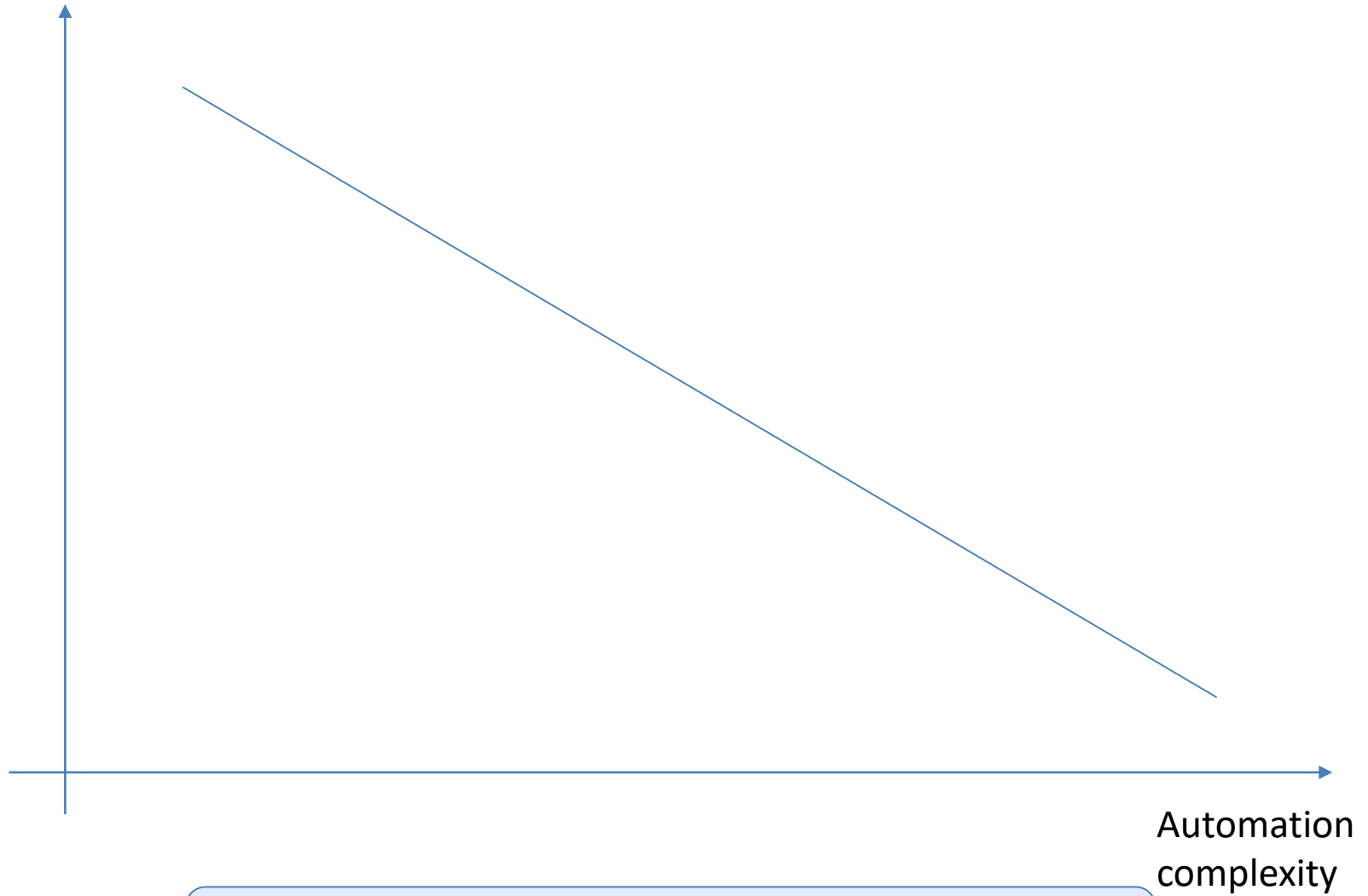
Human Autonomous System Oversight (HASO) Model

(Endsley, 2017)

“This is really complicated, just doesn’t make sense to me”

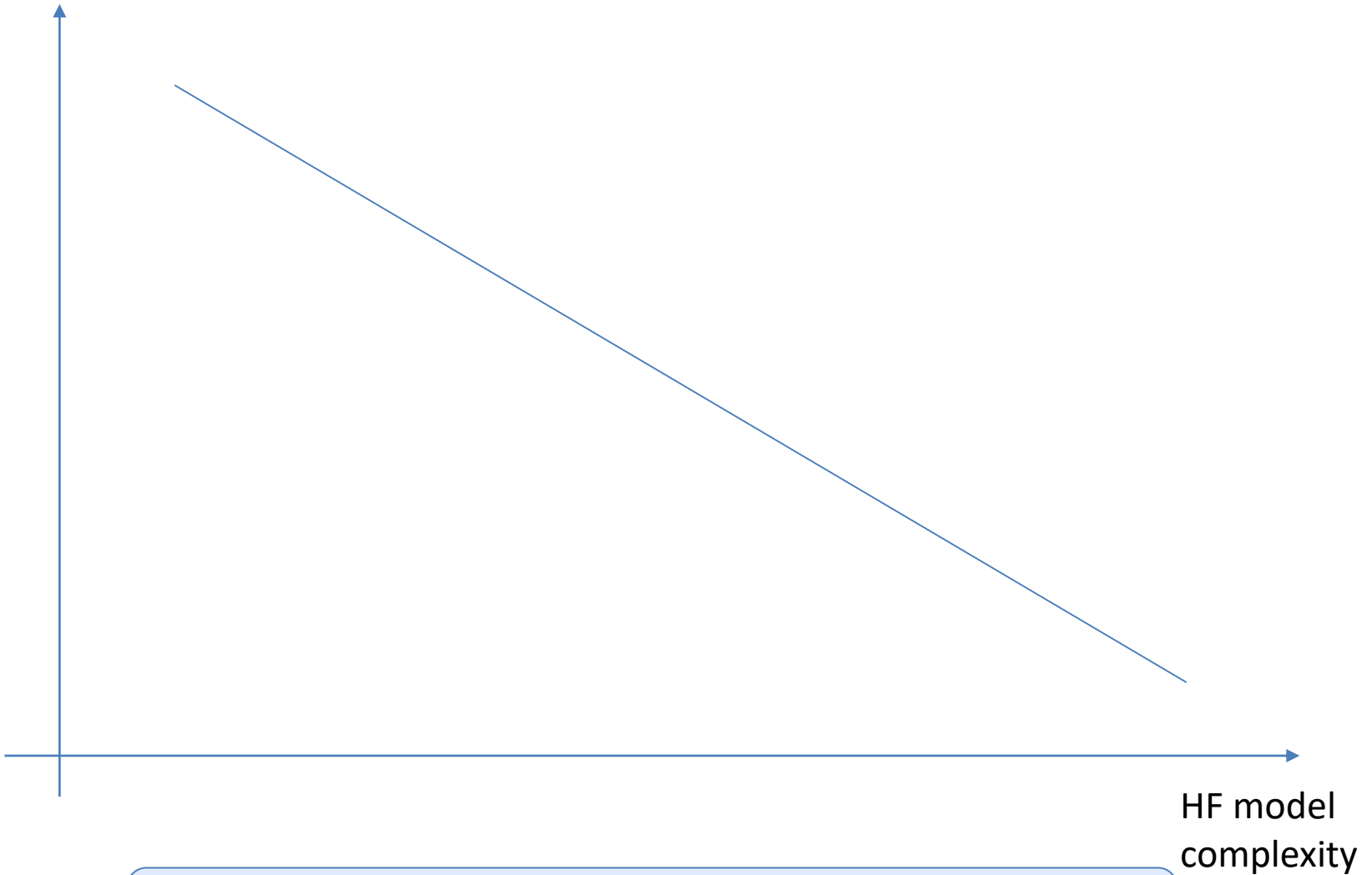
– Fredrik Matheson, “Promoting trust in AI applications”

Human
understanding of
automation



A well-known HF insight

Human engineers'
understanding of HF
model



This HF insight applies to our HF models too!

Tradeoff

Usability,
Learnability

Complexity



Higher layers: procedures, supervision, management, etc.



Human Controller

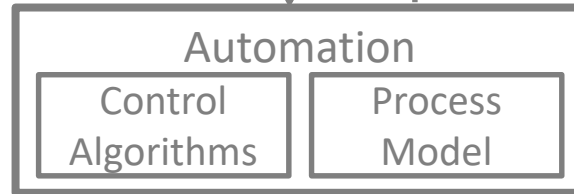
What should be here?

← Environment

Steer
Accelerate
Brake
Etc.

Enable, Disable,
Etc.

Warning signals



Change lane
Accelerate
Brake, Etc.

Manual override detected
Wheel speed
PRNDL
Etc.



Higher layers: procedures, supervision, management, etc.



Human Controller

Control
action
selection

Process Models

Update
Process
Models

Other Factors

← Environment

Enable, Disable,
Etc.

Warning signals

Automation

Control
Algorithms

Process
Model

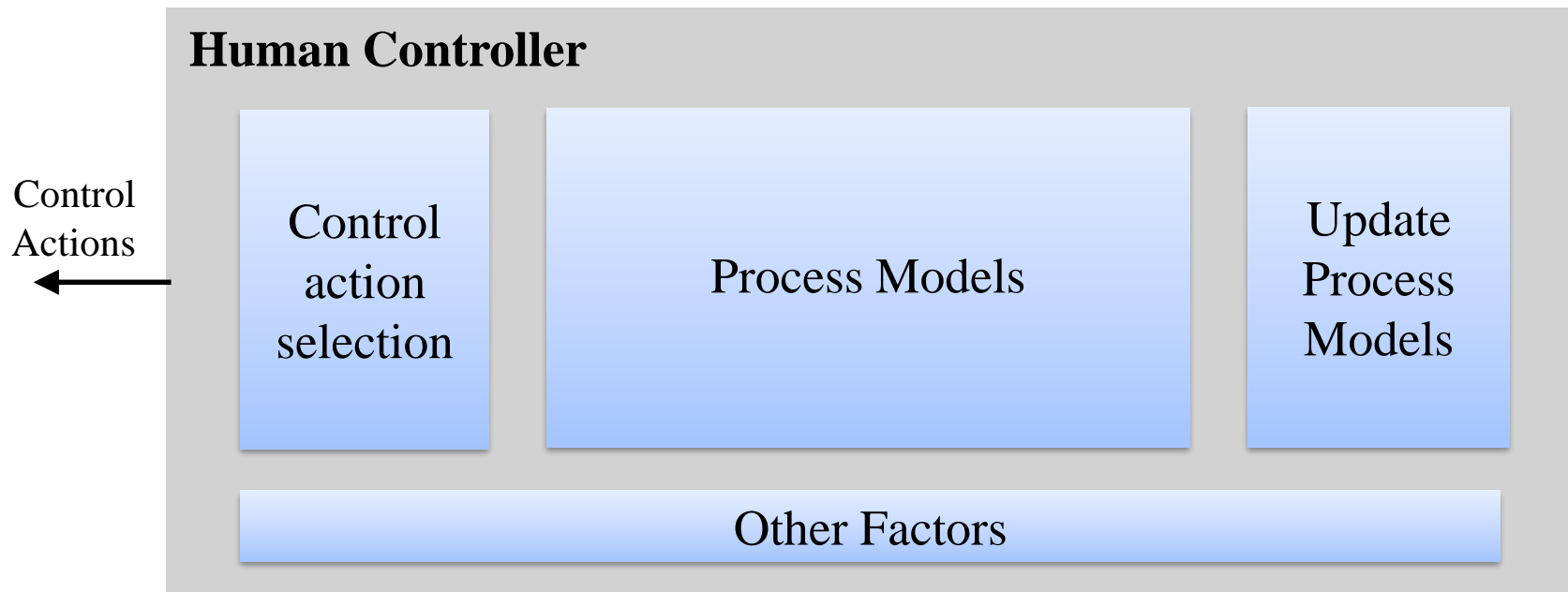
Steer
Accelerate
Brake
Etc.

Change lane
Accelerate
Brake, Etc.

Manual override detected
Wheel speed
PRNDL
Etc.

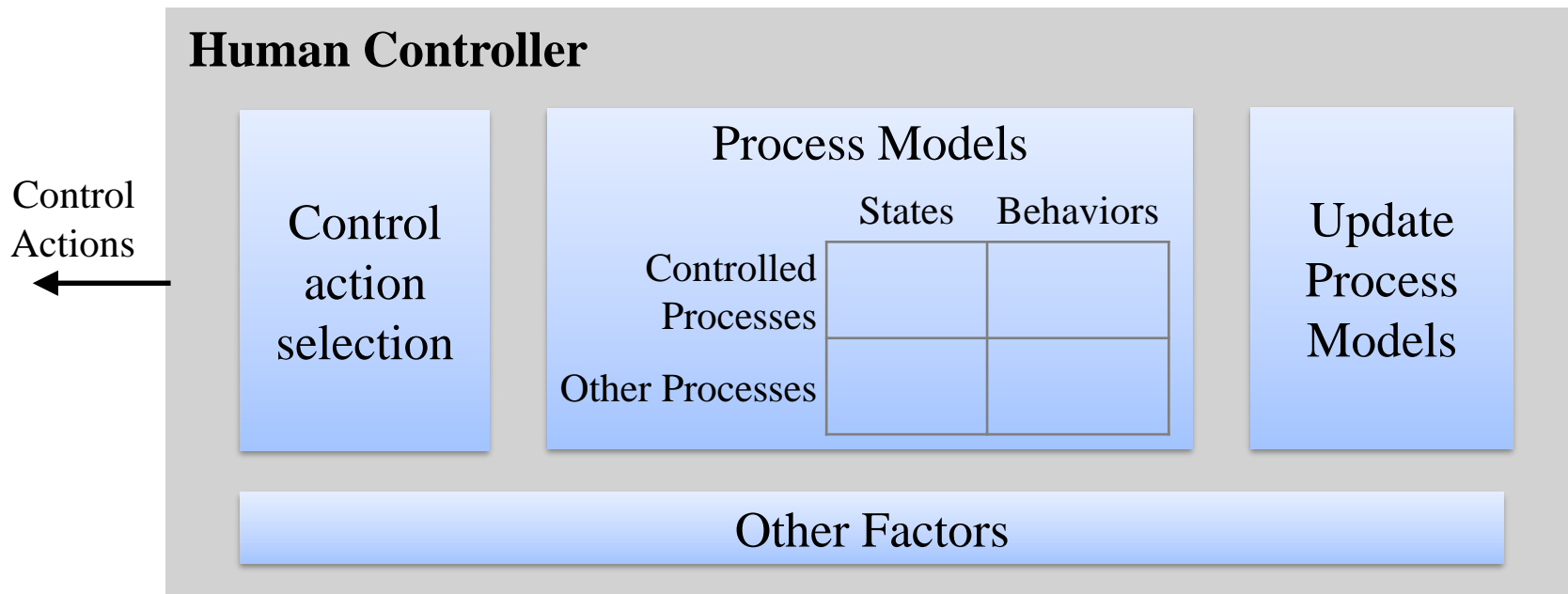
Physical Layer

STPA-HF Human Controller Model

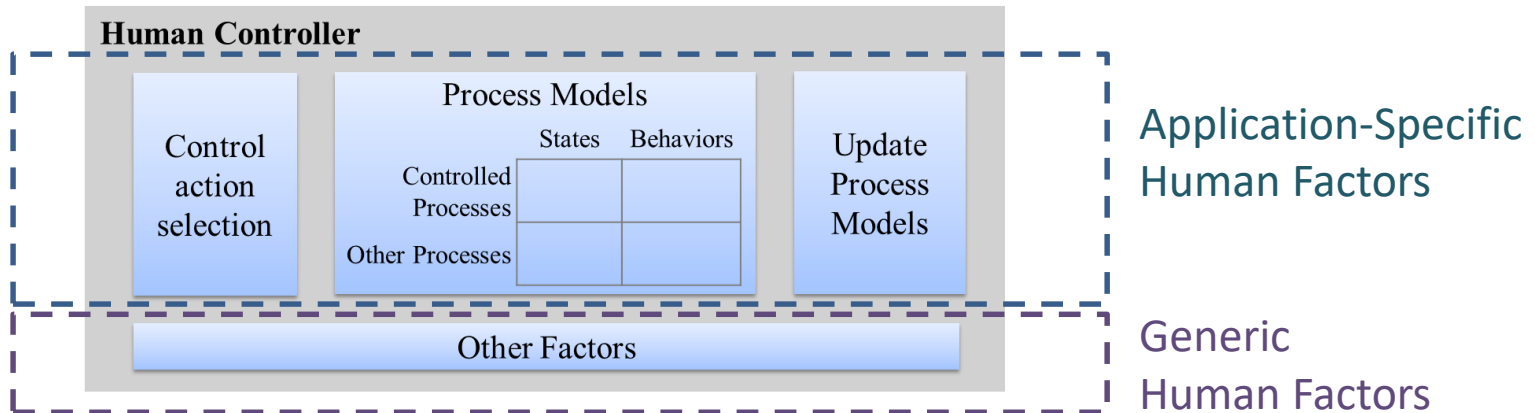


Based on accidents!

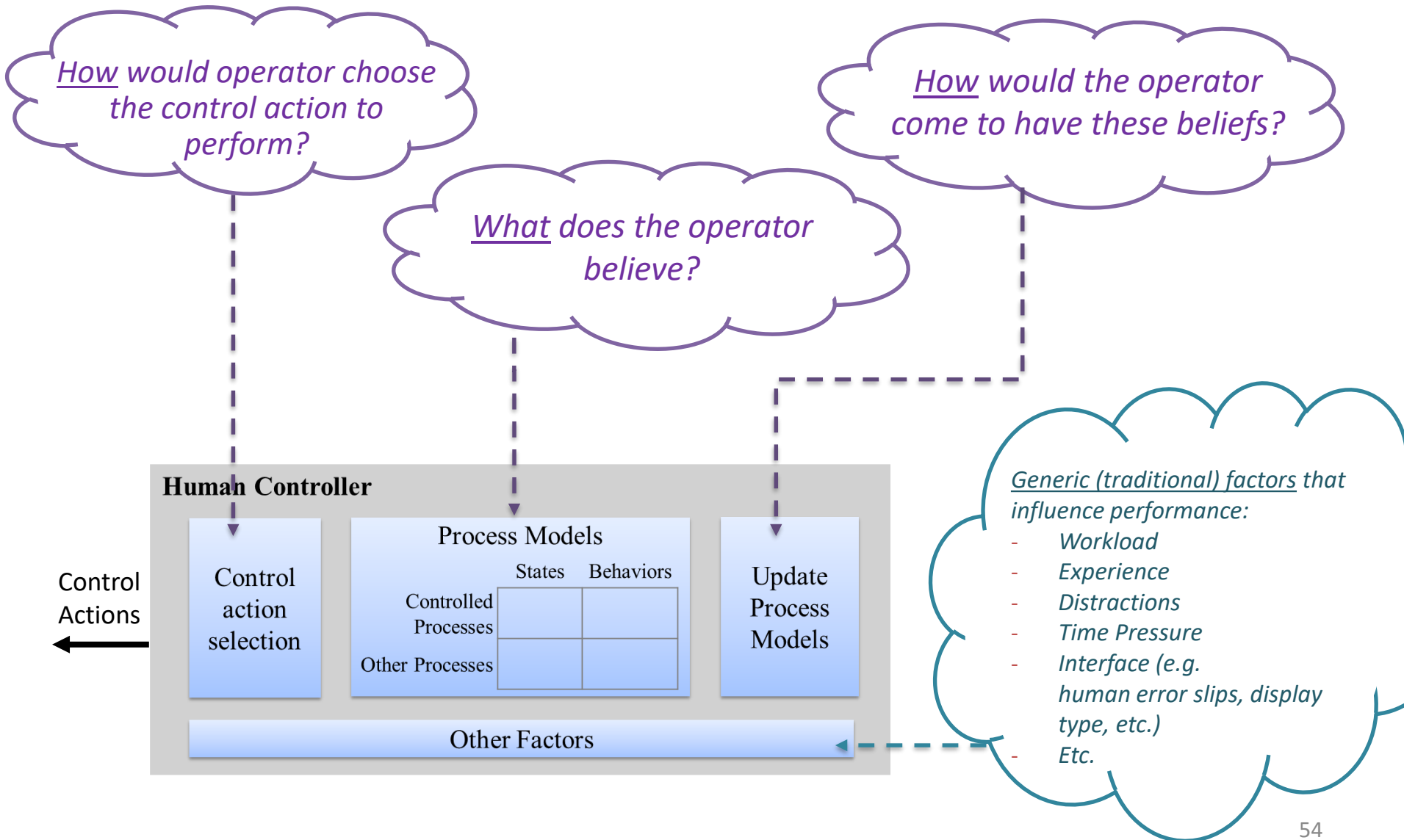
STPA-HF Human Model



Control Action Selection



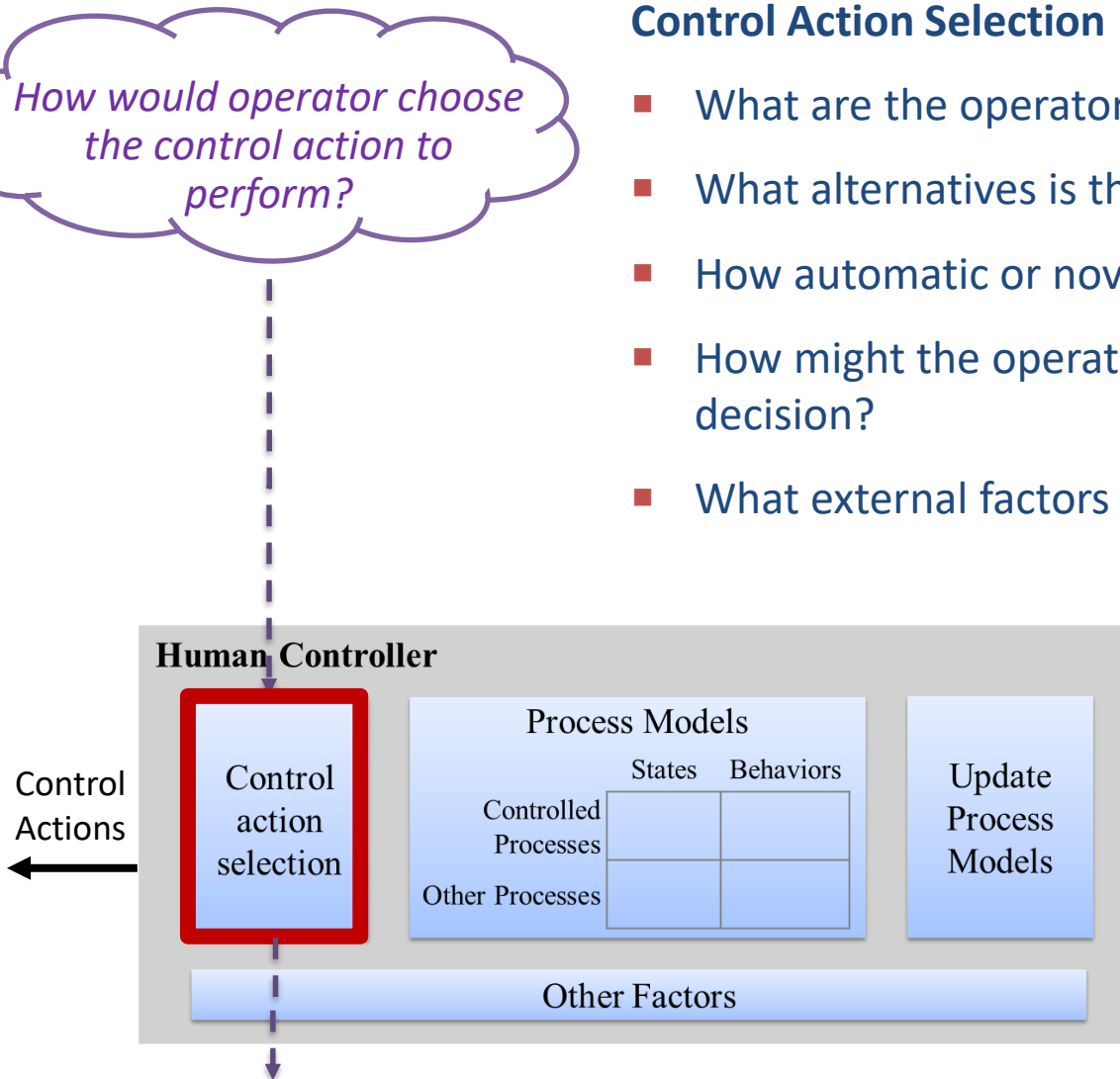
STPA-HF Human Control Model



STPA-HF Human Control Model

Control Action Selection

- What are the operator's goals?
- What alternatives is the operator choosing between?
- How automatic or novel is the behavior?
- How might the operator's process models affect their decision?
- What external factors would affect their decision?

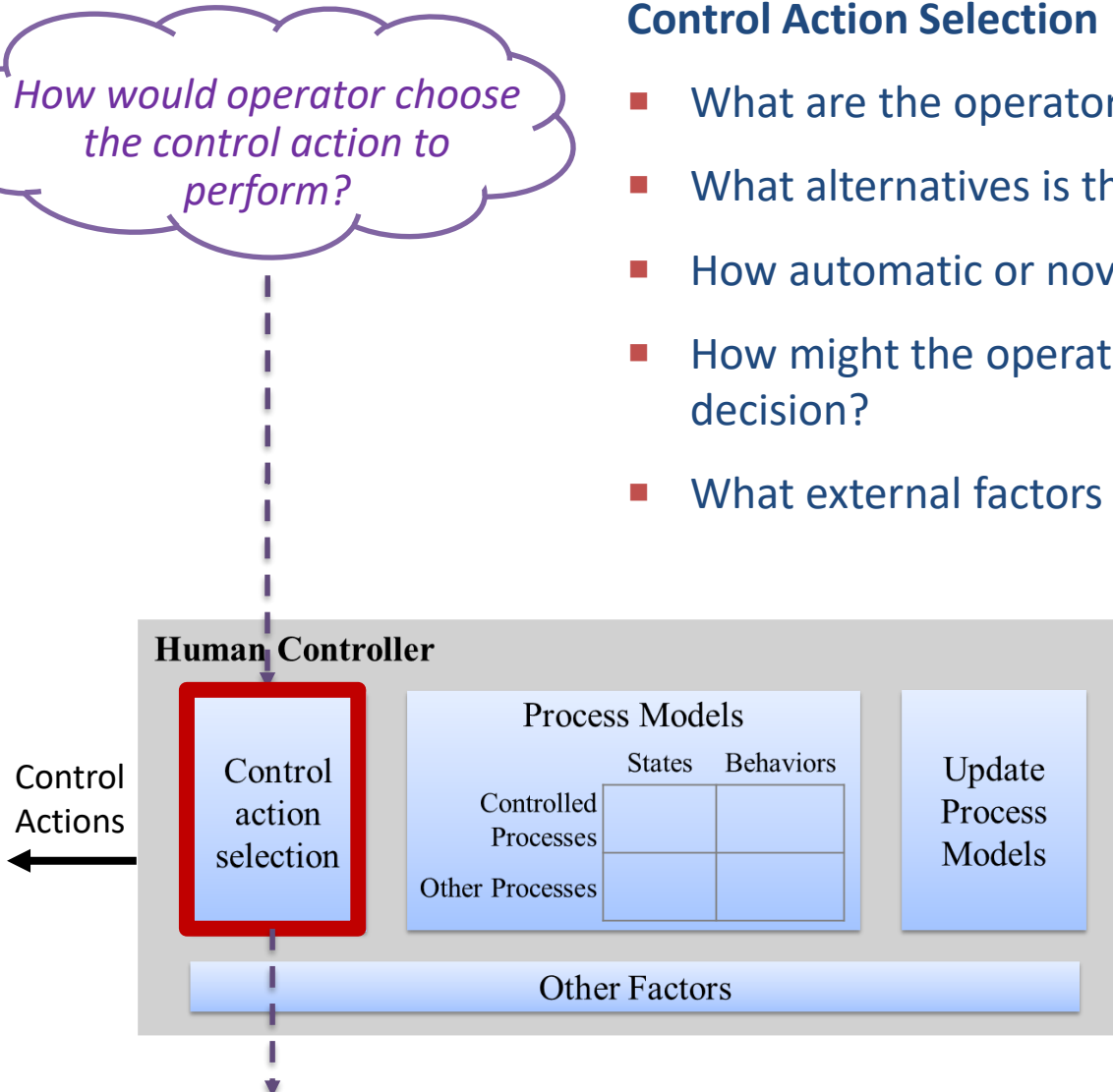


Example: Operator selects actions to maintain a (perceived) safe speed

STPA-HF Human Control Model

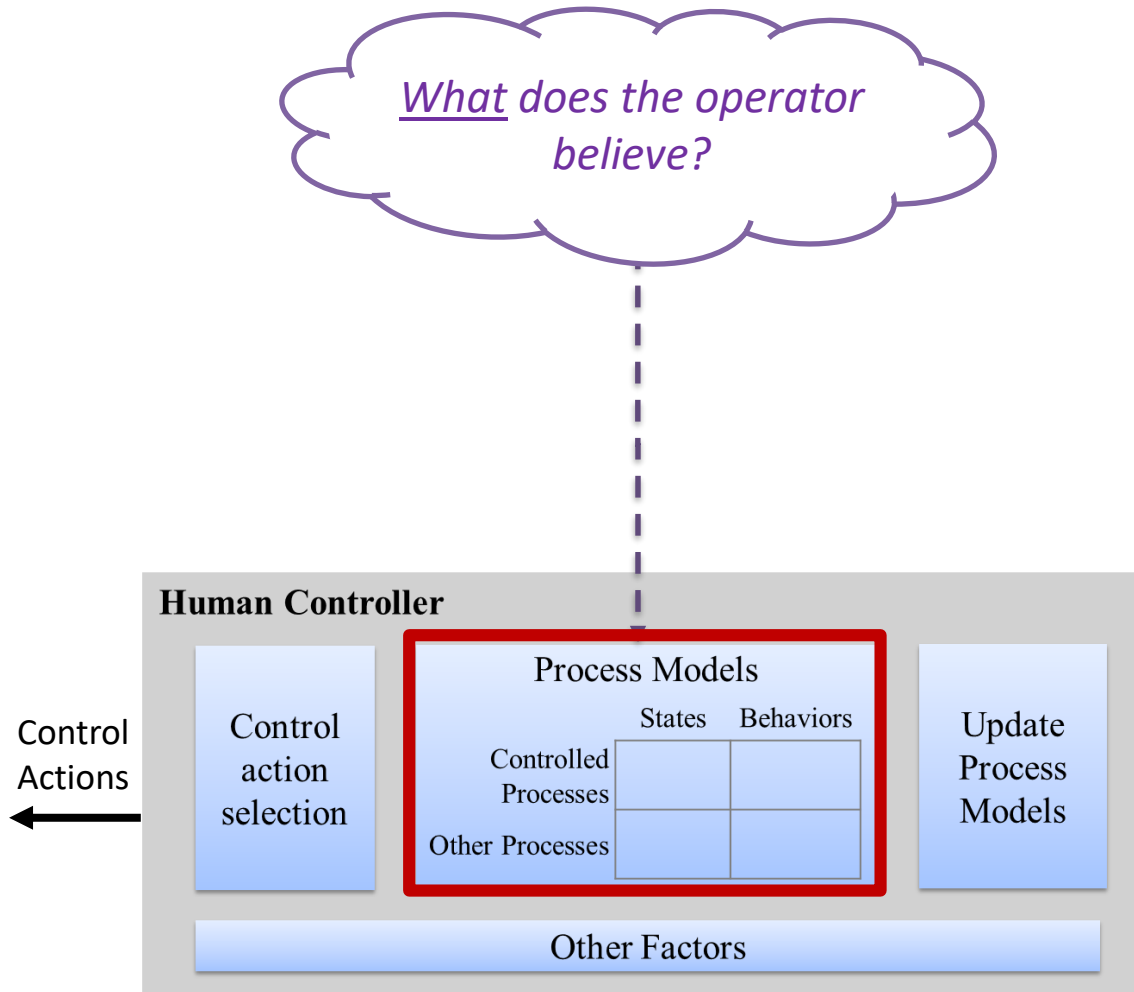
Control Action Selection

- What are the operator's goals?
- What alternatives is the operator choosing between?
- How automatic or novel is the behavior?
- How might the operator's process models affect their decision?
- What external factors would affect their decision?



Example: Pilot selects actions to avoid a storm cell ahead

STPA-HF Human Control Model

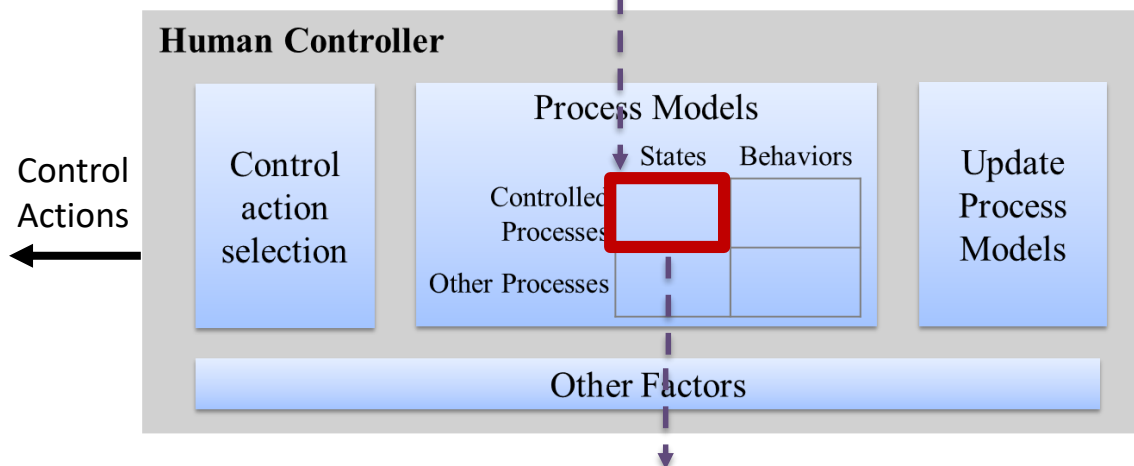


STPA-HF Human Control Model

What would the operator believe about their own process states?

Process Model of Controlled Process States

- Controlled processes: includes directly or indirectly controlled (e.g. automation, aircraft, engines, other people, self, etc.)
- Beliefs about modes and mode changes
- Beliefs about the current phase of process, for processes with multiple phases/stages
- Beliefs about system or process variables (eg. true/false)
- Etc.



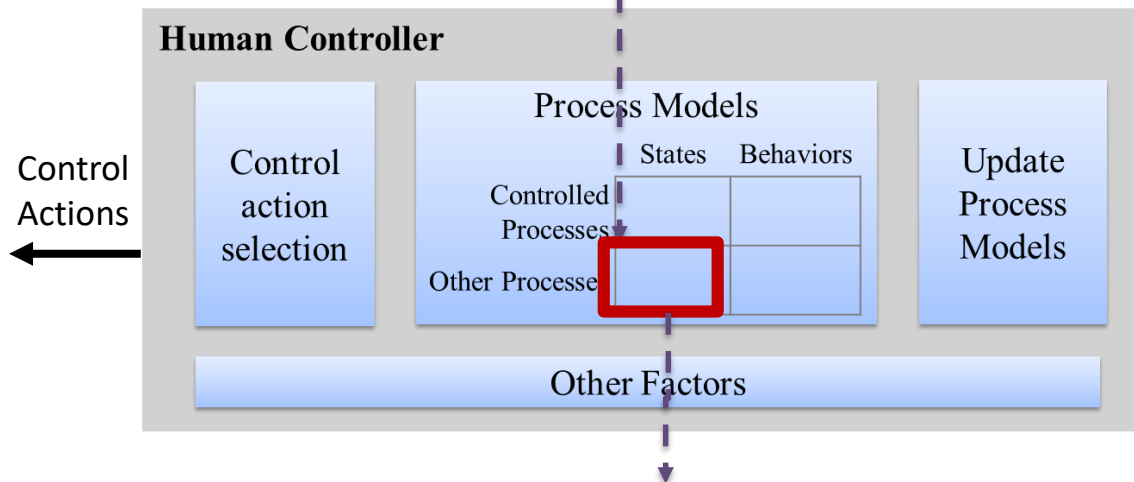
Example: Pilot believes their aircraft is in an overspeed, not a stall

STPA-HF Human Control Model

What would the operator believe about other process states?

Process Model of Other Process States

- Environmental states / conditions
- Familiar or unfamiliar environments
- Changes in environment
- State of outside controllers (e.g. other pilots, ATC)
- Social and organizational conditions
- Etc.



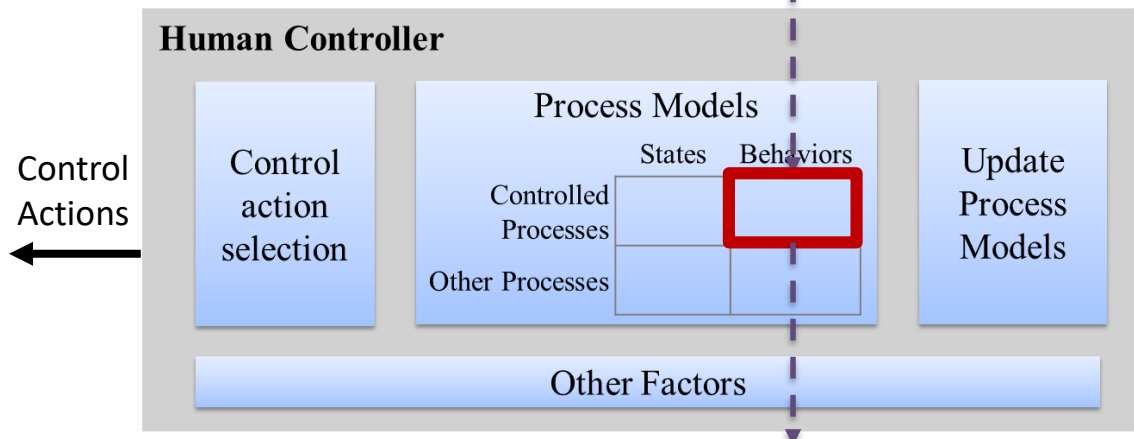
Example: Pilot believes there is a storm cell ahead

STPA-HF Human Control Model

What would the operator believe about their process behaviors?

Process Model of Controlled Process Behavior

- Beliefs about what the processes are capable of
- Beliefs about what processes will do
- Beliefs about how processes will behave in a particular mode or stage of operation
- Beliefs about if-then relationships between process input and process output
- Etc.



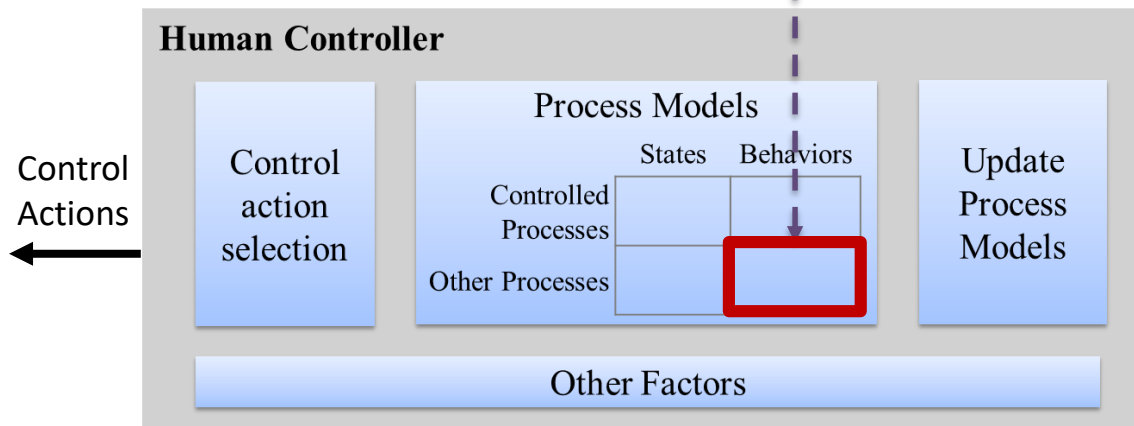
**Example: Pilot believes stall warning system behavior is erratic.
"If it were malfunctioning, this is what I'd see."**

STPA-HF Human Control Model

What would the operator believe about other process behaviors?

Process Model of Other Process Behaviors

- Beliefs about what the processes are capable of
- Beliefs about what processes will do
- Beliefs about how processes will behave in a particular mode or stage of operation
- Beliefs about if-then relationships between process input and process output
- Etc.

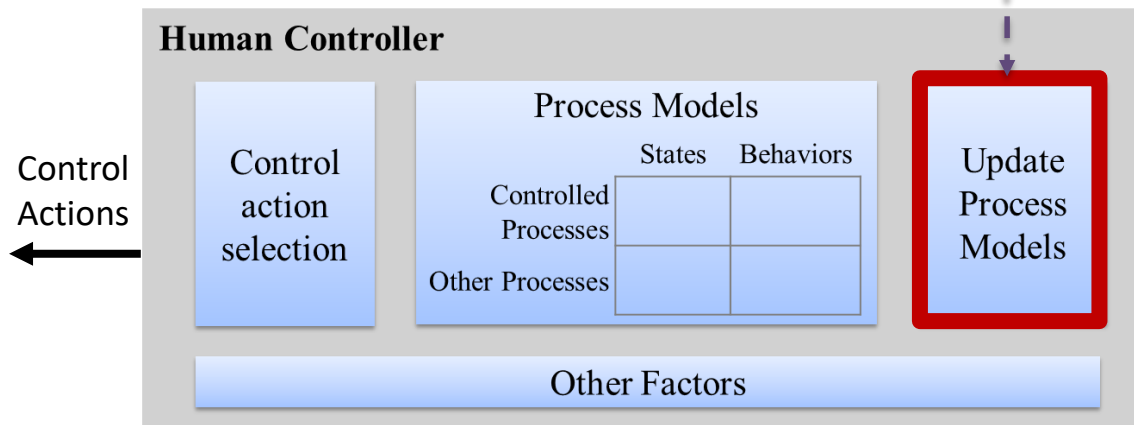


STPA-HF Human Control Model

How did the operator come to have these beliefs?

Process Model Updates (and Initial Formation!)

- Consider initial formation of process model vs. later updates
- Consider non-feedback inputs such as training programs and documentation
- Consider whether input/feedback was observed (*saliency, expectations*)
- Consider whether input/feedback was correctly perceived & interpreted



STPA-HF: Aviation Example



Select actions to maintain a
(perceived) safe speed

**UCA-2: Pilot
decreases speed while
the aircraft is in a stall
(speed is too low).**

Believes aircraft is in
an overspeed, not a
stall

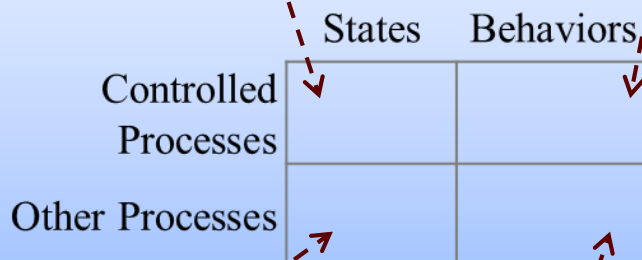
Believes
automated stall
warnings are
erroneous

Interprets buffeting
& noise as signs of
an overspeed
condition, since
overspeed is an
emphasized risk

Human Controller

Control
action
selection

Process Models



Update
Process
Models

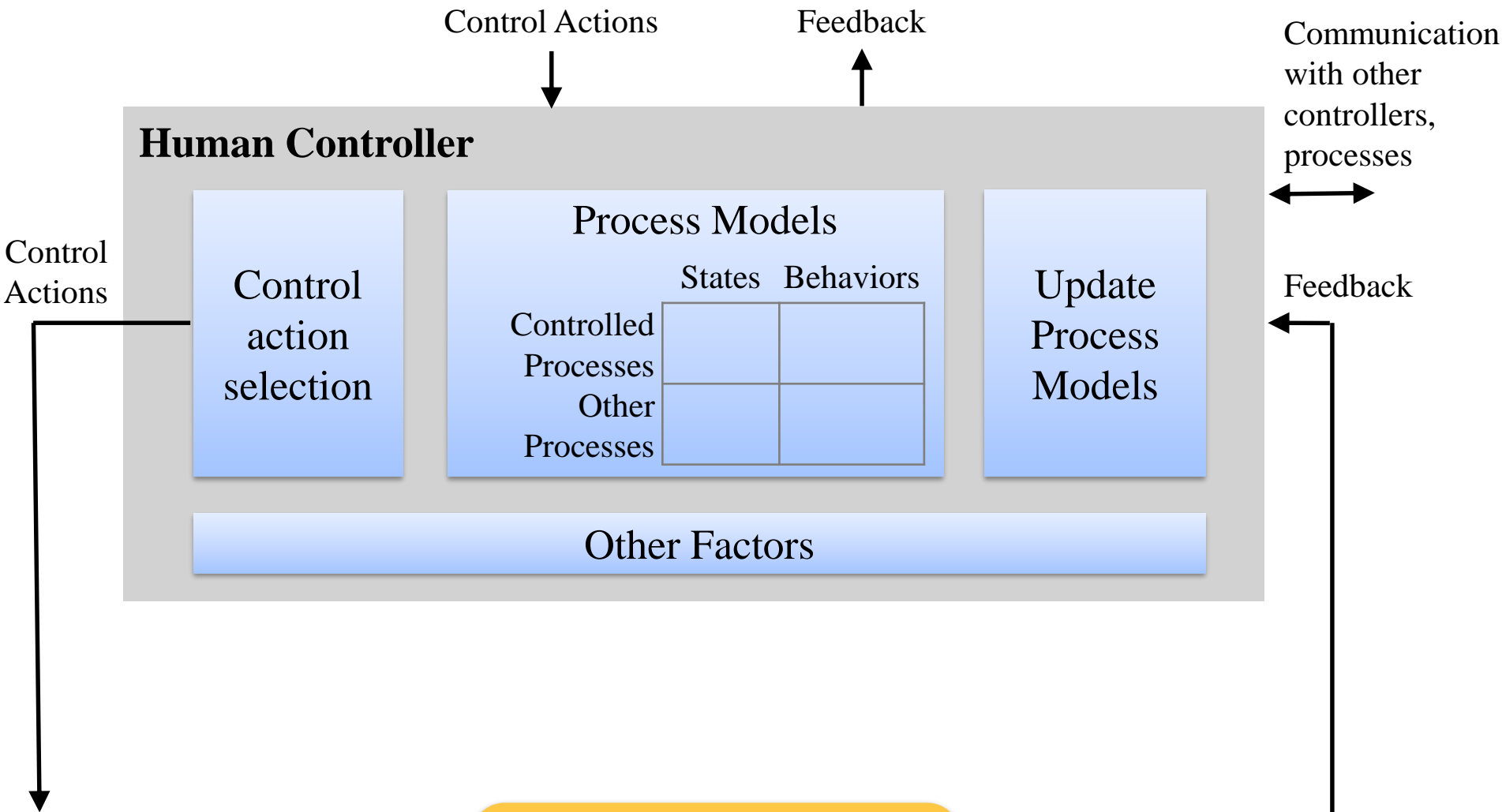
Other Factors

Feedback:

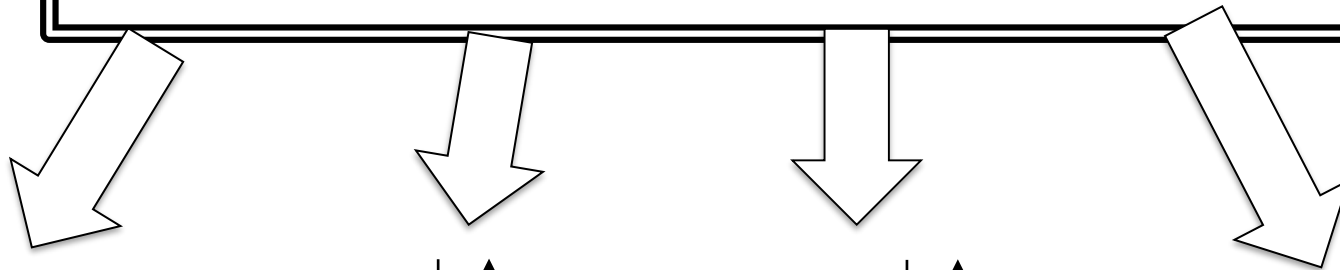
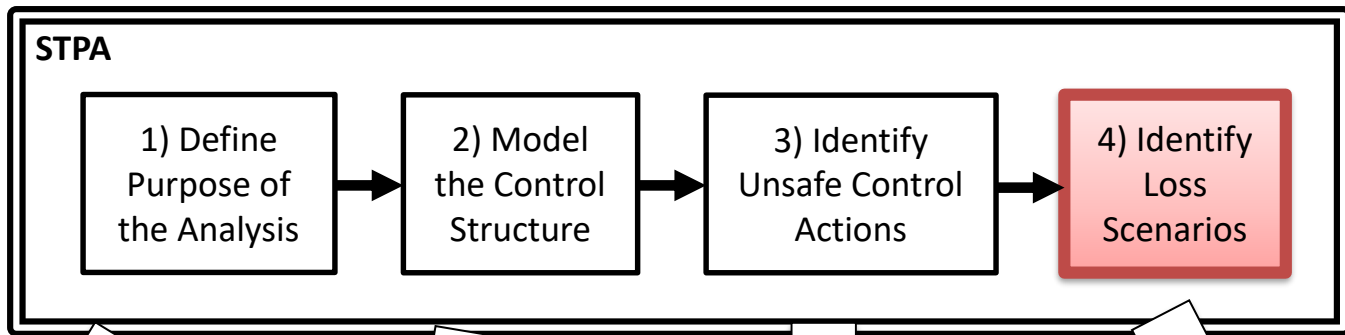
- ← Aero-dynamic noise audible
- Aircraft buffeting
- No speed indicators available

Storm cell ahead

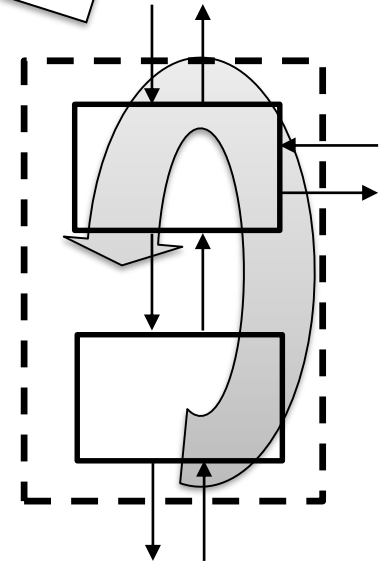
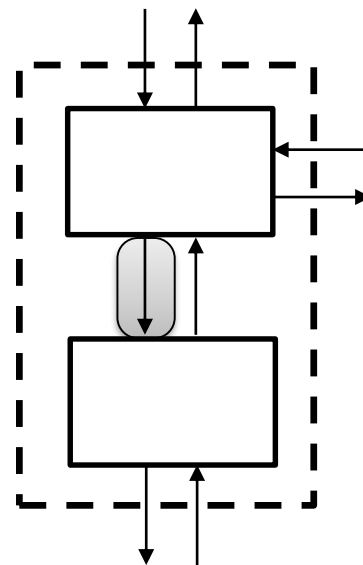
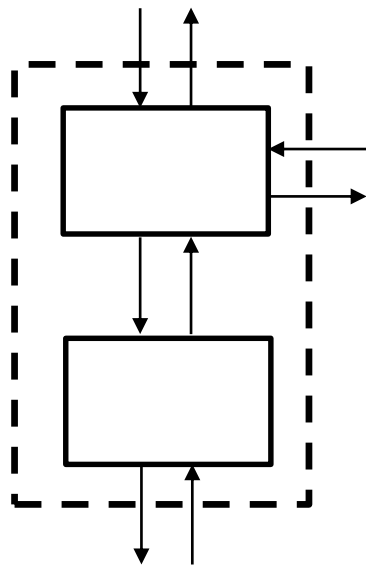
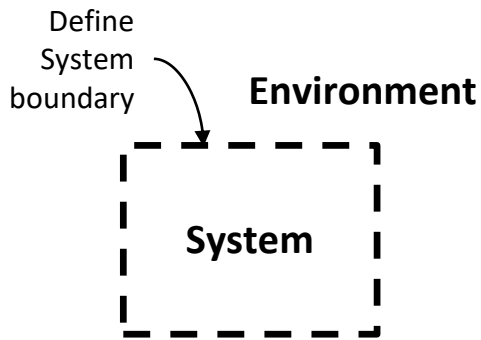
Climbing will lead to clearer skies
(causes deceleration)



This model is based on accidents!

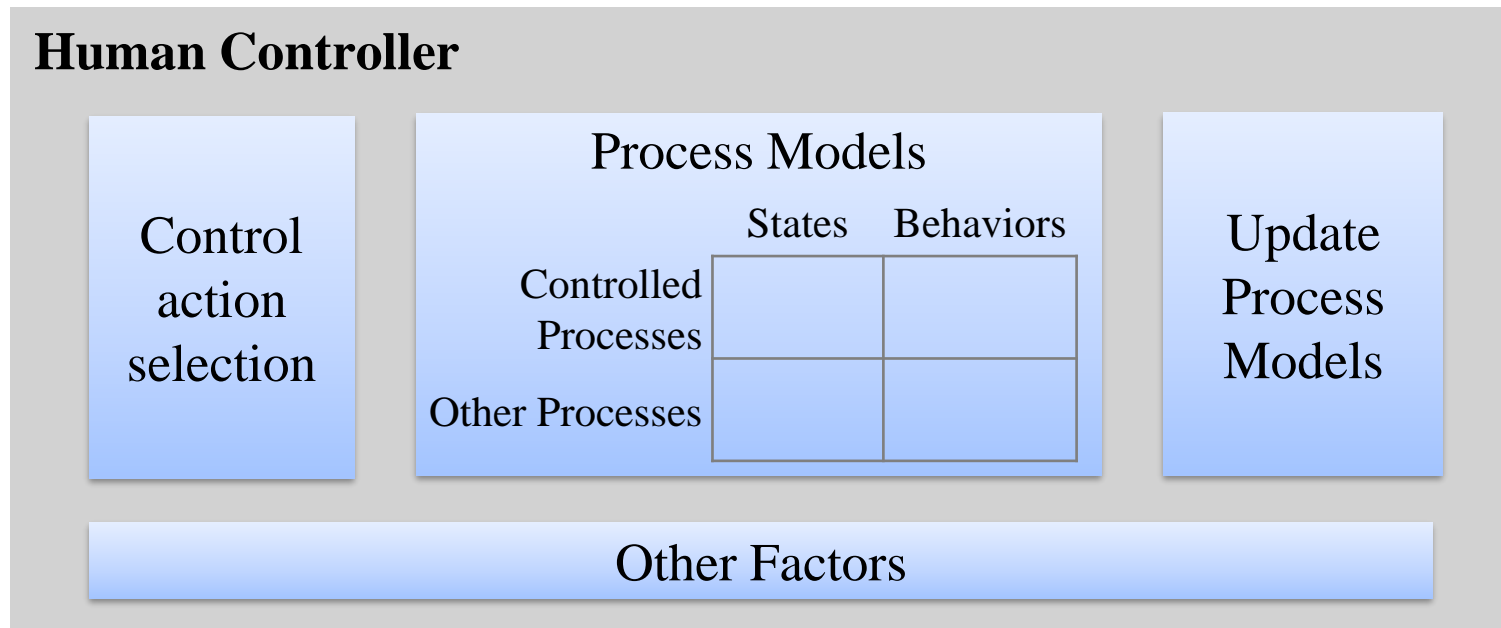


Identify Losses, Hazards



STPA-HF PROCESS

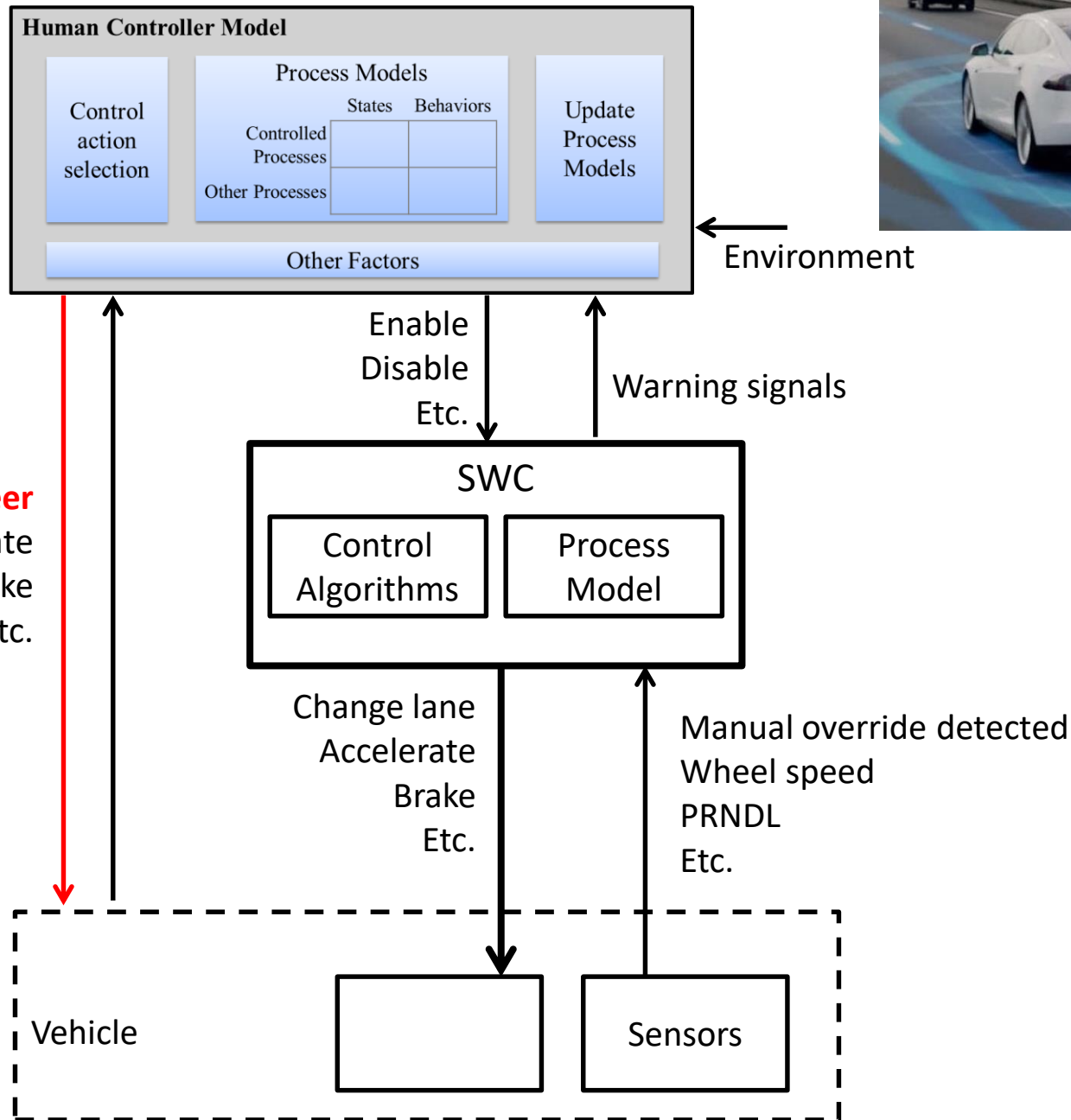
- Losses, Hazards
- Control structure
- UCAs
- Build scenarios
 - Identify Process Model variables
 - Identify Process Model Flaws
 - Identify flaws in Process Model Updates
 - Identify unsafe decisions (Control Action Selections)



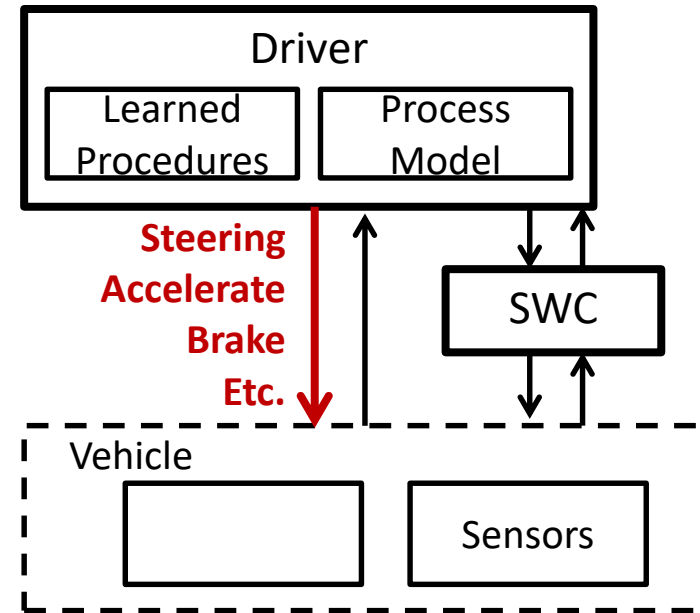
Does it work?

Does it anticipate causes
that led to real accidents and errors?

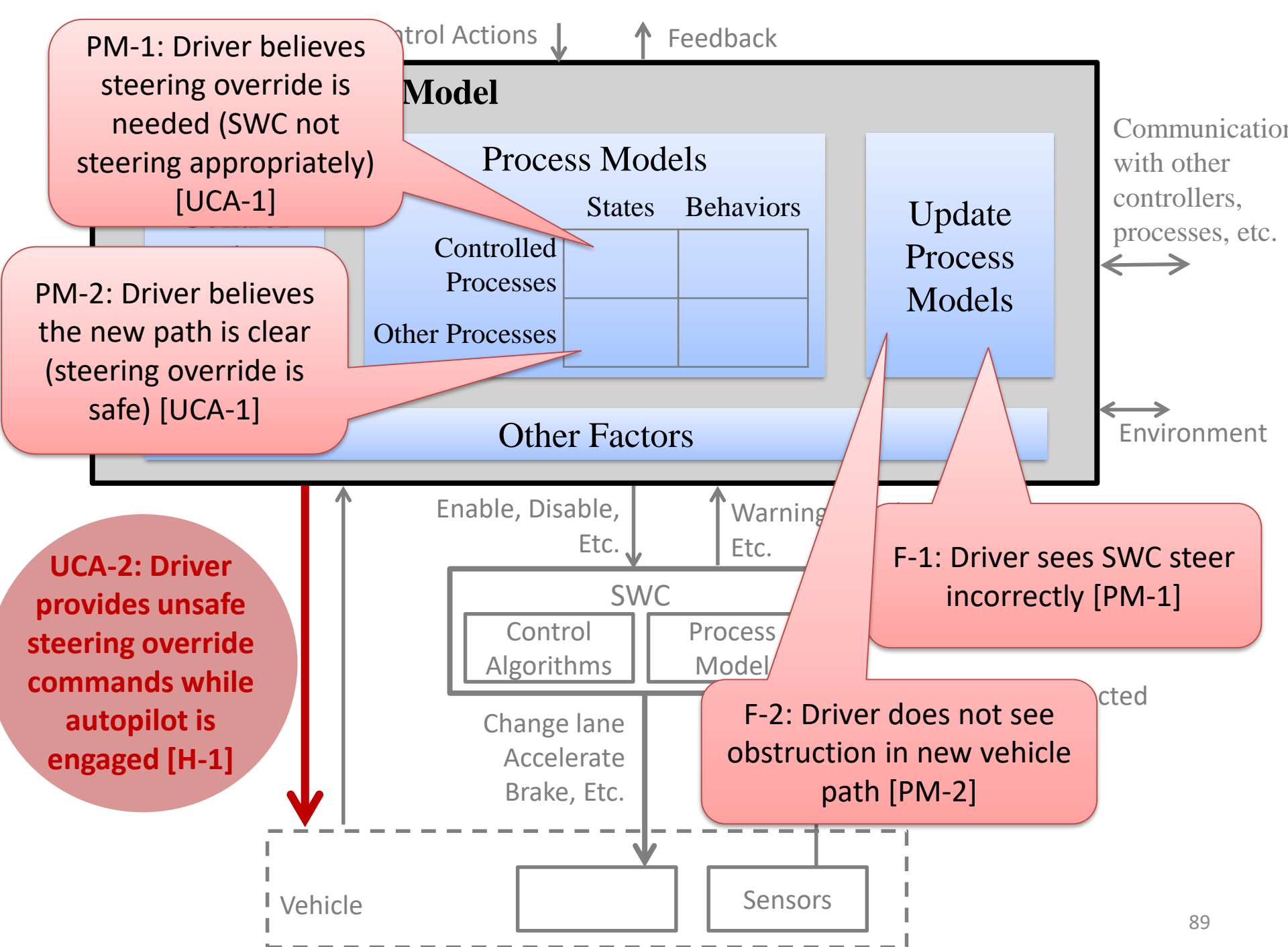
High-level Control Structure



STPA: Unsafe Control Actions (UCA)

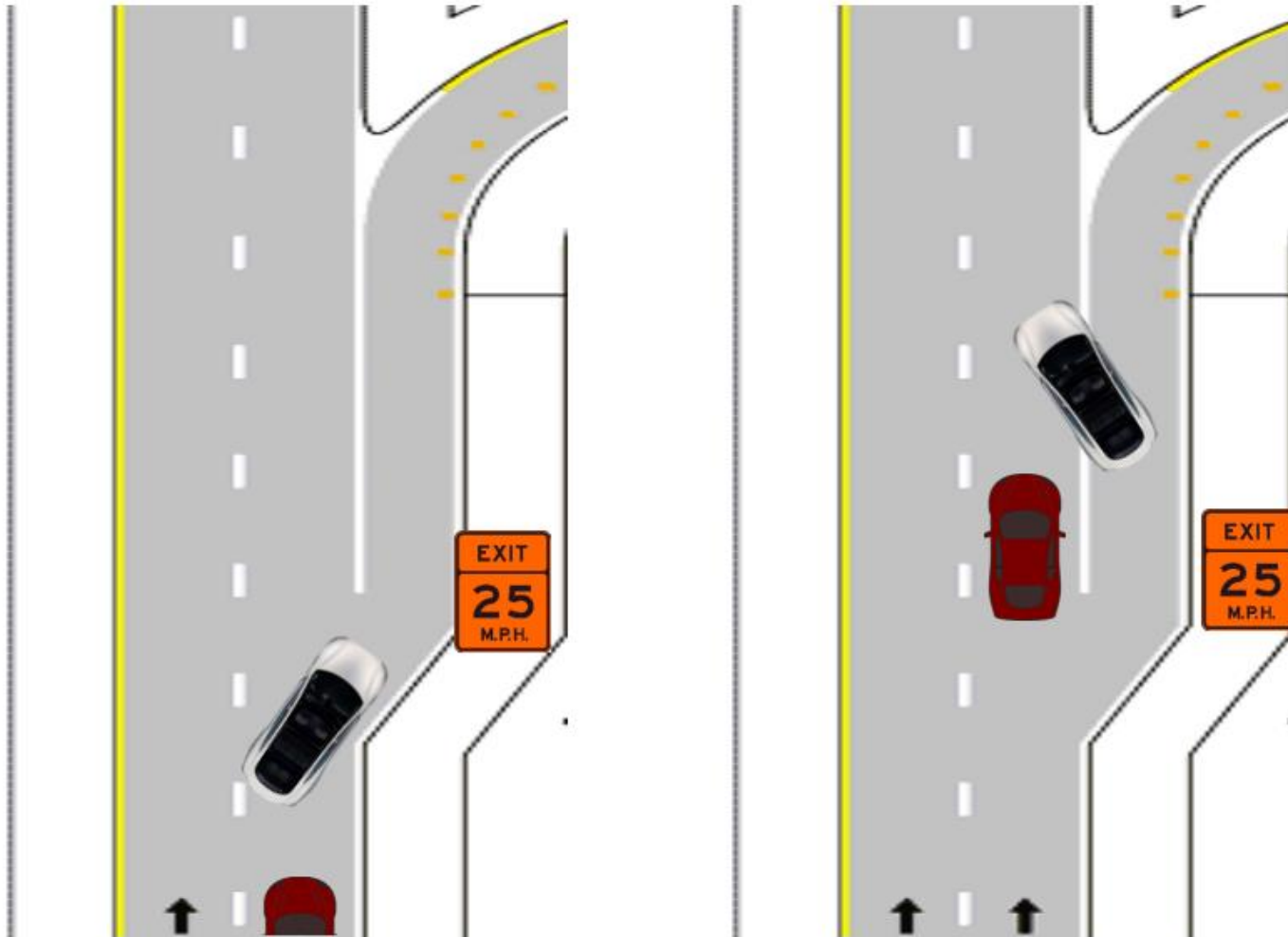


	Not providing causes hazard	Providing causes hazard	Too early, too late, out of order	Stopped Too Soon / Applied too long
Steering Command		UCA-2: Driver provides steering override cmds when autopilot is engaged, resulting in collision [L-1,L-2]		



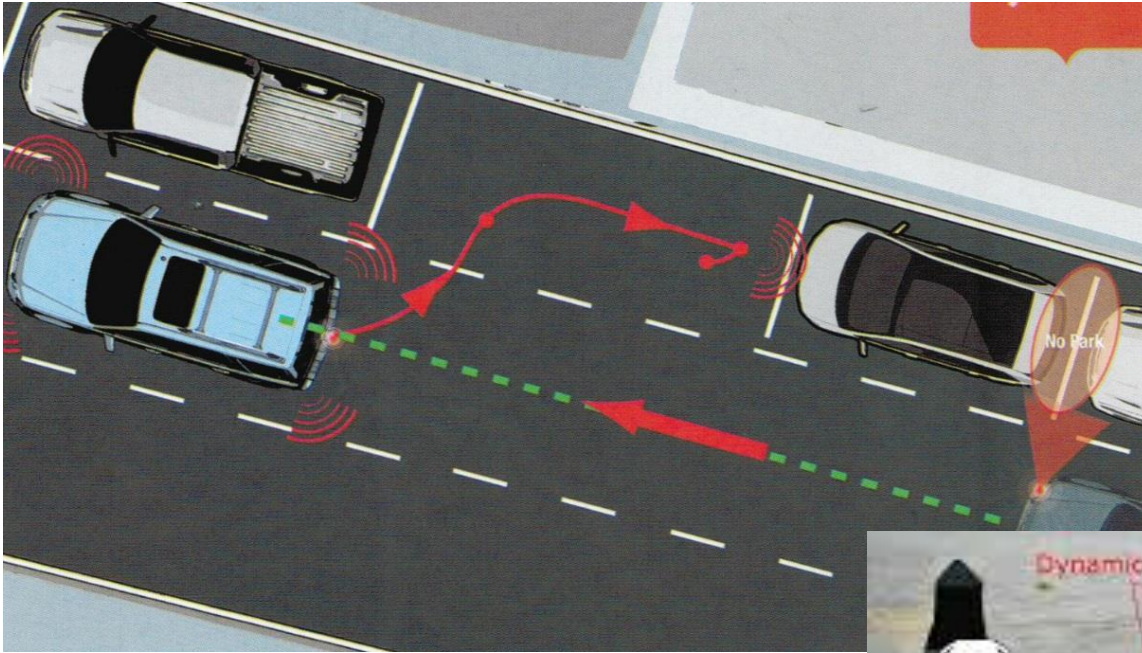
Scenario #2

UCA-2: Driver provides unsafe steering override commands when autopilot is engaged



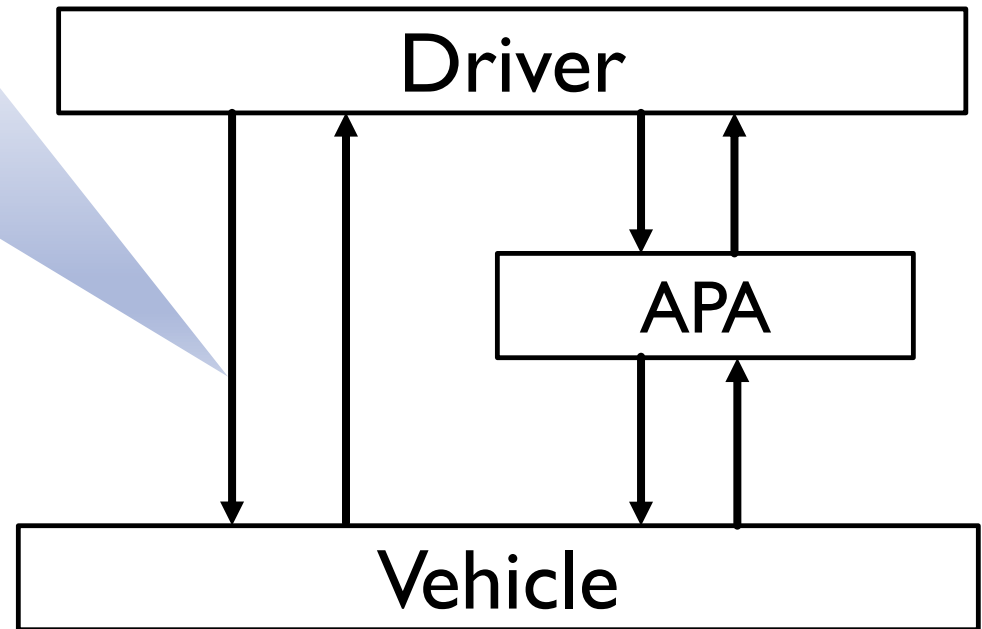
Can it work for other systems?

Automated Parking Assist (APA)



UNSAFE CONTROL ACTIONS

	Not Provided	Provided	Too early, too late, out of order	Stopped too soon, applied too long
Brake	UCA-I: Driver does not brake when auto-parking and computer doesn't react to an obstacle			



STPA-HF PROCESS



- Identify UCAs

- UCA-1: Driver does not brake when auto-parking and computer doesn't react to an obstacle



- Identify Process Model variables

- MM-1:APA is enabled/disabled
- MM-2:APA computer reacting appropriately/inappropriately
- MM-3: Obstacle on collision path

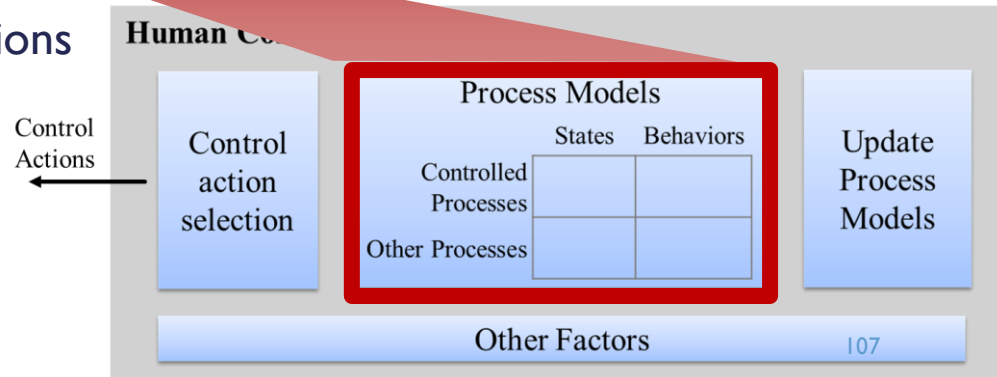
- Identify Process Model Flaws

- Identify flaws in Process Model Updates

- Identify unsafe Control Action Selections

STPA-HF PROCESS

- Identify UCAs
 - UCA-1: Driver does not brake when auto-parking and computer doesn't react to an obstacle
- Identify Process Model variables
 - MM-1: APA is enabled/disabled
 - MM-2: APA computer reacting appropriately/inappropriately
 - MM-3: Obstacle on collision path
- Identify Process Model Flaws
- Identify flaws in Process Model Updates
- Identify unsafe Control Action Selections



STPA-HF PROCESS



- Identify UCAs
- Identify Process Model variables
 - MM-1: APA is enabled/disabled
 - MM-2: APA computer reacting appropriately/inappropriately
 - MM-3: Obstacle on collision path



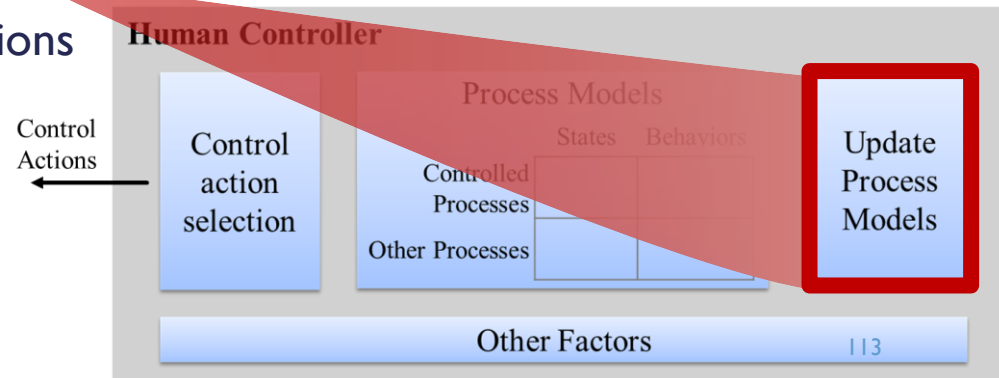
- Identify Process Model Flaws
 - Identify unsafe decisions (Control Action Selections)
 - Identify inadequate Process Model Updates

Process Models	
	States Behaviors
Controlled Processes	1. 2.
Other Processes	3. 4.

Type of MM flaw	Examples
1) Incorrect beliefs about controlled process state (including modes)	Driver thinks APA is enabled when APA is really disabled
2) Incorrect beliefs about controlled process behaviors	Driver thinks APA is reacting properly and will brake automatically
3) Incorrect beliefs about other process state (e.g. environment)	Driver thinks there is no obstacle when there is one
4) Incorrect beliefs about other process behavior (e.g. environment)	Driver knows there is an obstacle, but thinks it won't move on a collision path

STPA-HF PROCESS

- Identify UCAs
 - UCA-1: Driver does not brake when auto-parking and computer doesn't react to an obstacle
- Identify Process Model variables
 - MM-1: APA is enabled/disabled
 - MM-2: APA computer reacting appropriately/inappropriately
 - MM-3: Obstacle on collision path
- Identify Process Model Flaws
- Identify flaws in Process Model Updates
- Identify unsafe Control Action Selections



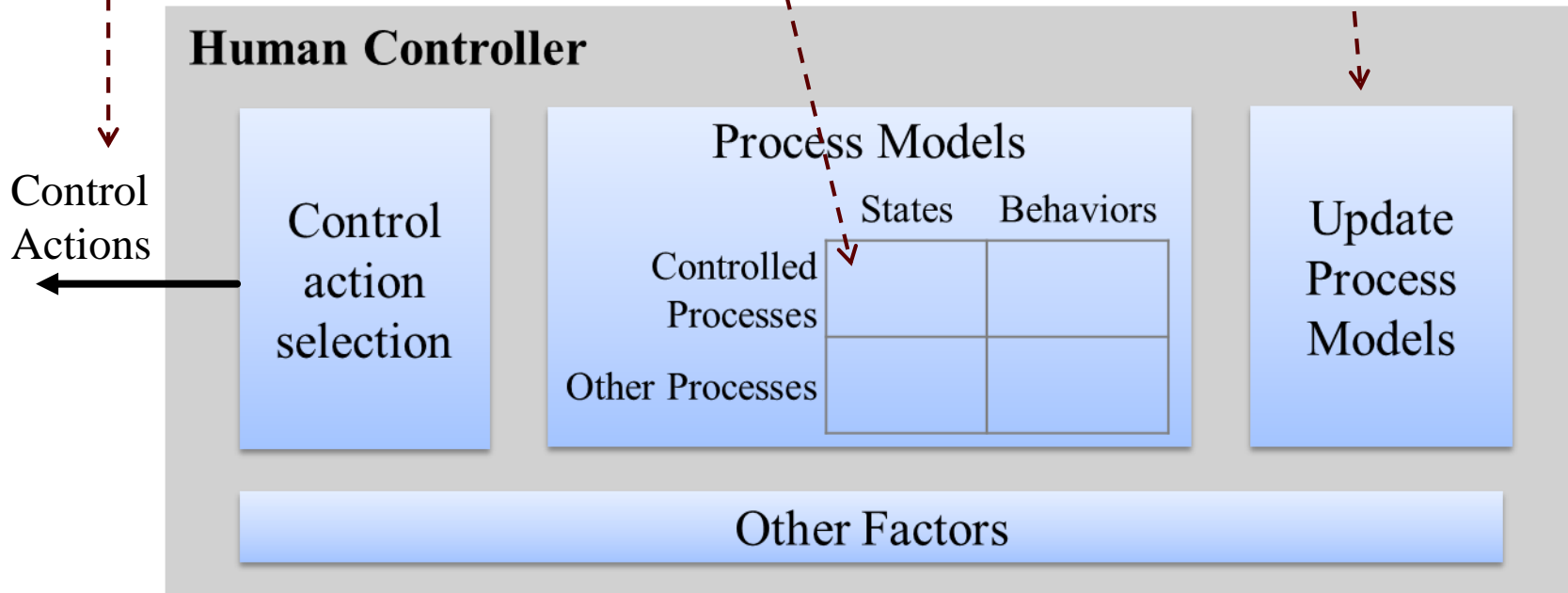
STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver believes APA is enabled when APA is really disabled (MM-1)

Consider:

1. Automatic mode changes
2. Previous cmds ignored
3. Phases of operation
4. Etc.

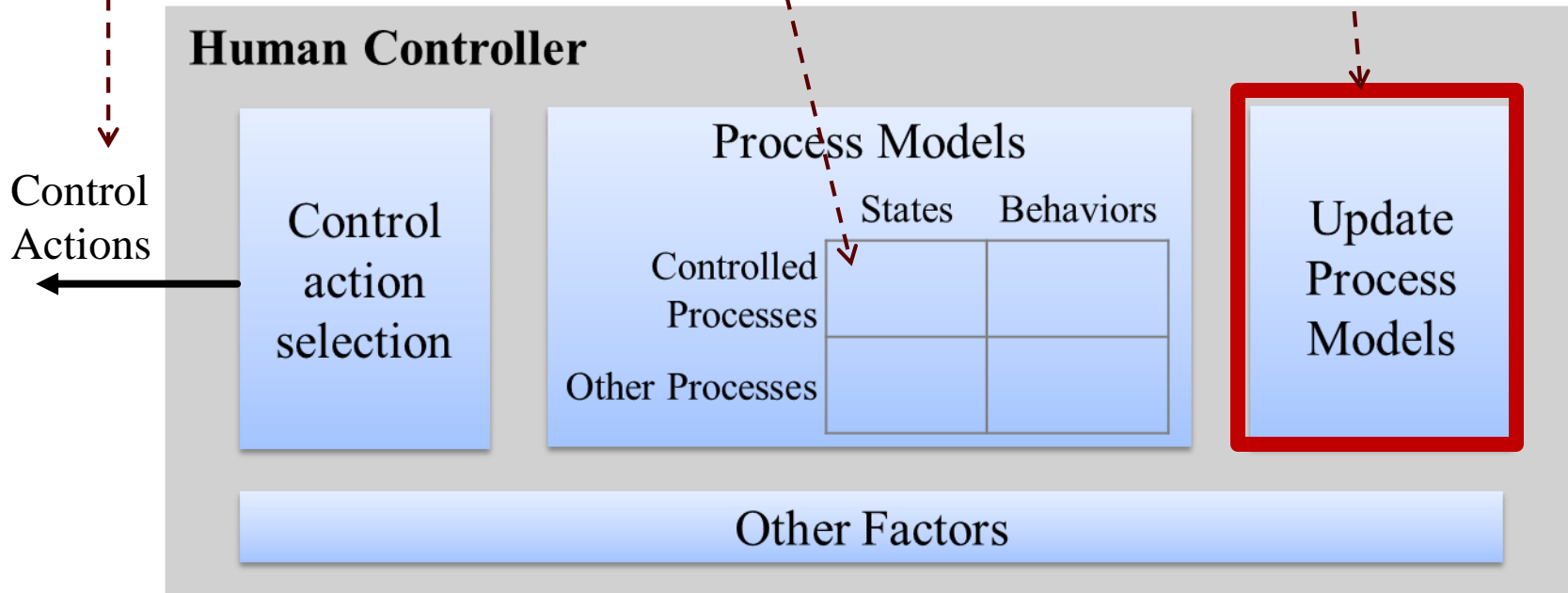


STPA-HF: ENGINEERING FOR HUMANS

APA automatically disabled itself but driver didn't notice the change

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver believes APA is enabled when APA is really disabled (MM-1)

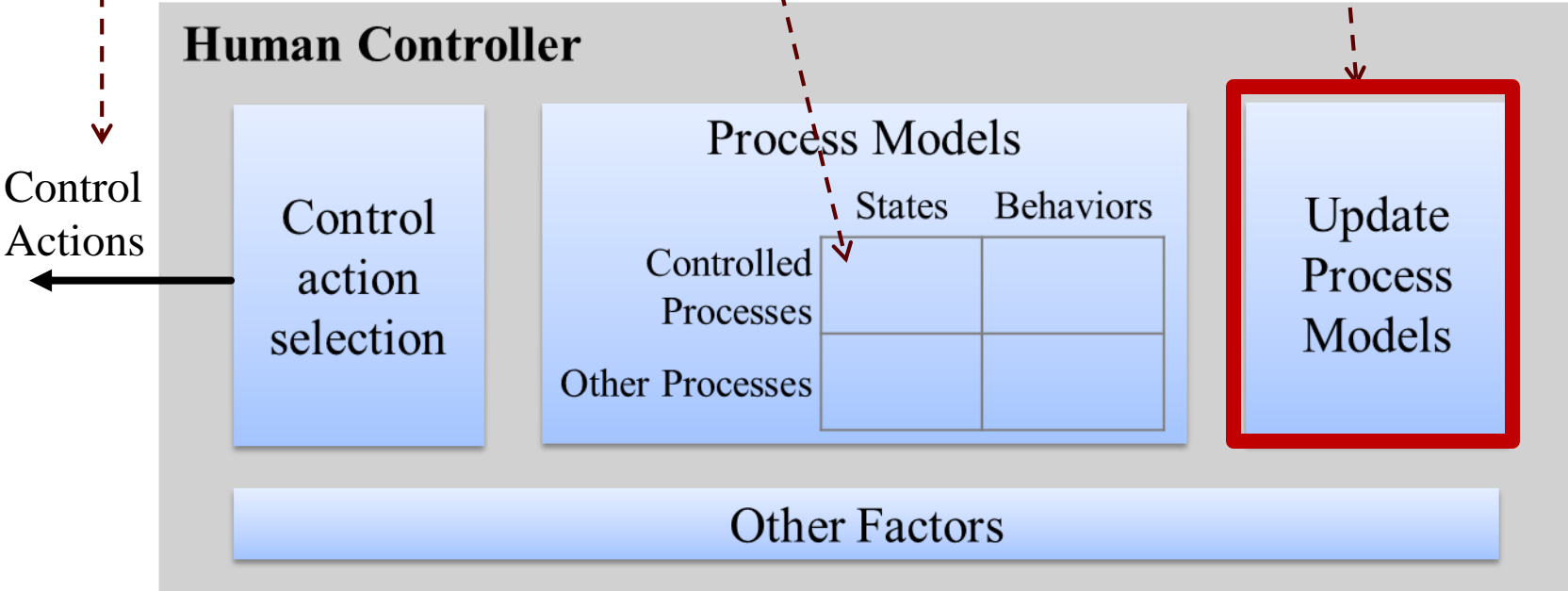


STPA-HF: ENGINEERING FOR HUMANS

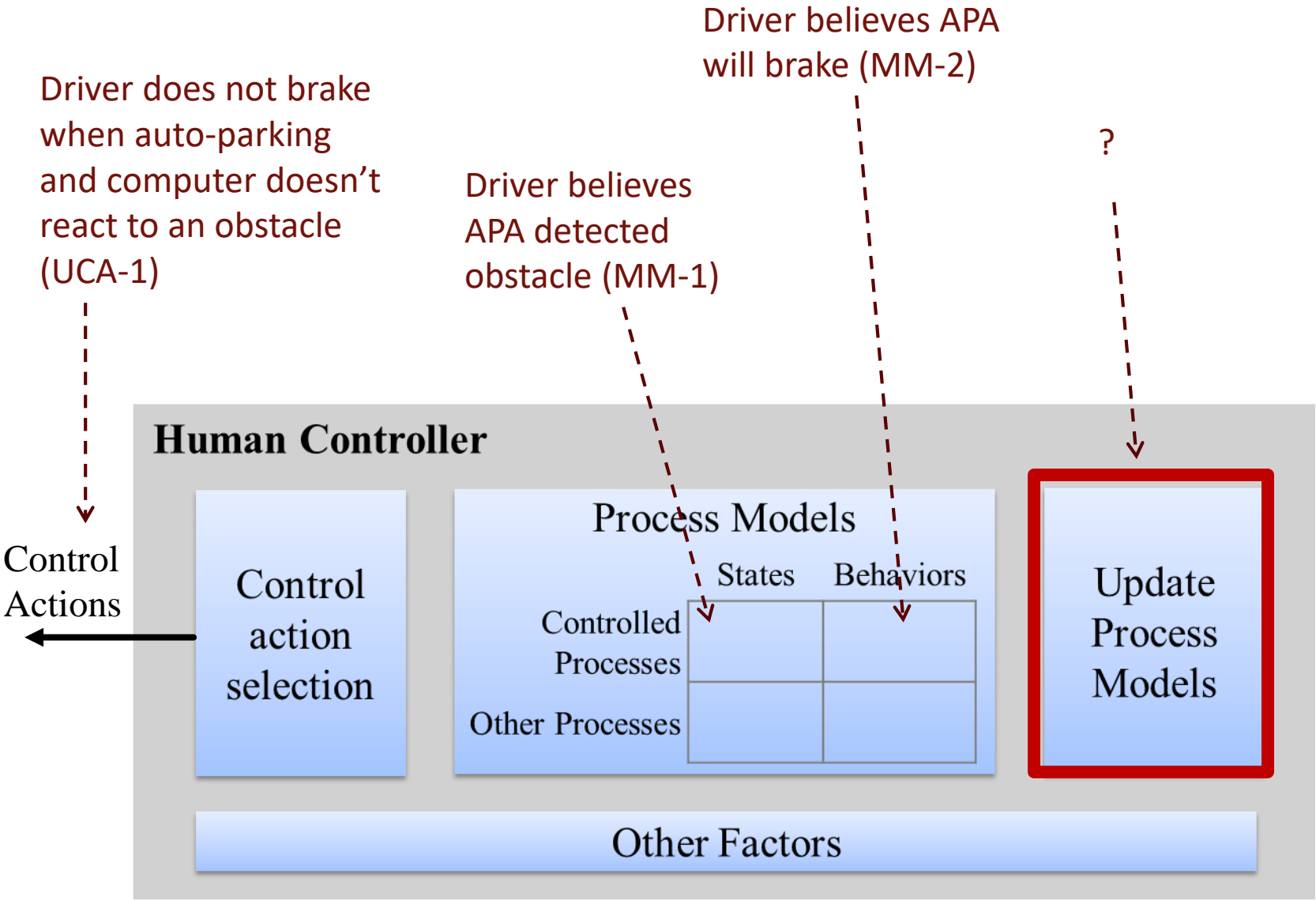
Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver believes APA is enabled when APA is really disabled (MM-1)

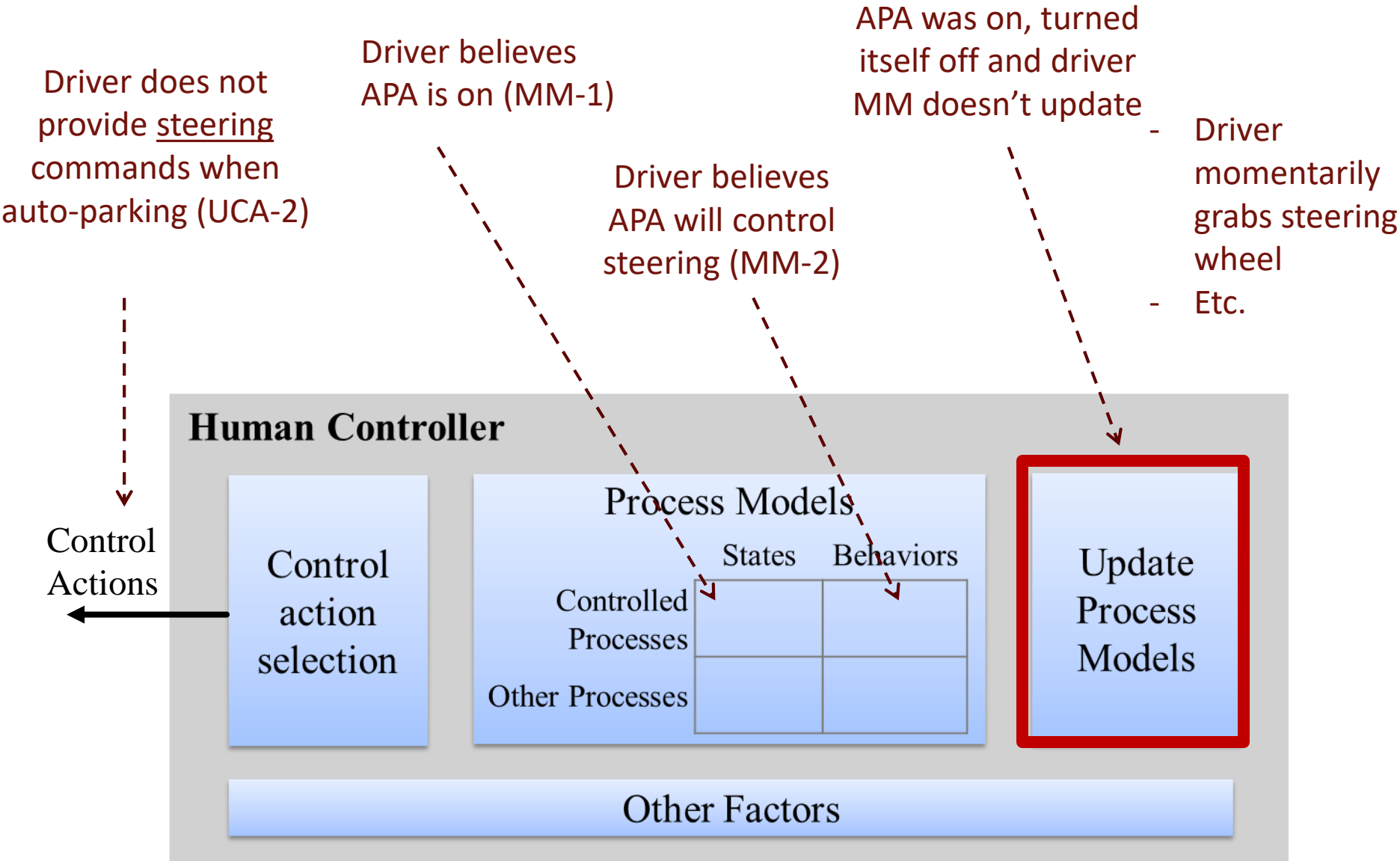
APA automatically disabled itself, driver noticed the change but didn't understand it



STPA-HF: ENGINEERING FOR HUMANS

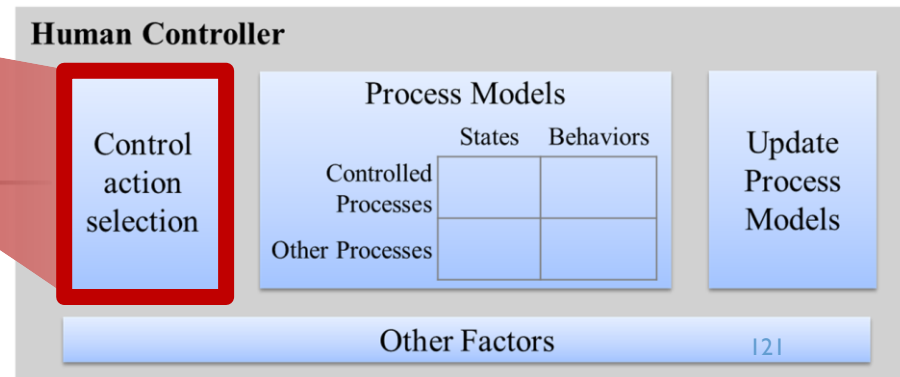


STPA-HF: ENGINEERING FOR HUMANS



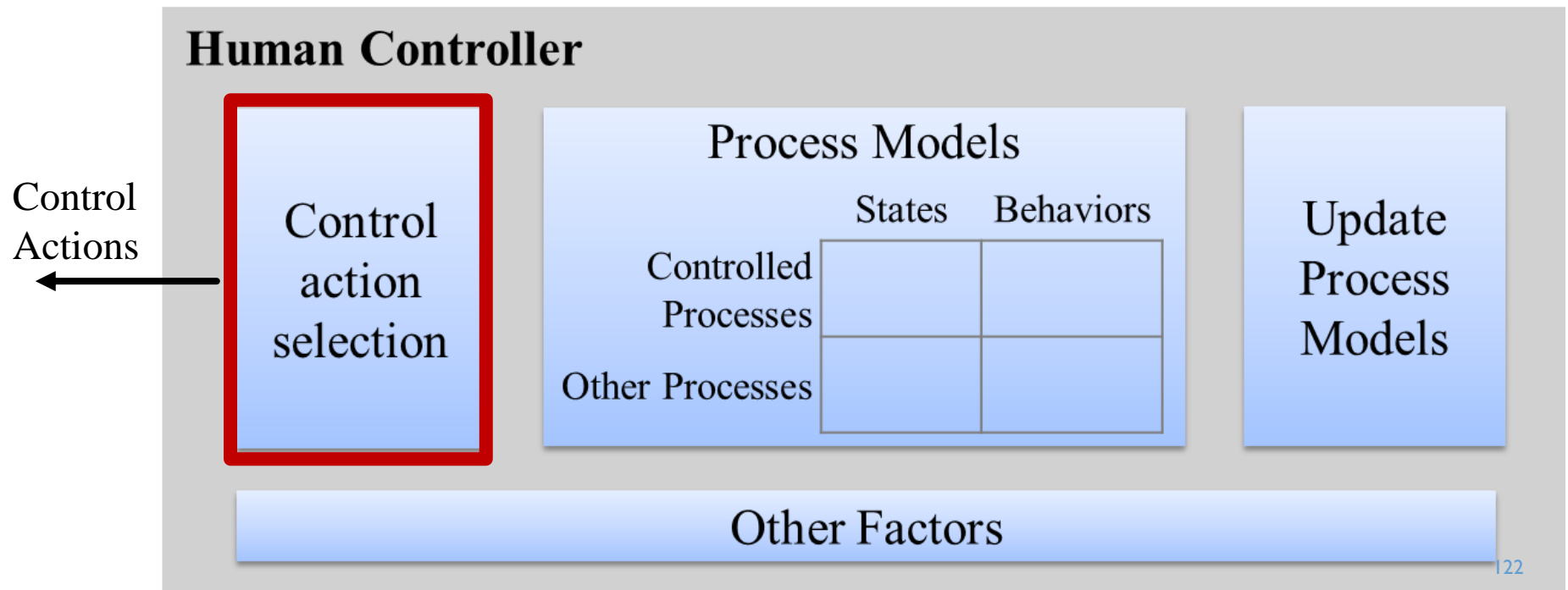
STPA-HF: ENGINEERING FOR HUMANS

- Identify UCAs
 - UCA-1: Driver does not brake for an obstacle when computer does not react appropriately to the obstacle
- Identify Process Model variables
 - MM-1: APA reacting appropriately/inappropriately
 - MM-2: Obstacle on collision path
- Identify Process Model Flaws
- Identify flaws in Process Model Updates
- Identify unsafe Control Action Selections



STPA-HF: ENGINEERING FOR HUMANS

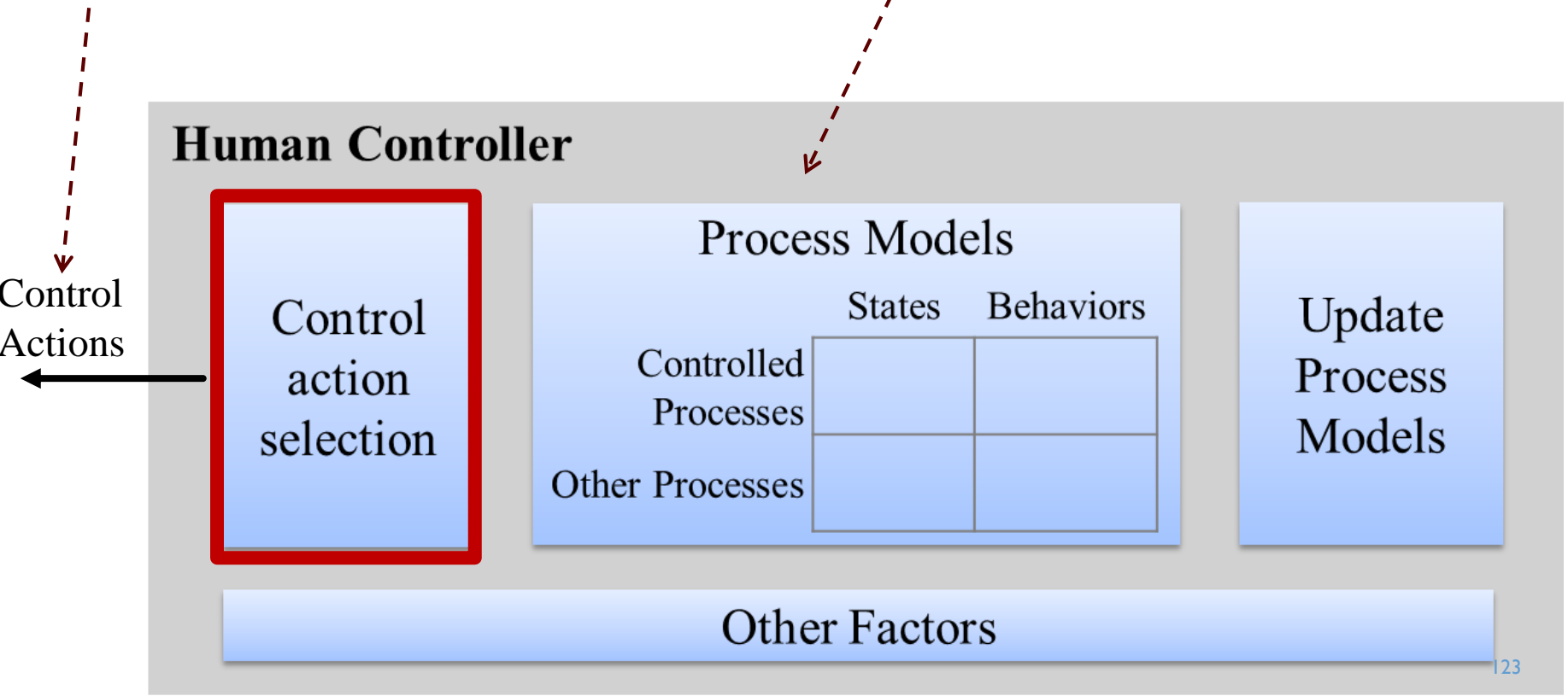
- ➔ ■ Identify unsafe Control Action Selections
 - Consider whether the driver is aware they can control X
 - Consider alternative driver controls/actions
 - Consider other driver goals



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Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver knows APA is on
Driver knows APA hasn't reacted yet
Driver knows there is an obstacle in the way
Driver knows obstacle is on collision path

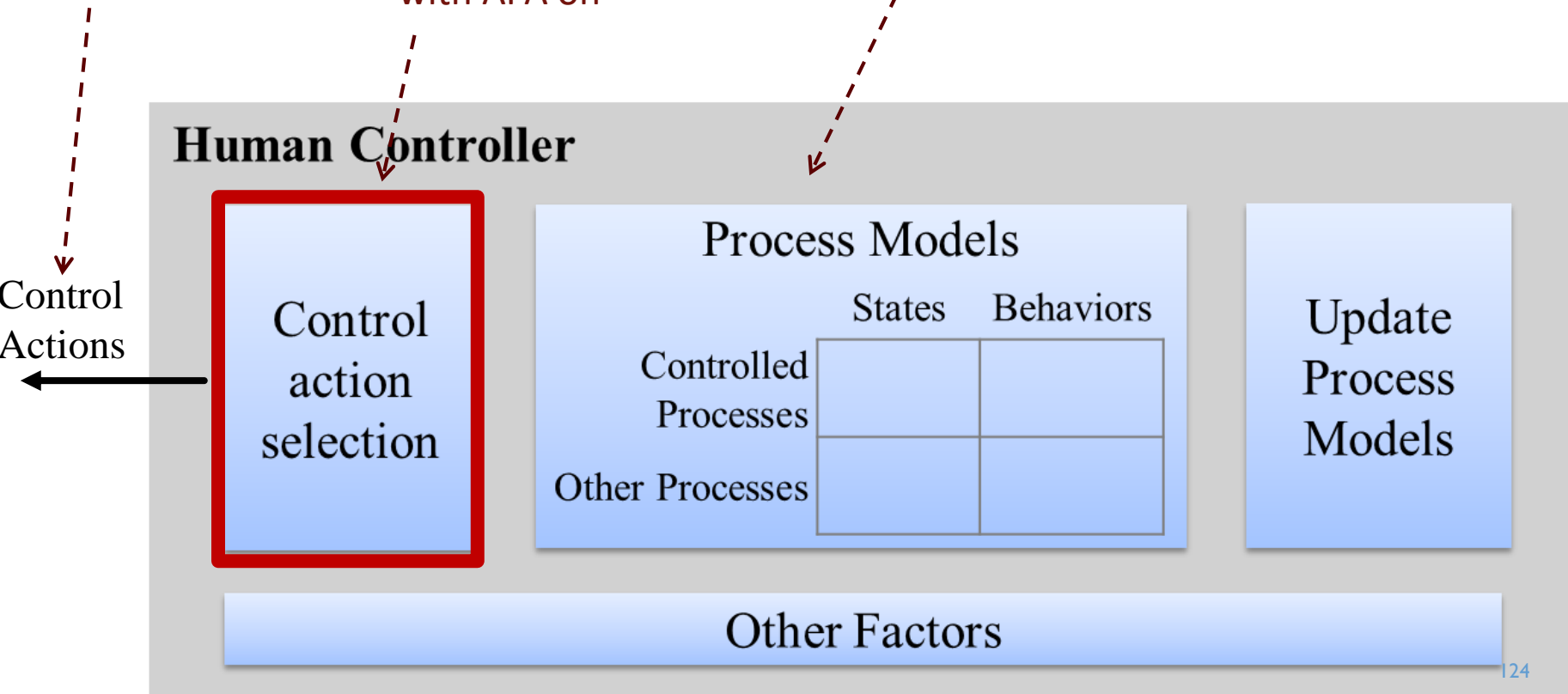


STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver may not know they can control brake with APA on

Driver knows APA is on
 Driver knows APA hasn't reacted yet
 Driver knows there is an obstacle in the way
 Driver knows obstacle is on collision path

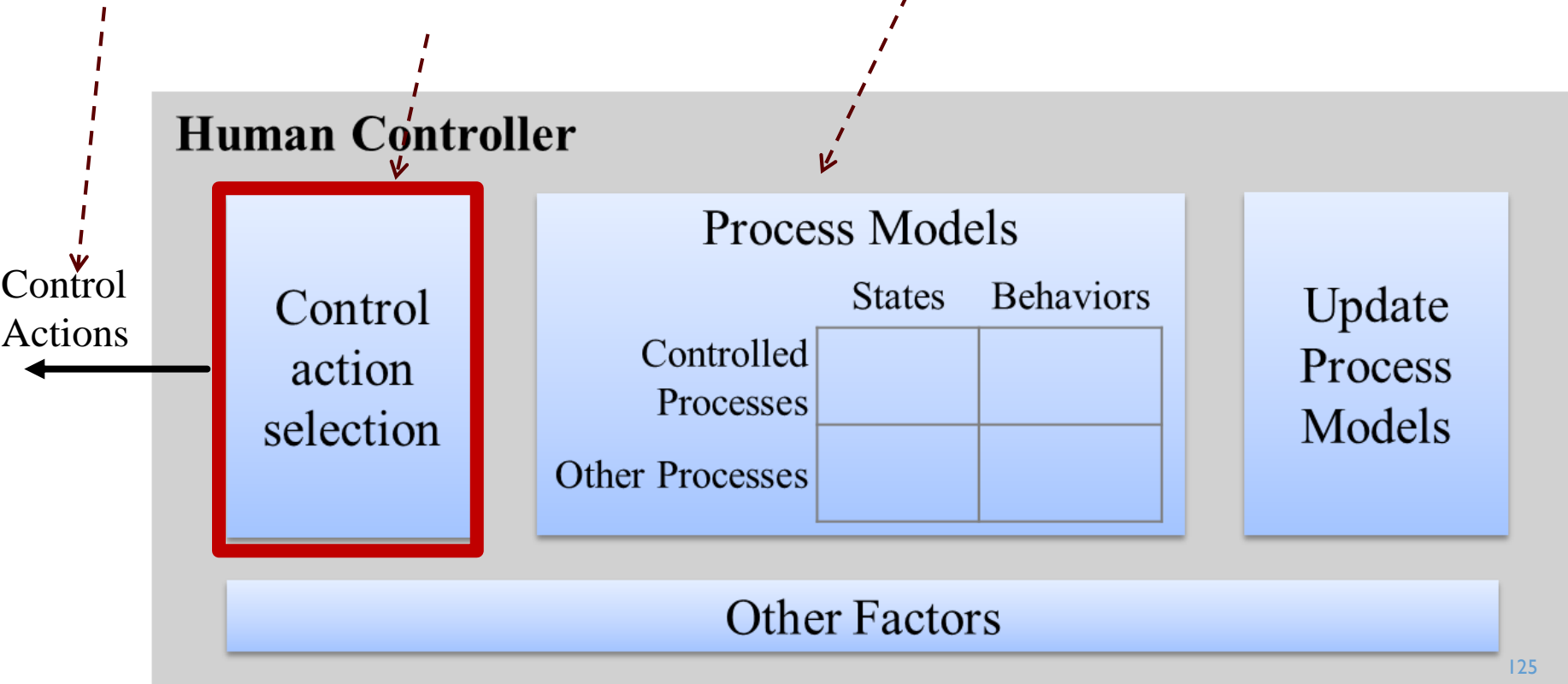


STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver knows APA is on
Driver knows APA hasn't reacted yet
Driver knows there is an obstacle in the way
Driver knows obstacle is on collision path

Driver may decide to disable APA instead

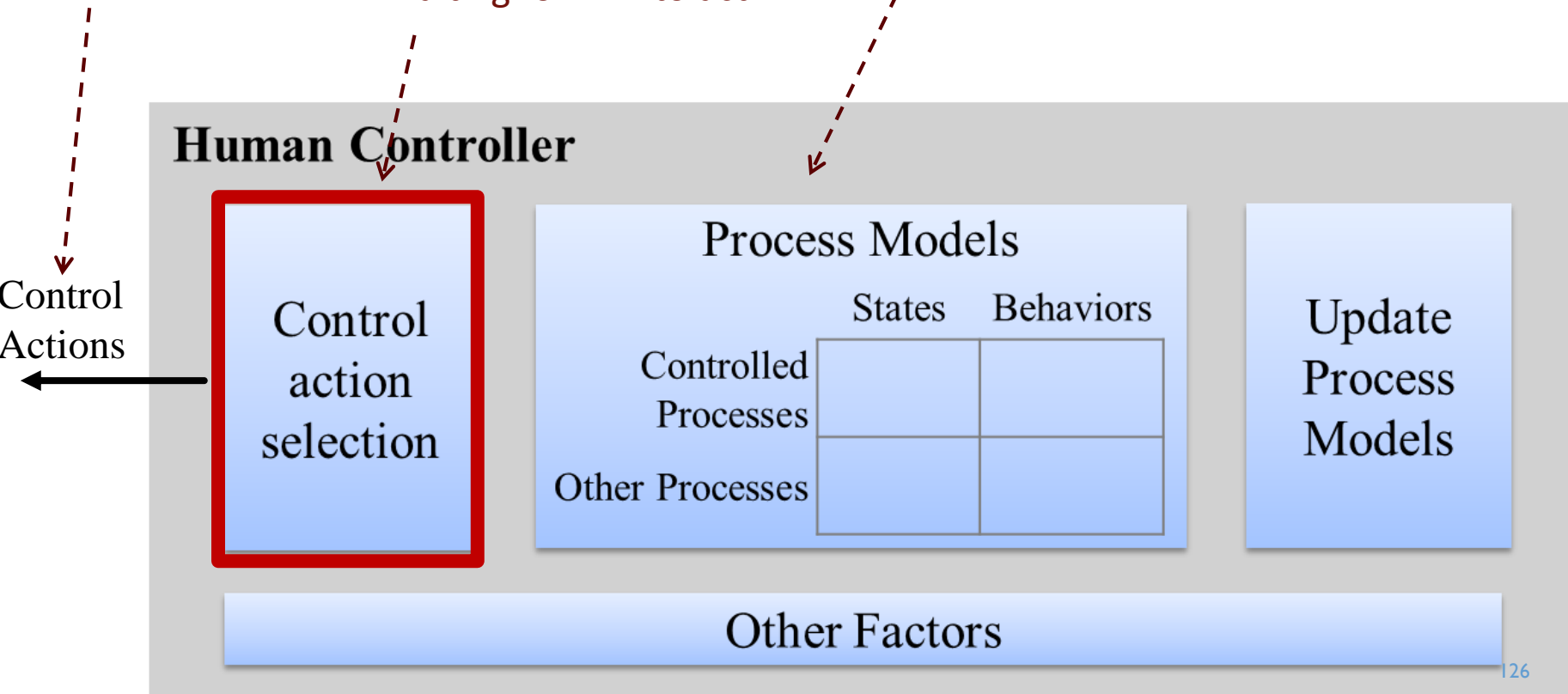


STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver knows APA is on
 Driver knows APA hasn't reacted yet
 Driver knows there is an obstacle in the way
 Driver knows obstacle is on collision path

Driver may still be waiting for APA to act



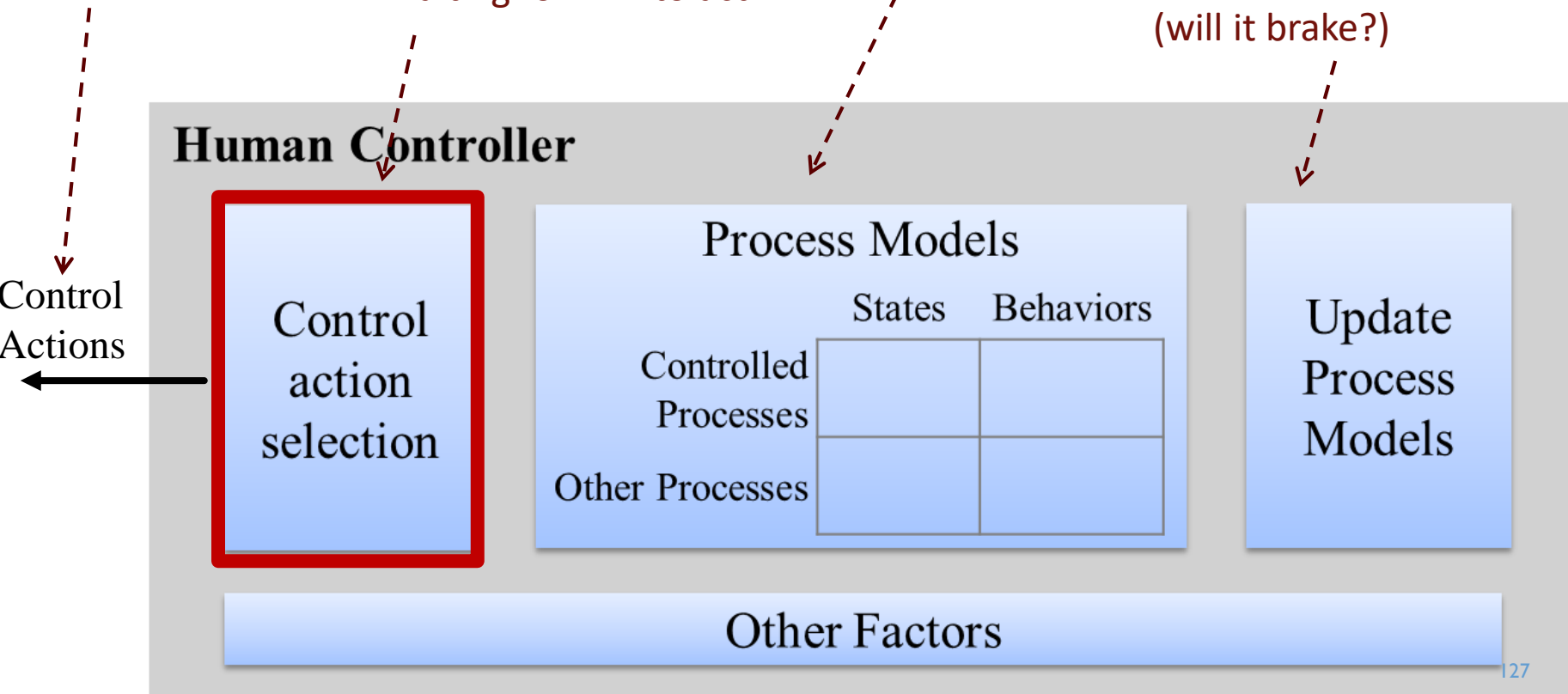
STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver knows APA is on
 Driver knows APA hasn't reacted yet
 Driver knows there is an obstacle in the way
 Driver knows obstacle is on collision path

Driver may still be waiting for APA to act

No mechanism provided to update expectation (will it brake?)



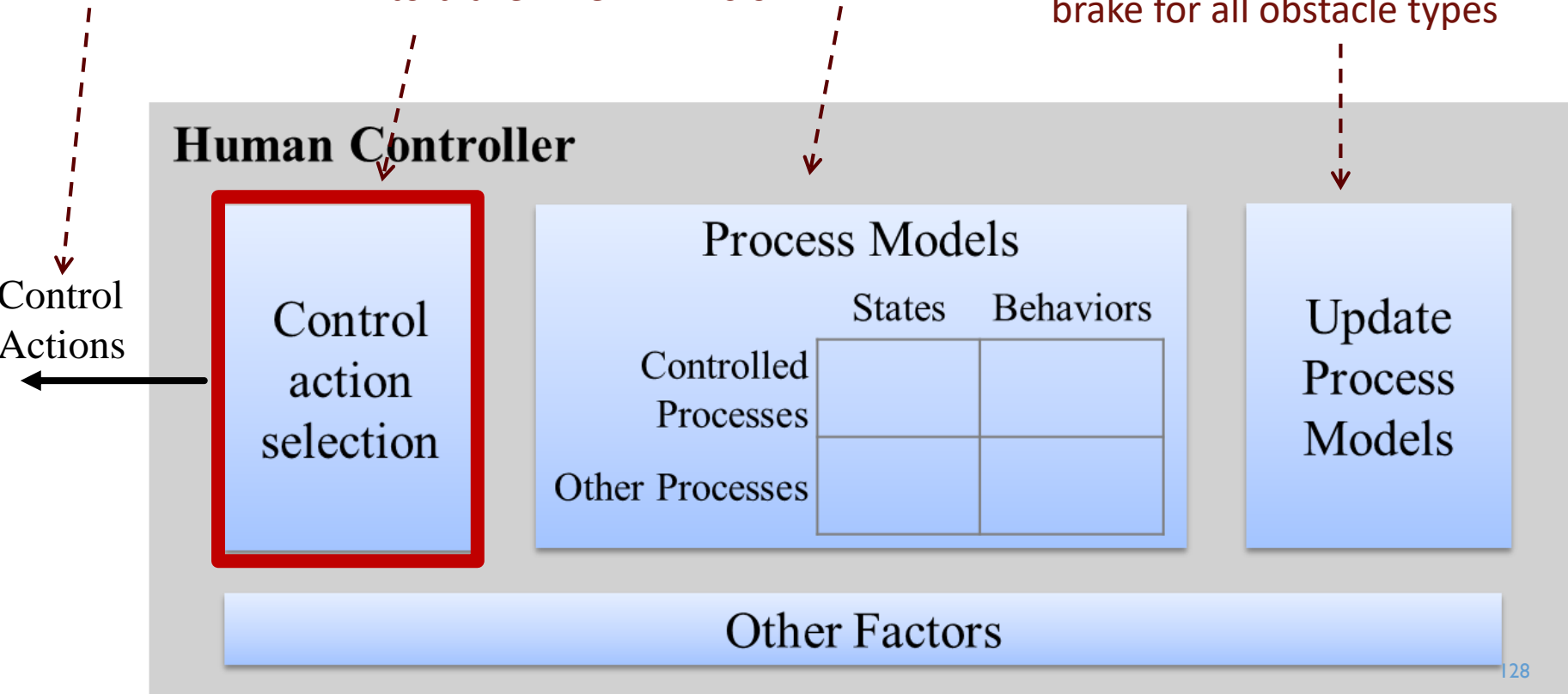
STPA-HF: ENGINEERING FOR HUMANS

Driver does not brake when auto-parking and computer doesn't react to an obstacle (UCA-1)

Driver knows APA is on
 Driver knows APA hasn't reacted yet
 Driver knows there is an obstacle in the way
 Driver knows obstacle is on collision path

Driver rule: I don't need to brake when APA is on

Driver has seen APA brake for parked cars, assumes it can brake for all obstacle types



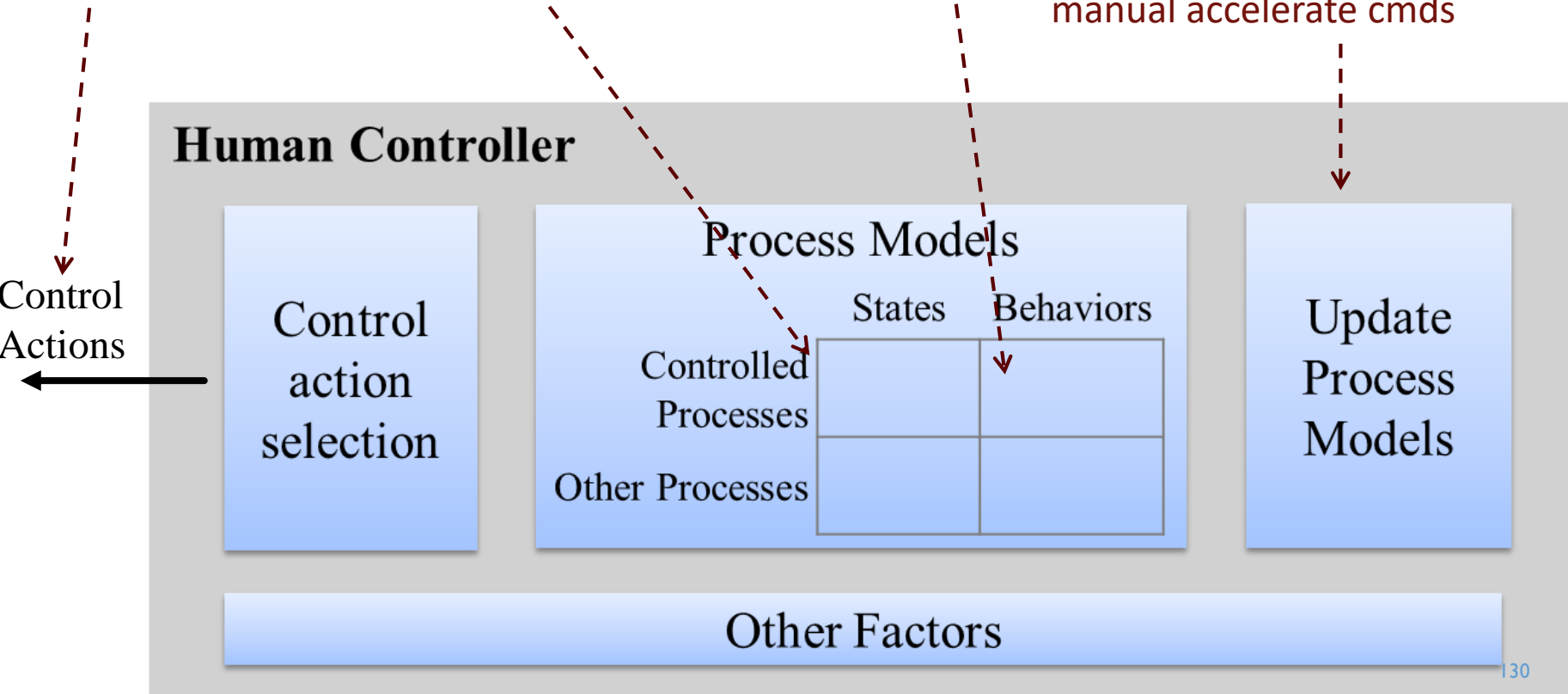
STPA-HF: ENGINEERING FOR HUMANS

Driver does not provide manual steering commands when APA is off (UCA-3)

Driver believes APA will temporarily disable during steering override, then reenable

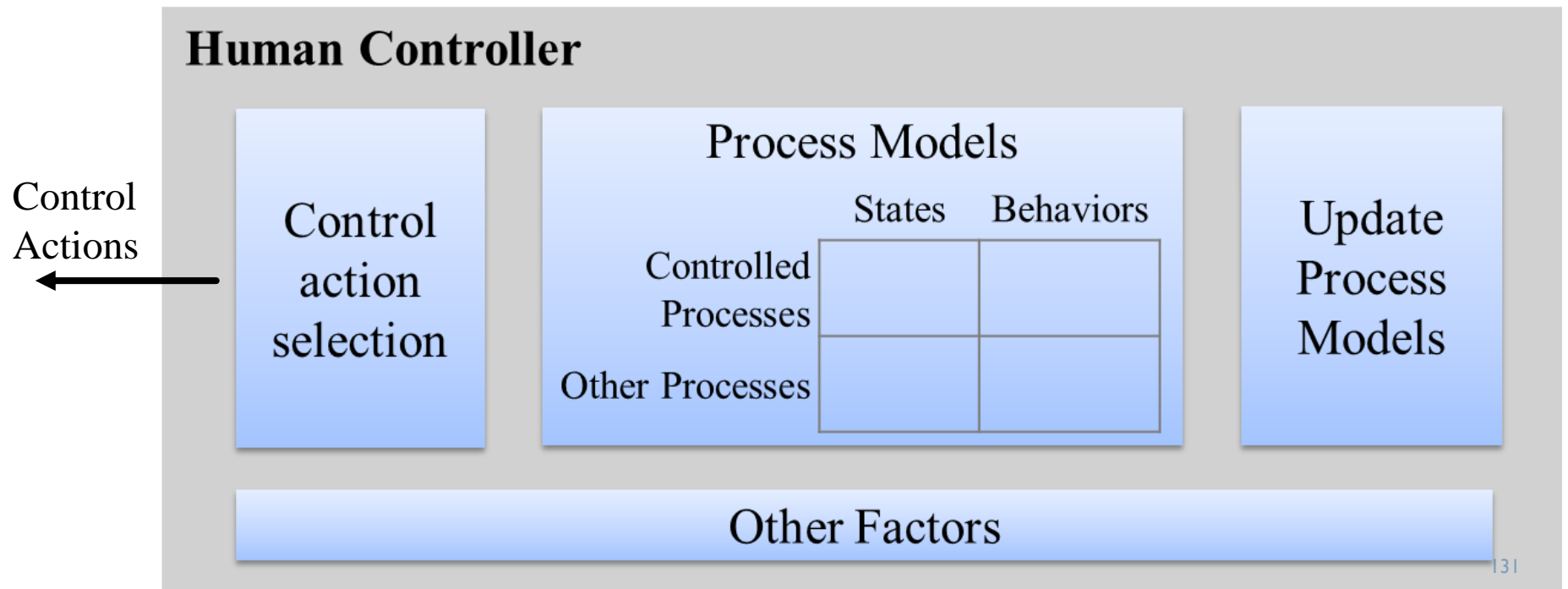
MM-3: Driver believes APA still on

Driver has seen APA automatically reenable after manual accelerate cmds



STPA-HF: ENGINEERING FOR HUMANS

- Identify UCAs
- Identify Process Model variables
- Identify Process Model Flaws
- Identify flaws in Process Model Updates
- Identify unsafe decisions (Control Action Selections)



Can it work for other systems?

VOLVO CITY SAFETY SYSTEM

From Volvo website:

- City Safety is a support system designed to help the driver avoid low speed collisions when driving in slow-moving, stop-and-go traffic.
- City Safety triggers brief, forceful braking if a low-speed collision is imminent.



VOLVO CITY SAFETY PREVENTING AN ACCIDENT



VOLVO CITY SAFETY PREVENTING AN ACCIDENT



www.PortlandVolvo.com

ACCIDENT WITH CITY SAFETY



VOLVO RESPONSE

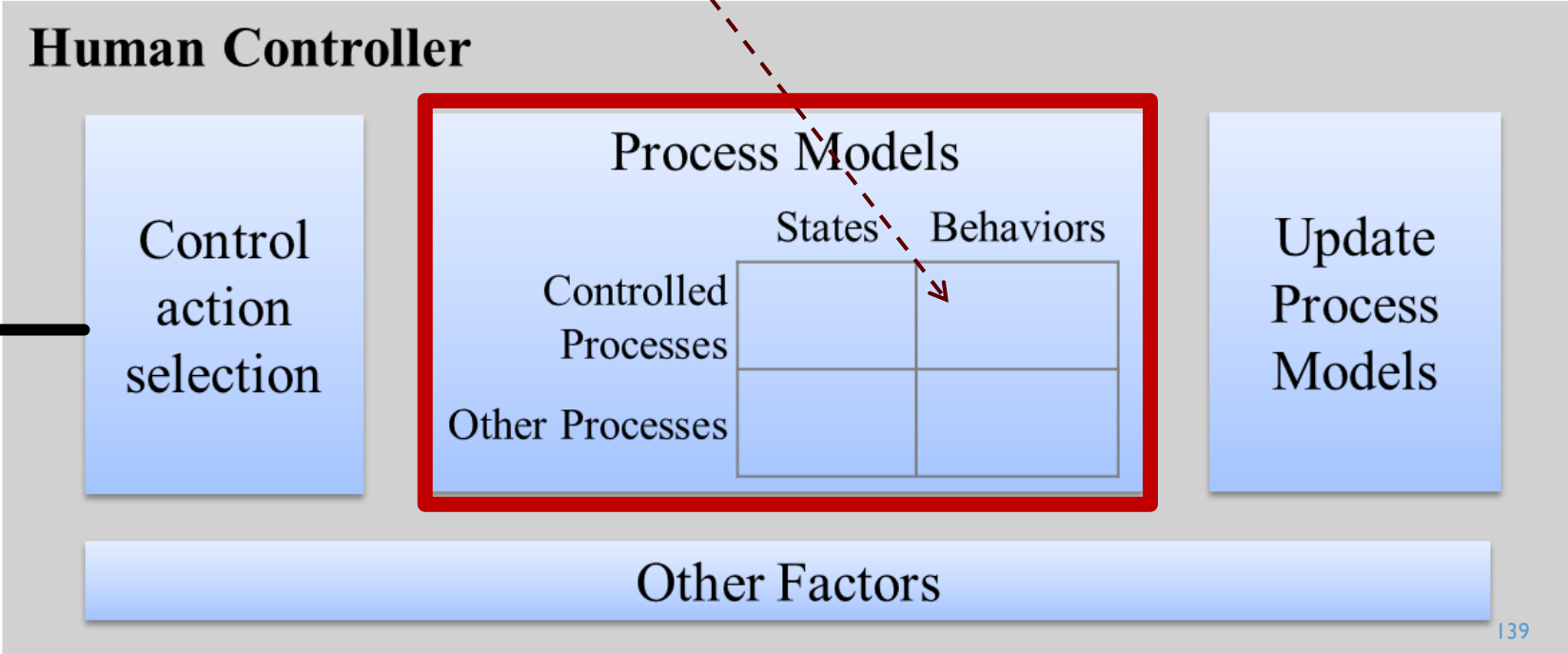
- “The Volvo XC60 comes with City Safety as a standard feature
- “however this does not include the Pedestrian detection functionality ... this is sold as a separate package.”
- Optional pedestrian detection functionality costs \$3,000

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Driver believes City Safety System can automatically brake for pedestrians (it can't)

Driver does not brake for pedestrian (UCA-1)

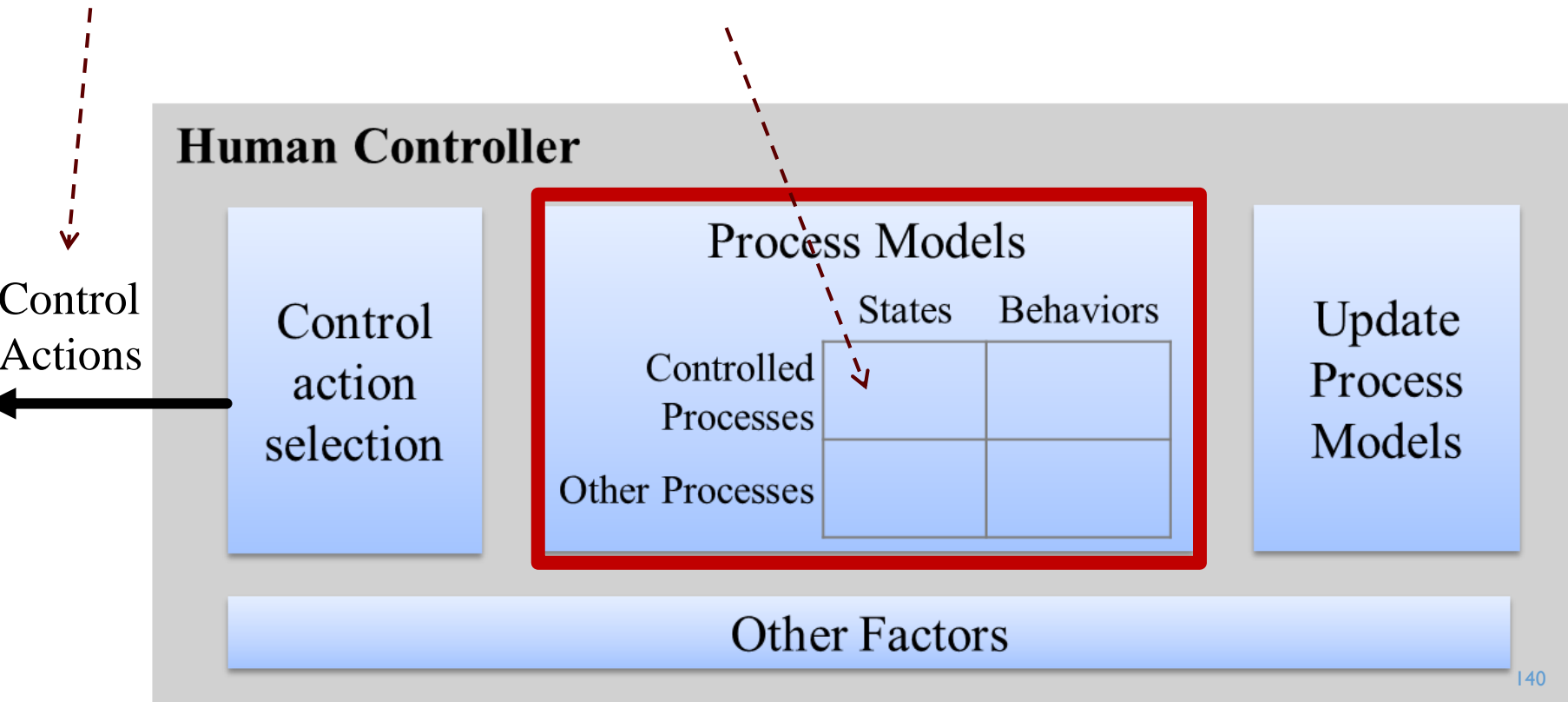


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Driver does not brake for pedestrian (UCA-1)

Driver thinks City Safety System is on (it is really off)



VOLVO RESPONSE

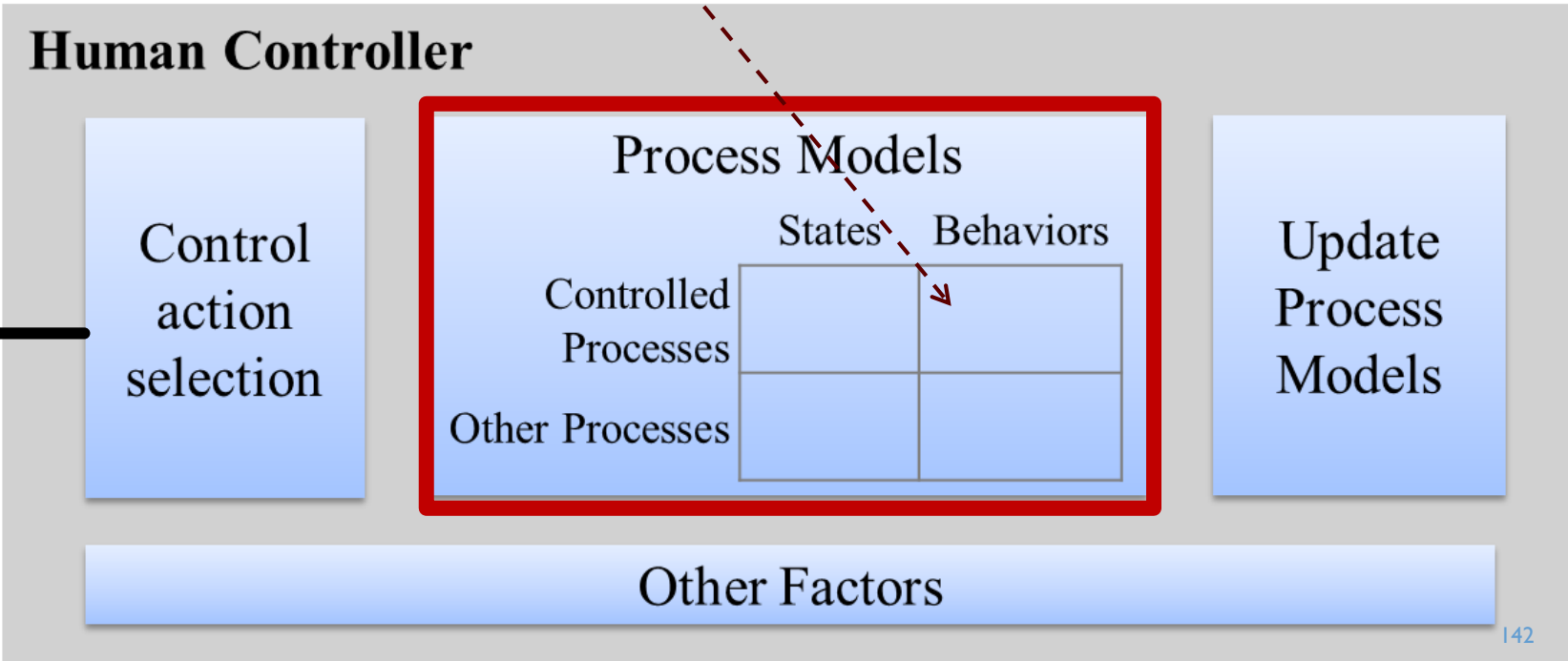
- “The Volvo XC60 comes with City Safety as a standard feature ...
- “however this does not include the Pedestrian detection functionality ... this is sold as a separate package.”
- Optional pedestrian detection functionality costs \$3,000
- Even with pedestrian detection, it mostly likely would not have worked because the driver accelerated

STPA-HF: ENGINEERING FOR HUMANS



Driver thinks City Safety System can intervene during acceleration (it can't)

Driver does not brake for pedestrian (UCA-1)



Control Actions

VOLVO CITY SAFETY SYSTEM

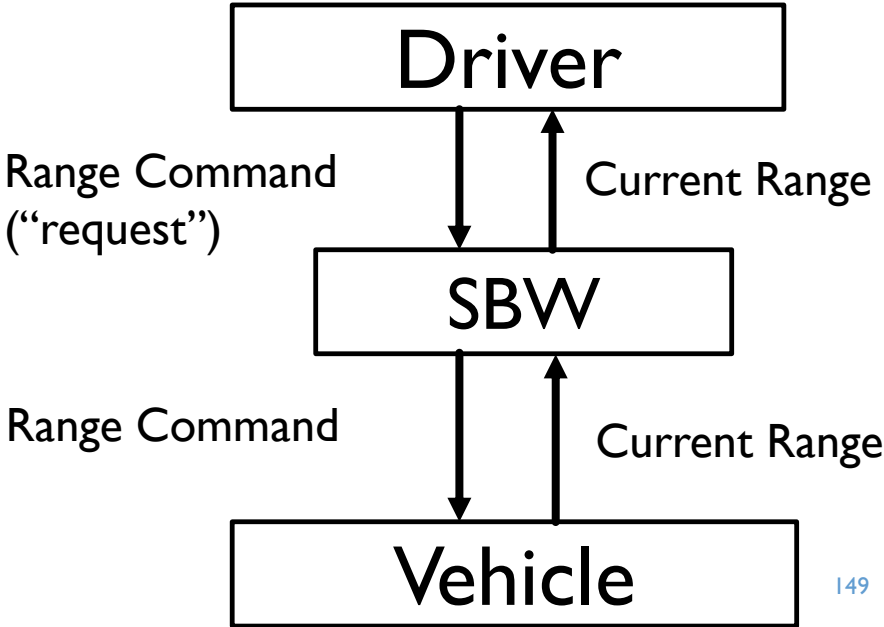
From Volvo:

- City Safety is not active if your vehicle's speed is **below approximately 2 mph**. This means that City Safety will not react if your vehicle approaches another vehicle at very low speed, for example, **when parking**.
- The function is active at speeds up to approximately **30 mph**
- However, the system will not intervene in situations where the **driver actively steers** the vehicle or **applies the brakes**, even if a collision cannot be avoided
- City Safety activates in situations where the driver has not applied the brakes in time, which means that the system cannot help the driver in all situations.
- City Safety does not function in all driving situations or in all **traffic, weather** or road conditions.
- City Safety only reacts to vehicles traveling in the **same direction** as your vehicle
- City Safety ... does not react to **small vehicles** or motorcycles
- City Safety is not activated when your vehicle is **backing up**.
- This system can help prevent a collision if the difference in speed between your vehicle and the vehicle ahead is **less than 9 mph**. If the difference in speed is greater, a collision cannot be avoided but the speed at which the collision occurs can be reduced. **The driver must apply the vehicle's brakes for full braking effect.**



Range =

- Park
- Reverse
- Neutral
- Drive
- Etc.



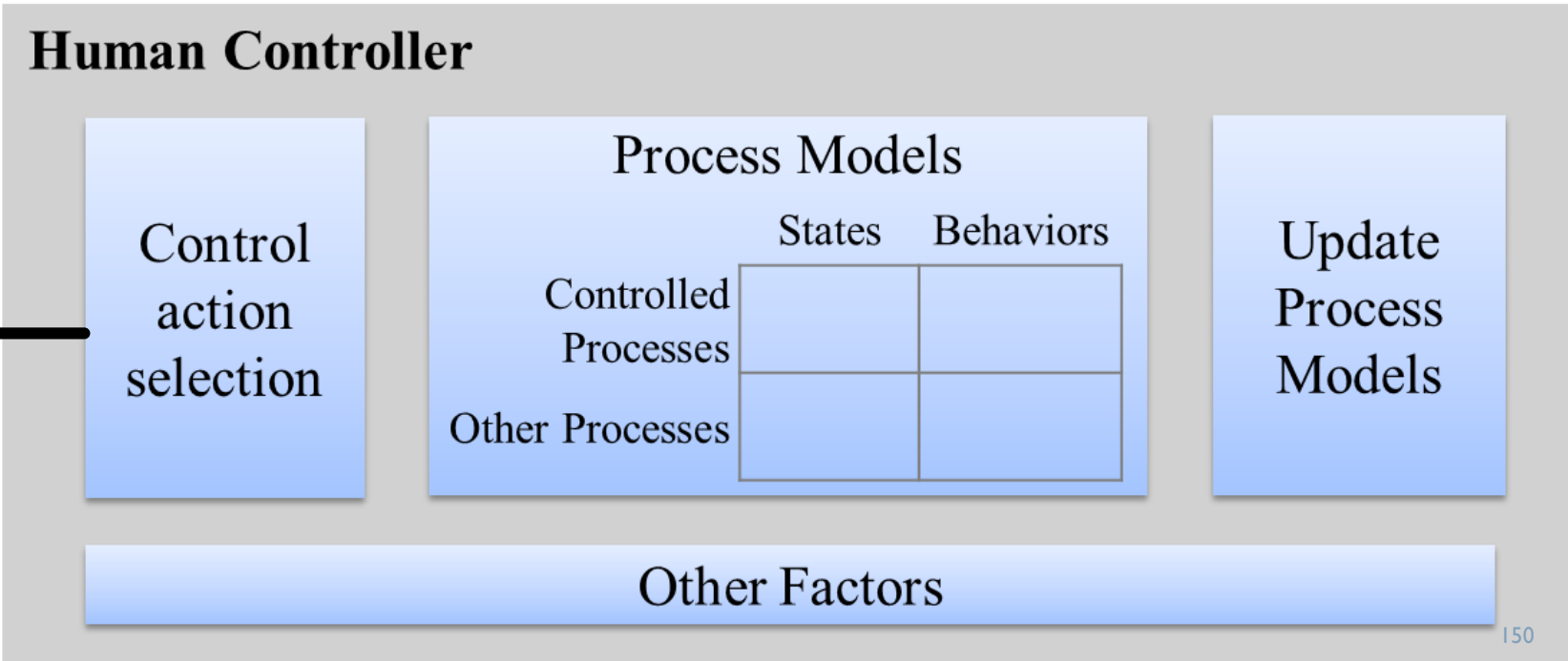
STPA-HF: ENGINEERING FOR HUMANS



Driver exits vehicle when vehicle is not in park (UCA-1)



Control Actions

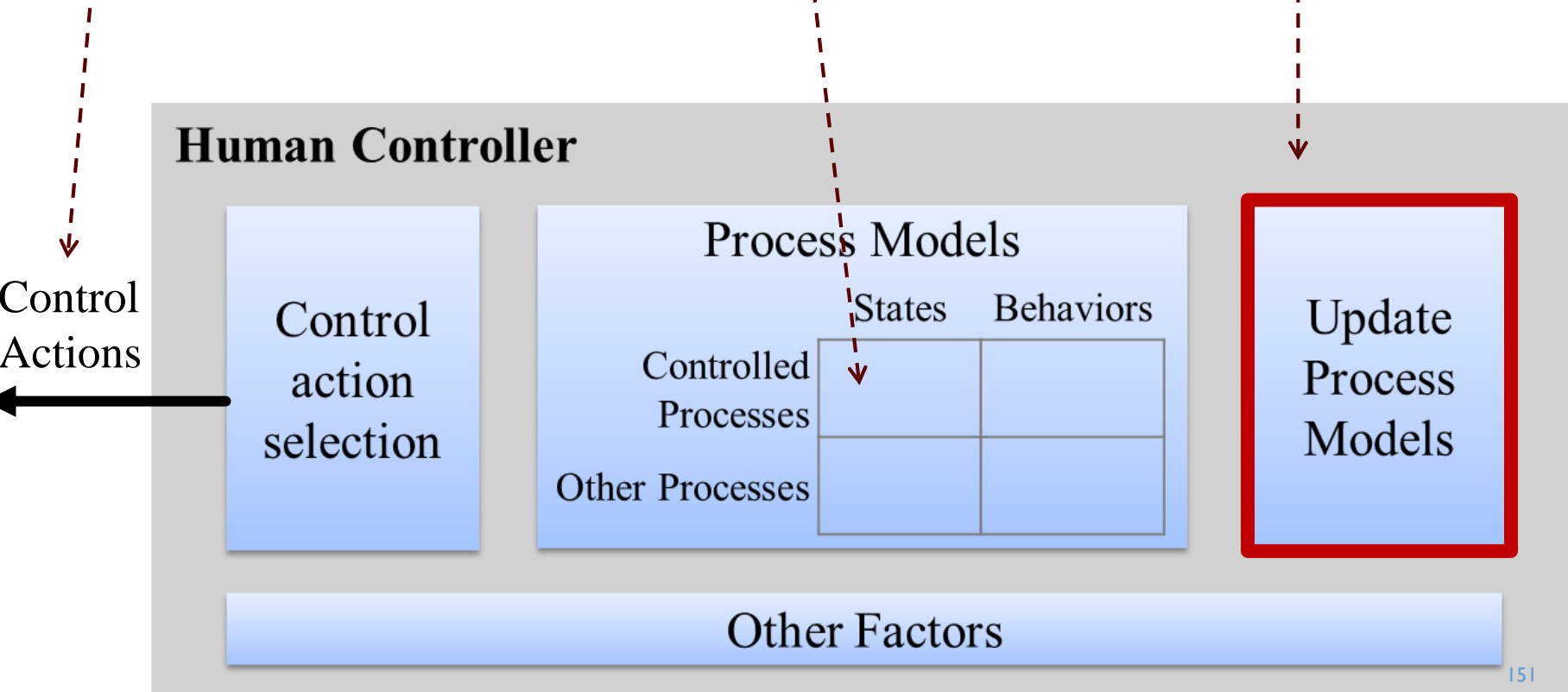


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Driver exits vehicle when vehicle is not in park (UCA-1)

Driver incorrectly believes vehicle is in Park (MM-1)

- Consider:
1. Automatic mode changes
 2. Previous cmds ignored
 3. Phases of operation
 4. Etc.

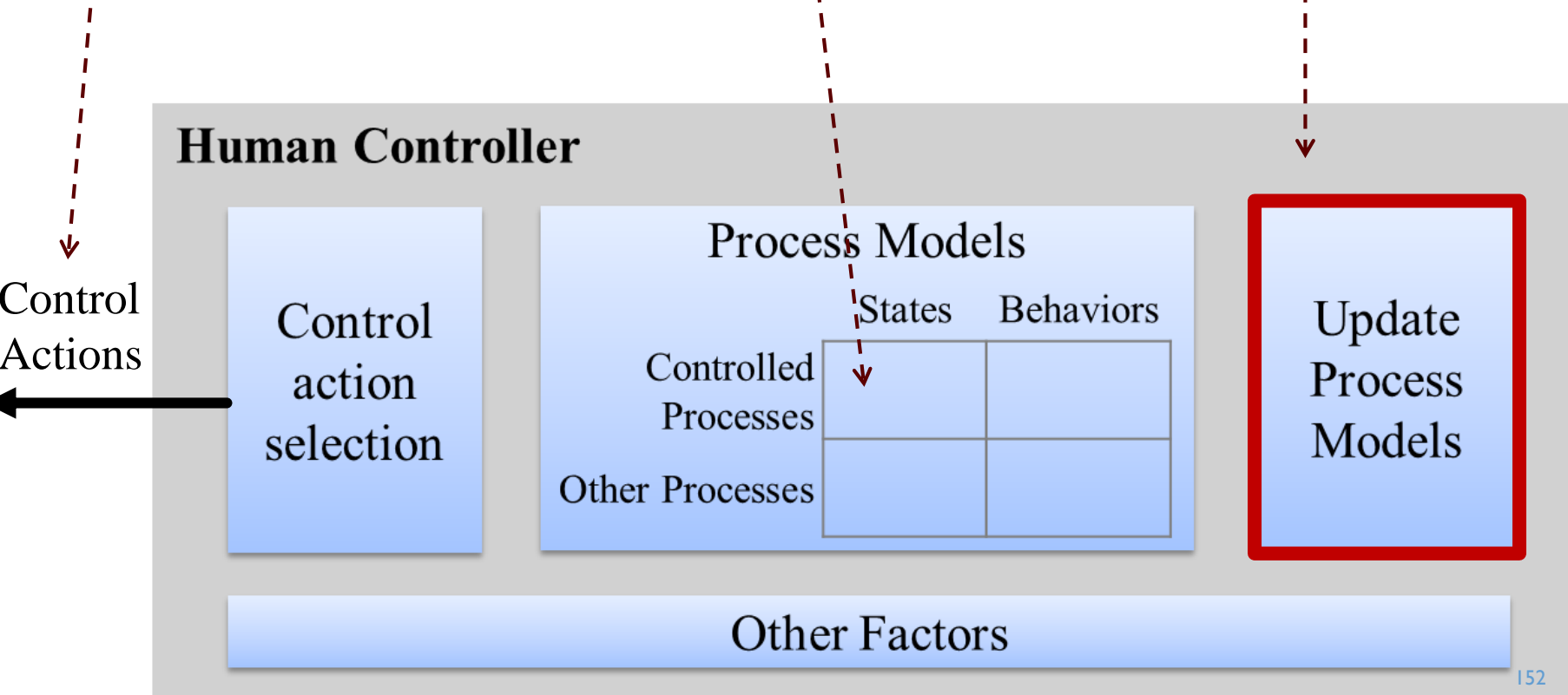


STPA-HF: ENGINEERING FOR HUMANS

Driver exits vehicle when vehicle is not in park (UCA-1)

Driver incorrectly believes vehicle is in Park (MM-1)

Driver didn't notice vehicle ignored previous Park command

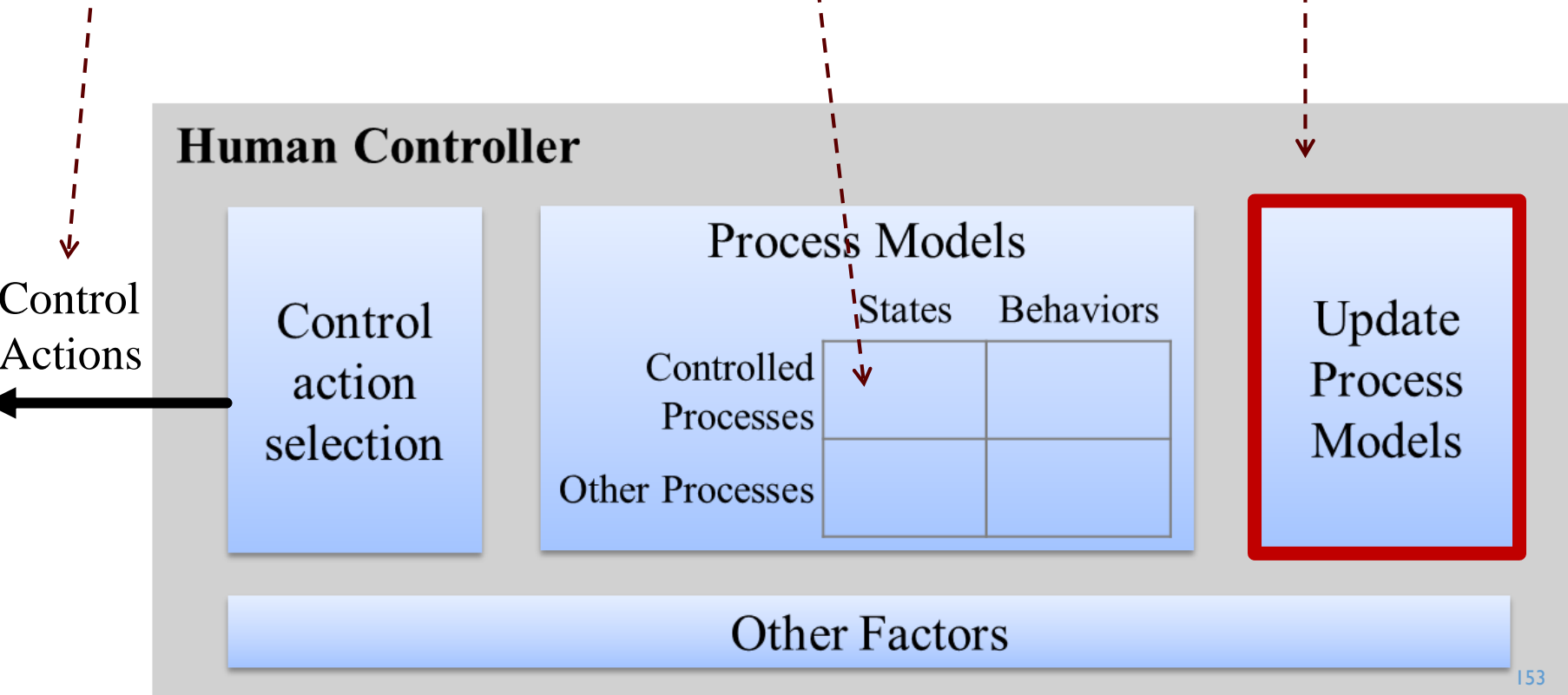


STPA-HF: ENGINEERING FOR HUMANS

Driver exits vehicle when vehicle is not in park (UCA-1)

Driver incorrectly believes vehicle is in Park (MM-1)

Driver didn't notice vehicle automatically shifted to Neutral

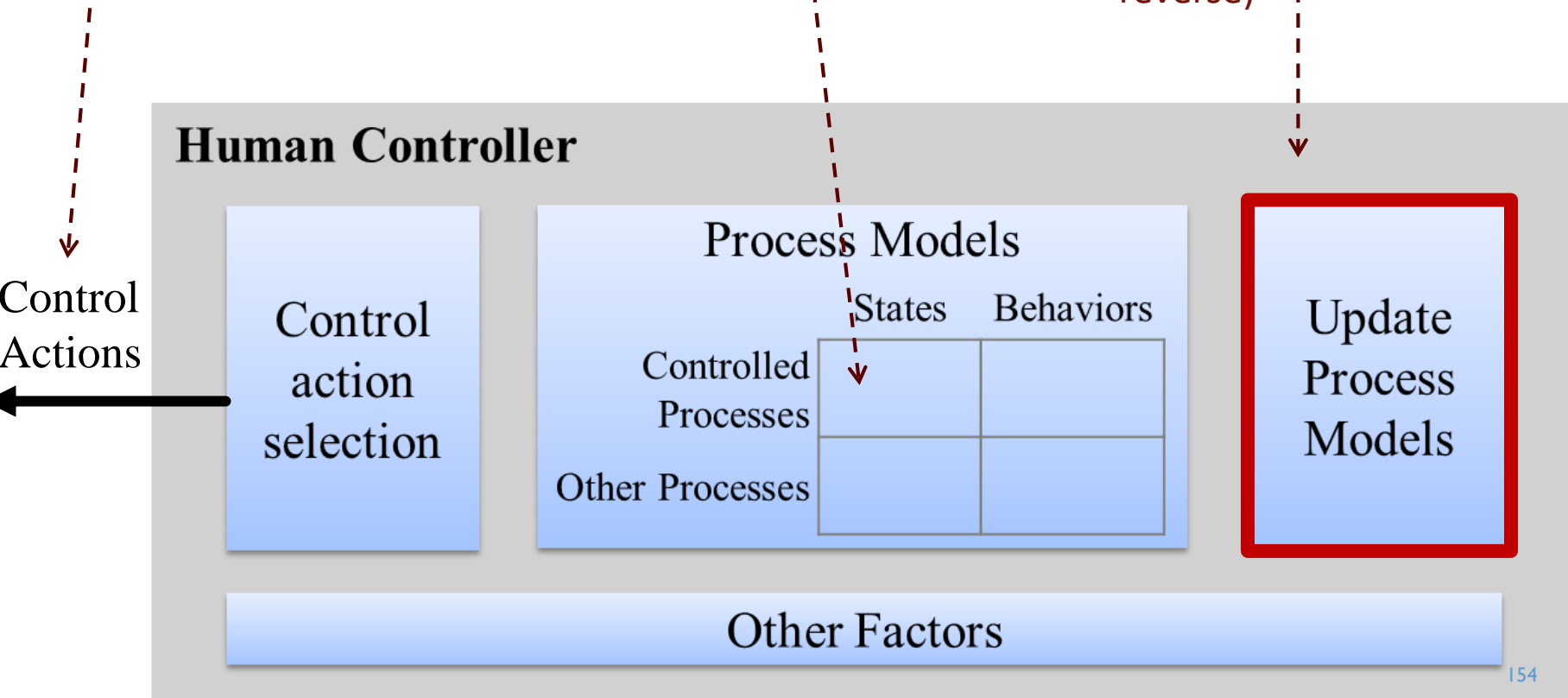


STPA-HF: ENGINEERING FOR HUMANS

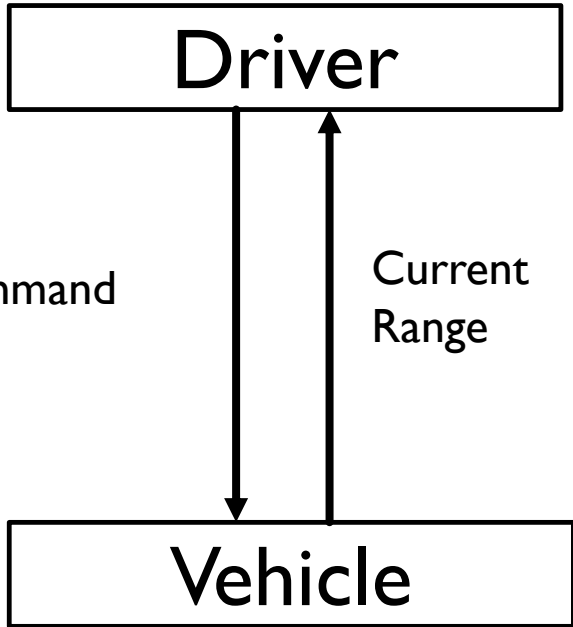
Driver accelerates when vehicle is not in appropriate range (e.g. reverse instead of drive)

Driver incorrectly believes vehicle is in Drive (MM-1)

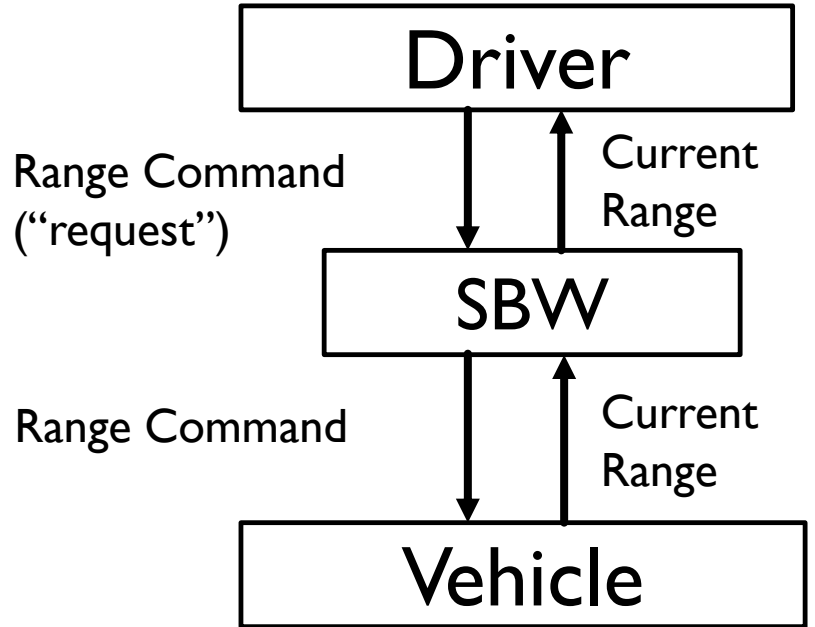
Driver didn't notice vehicle ignored cmd to shift to Drive (stayed in reverse)



Old System



New System

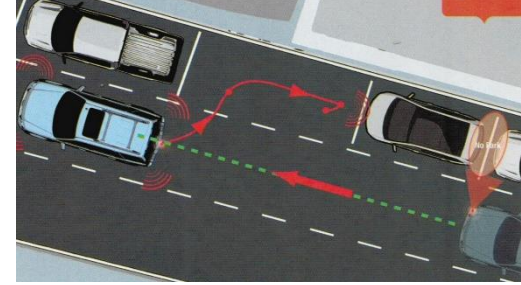


Driver Unsafe Scenarios



Driver Unsafe Scenarios

AUTOMATED PARKING



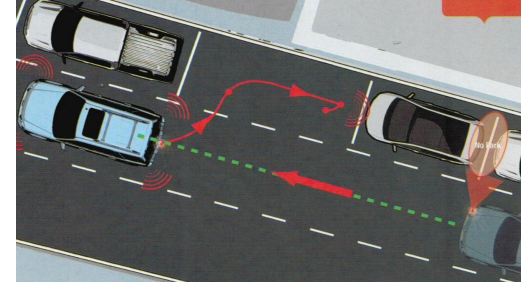
Features of each system considered for this analysis:

	Level 0*	Level 1	Level 2a	Level 2b	Level 3
	No Driving Automation	“Driver Assistance”	“Partial Automation”	“Partial Automation”	“Conditional Automation”
Steering	-	✓	✓	✓	✓
Braking	-	-	✓	✓	✓
Shifting and Acceleration	-	-	-	✓	✓
Object and Event Detection and Response	-	-	-	-	✓

*System numbering is consistent with SAE definitions for levels of automation, while “a” and “b” indicate different implementations which are classified within the same SAE level.

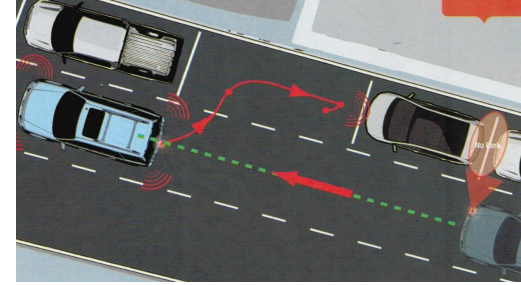
Analysis reuse

AUTOMATED PARKING

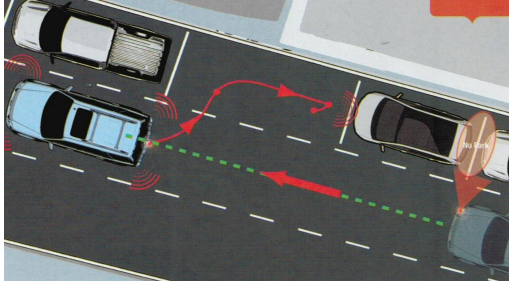


	Level 1 “Driver Assistance”	Level 2a “Partial Automation”	Level 2b “Partial Automation”	Level 3 “Conditional Automation”
Driver UCAs				
APA Computer UCAs	5	13	28	28
Total				

AUTOMATED PARKING



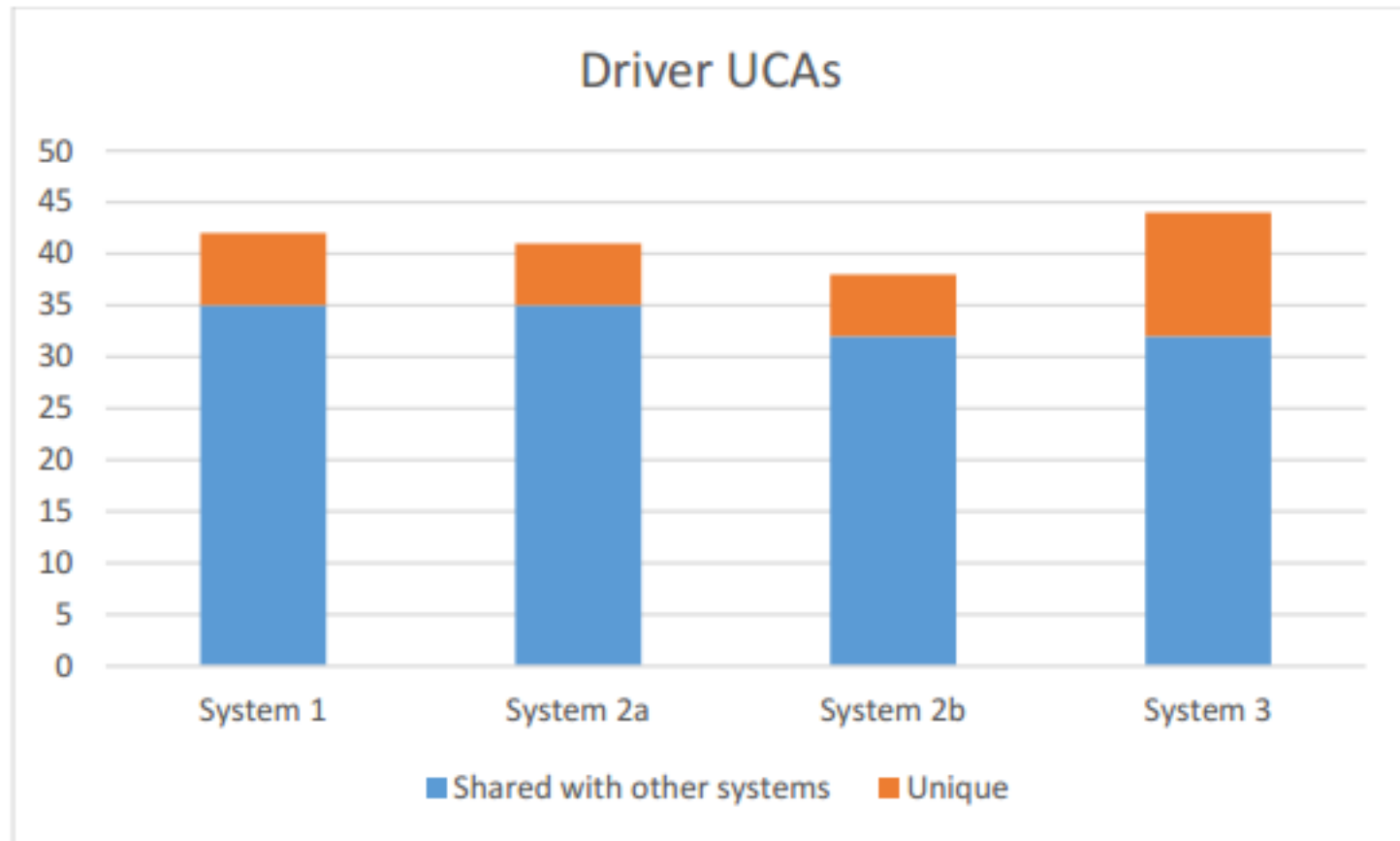
	Level 1 “Driver Assistance”	Level 2a “Partial Automation”	Level 2b “Partial Automation”	Level 3 “Conditional Automation”
Driver UCAs	42	41	38	44
APA Computer UCAs	5	13	28	28
Total				



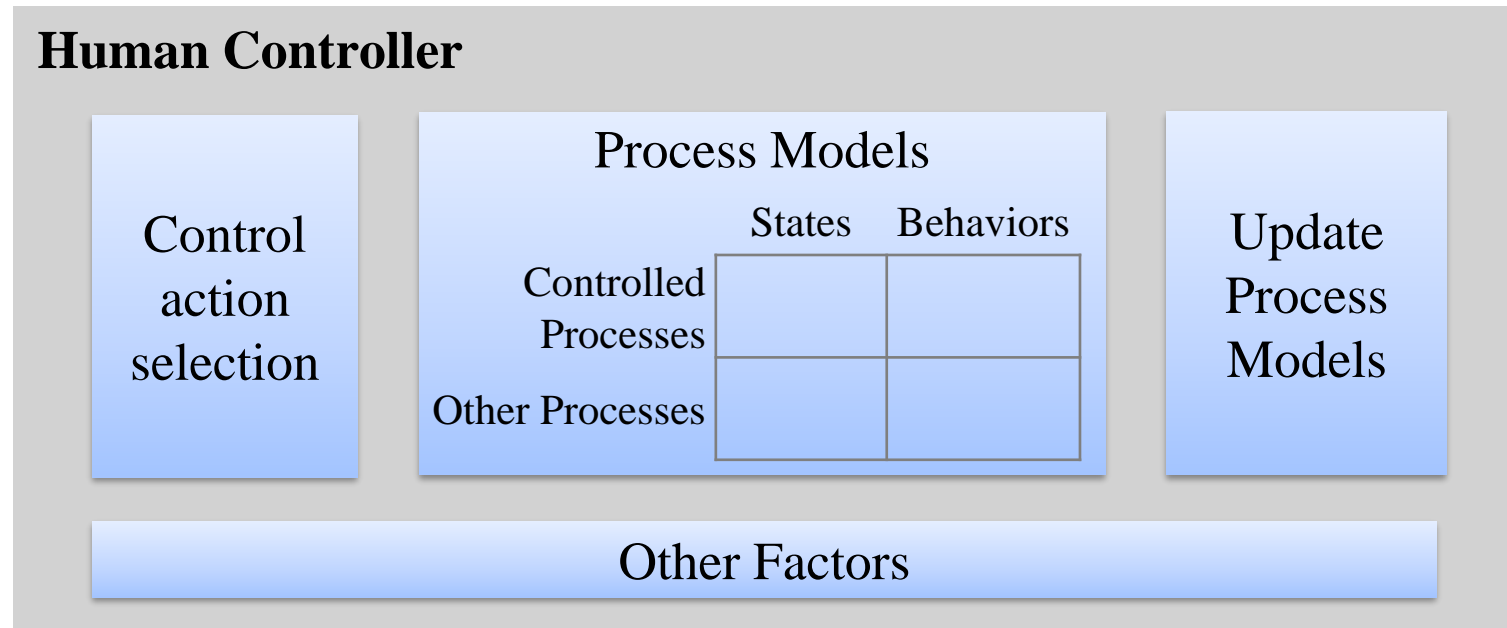
AUTOMATED PARKING

	Level 1 “Driver Assistance”	Level 2a “Partial Automation”	Level 2b “Partial Automation”	Level 3 “Conditional Automation”
Driver UCAs	42	41	38	44
	35 in common		32 in common	
		30 in common		
APA Computer UCAs	5	13	28	28
	5 in common		28 in common	
		13 in common		
Total	47	54	66	72
	40 in common		60 in common	
		43 in common		

	Level 1	Level 2a	Level 2b	Level 3
Driver UCAs	42	41	38	44
APA Computer UCAs	5	13	28	28
Total	47	54	66	72



CONCLUSIONS



STPA-HF: New human engineering process:

- Easy for engineers to learn, use
- Drives engineering requirements and concepts from the start
- Can be used earlier in design process than detailed simulations or prototypes
- Successful in industry, adoption

Next time: Advanced tutorial?

(if there is interest)

Example

1) Identify UCAs

UCA-1: Driver does not stop engine when there is an emergency

2) Identify mental models learned from old system

To turn off vehicle:



Vehicle started

T

Key turned to Off

T

3) Translate into process models for new system

To turn off vehicle:

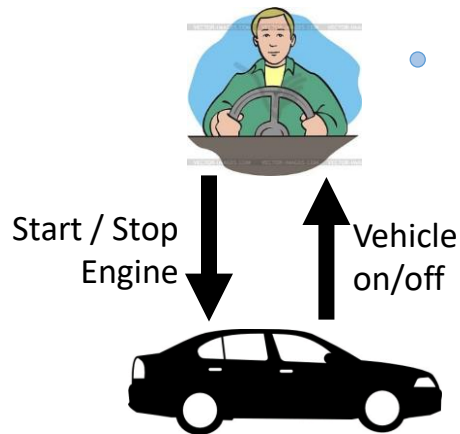


Vehicle started

T

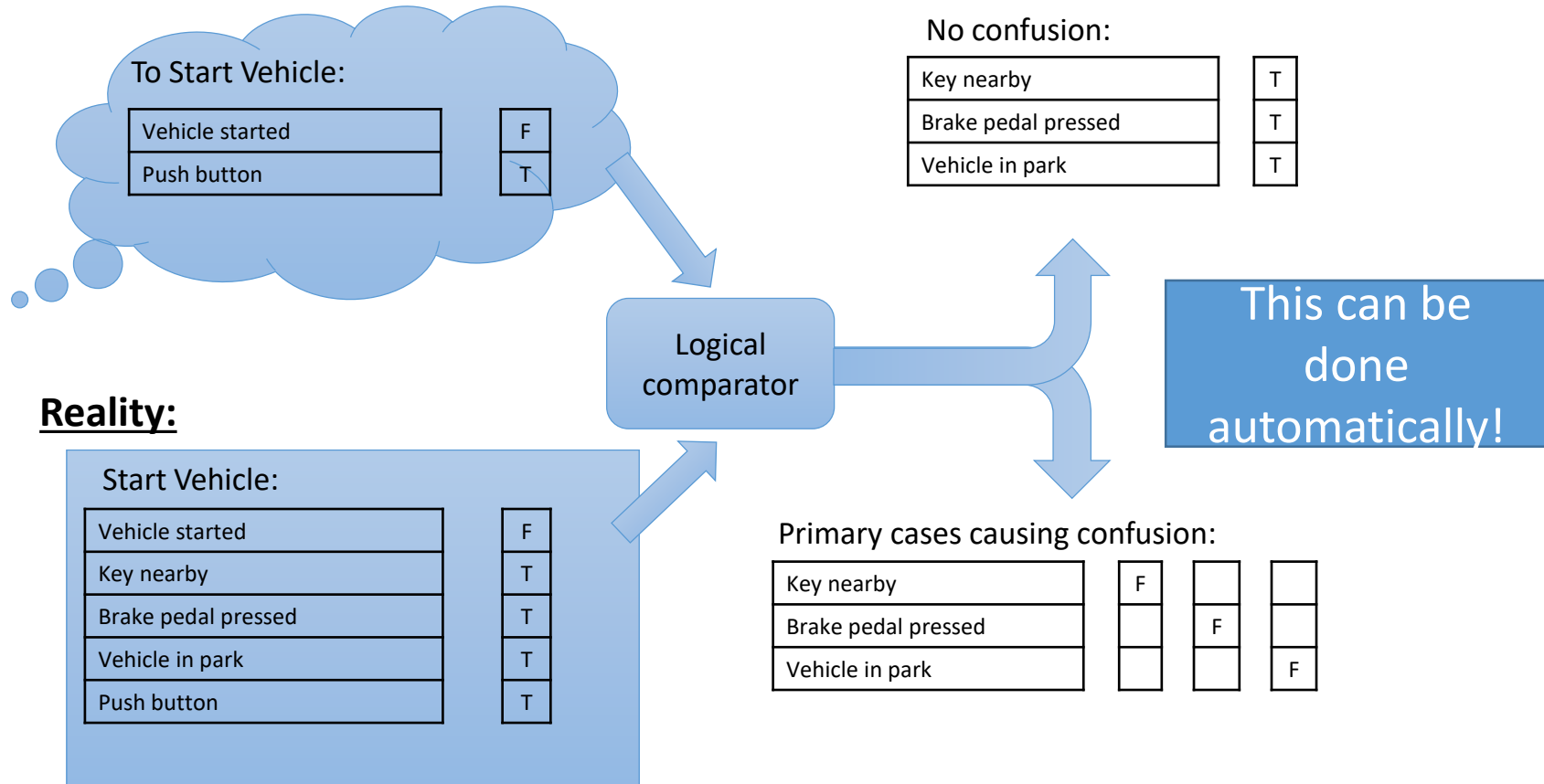
Push button

T



Customer satisfaction / annoyance

Process Model:



1) Identify Braking UCAs (Not Providing Causes Example)

UCA 1-20: Driver does not provide brakes after APA is engaged and an object is in the space

APA Braking Example

2) Identify process models learned from old system

To stop APA for obstacle:
Do nothing: Tesla will automatically brake if an object is present

3) Translate into process models for new system

To stop APA for obstacle:
Do nothing: Range Rover should brake automatically if an object is in the space

Will this process model cause a UCA?

