Compatibility of STPA with GM System Safety Engineering Process

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       - Apply PHA which includes vehicle functional HAZOP analysis
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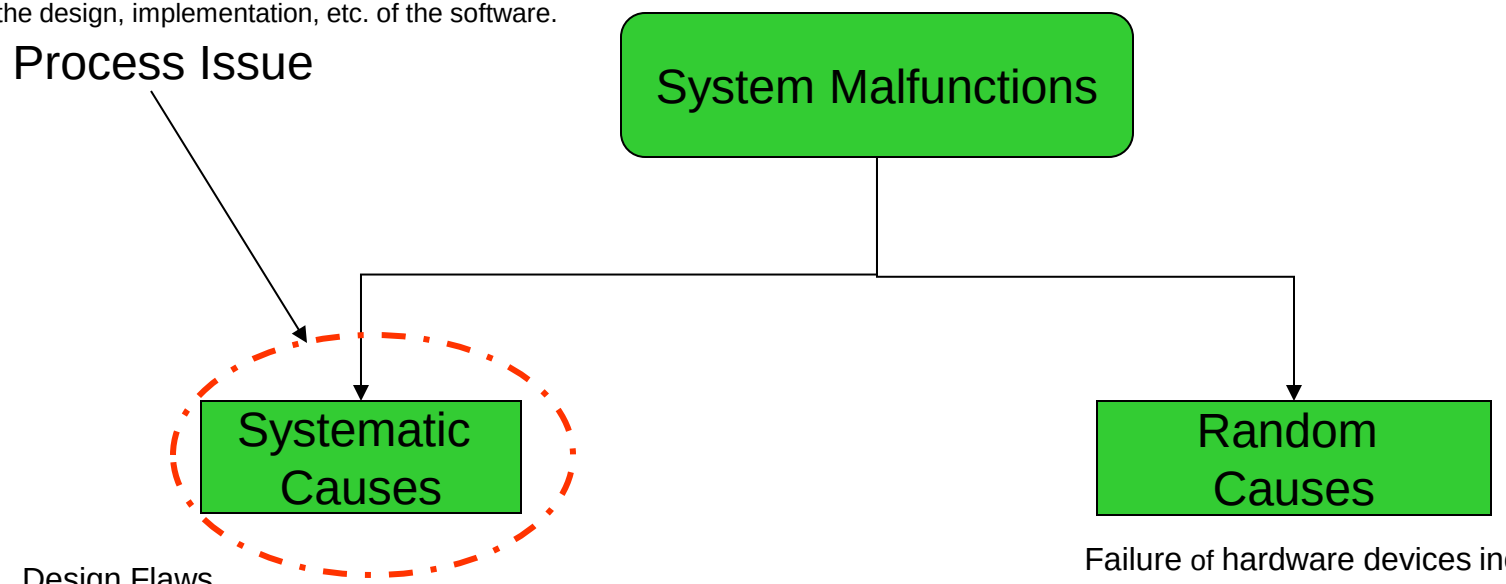
- Electronics and software content continue to increase in automotive systems
- Safety-critical systems require disciplined and comprehensive engineering effort to identify safety related risks and eliminate or control them
  - Need to address both random and systematic concerns
- GM has been engaged in engineering safety-critical systems since the early 1980's
  - Internally developed robust processes have been put in place to verify the integrity of these systems since the launch of electronic throttle control (ETC) in 1997
    - Safety process influenced by MIL STD 882
- The product engineering processes are continuously enhanced to handle growing complexity of systems, optimize efficiency and also to be aligned with the ISO 26262

System Safety- Random and Systematic

systematic failure (Per IEC 61508 definition):
failure related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors
Examples of causes of systematic failures include human error in
– the safety requirements specification;
– the design, manufacture, installation, operation of the hardware;
– the design, implementation, etc. of the software.



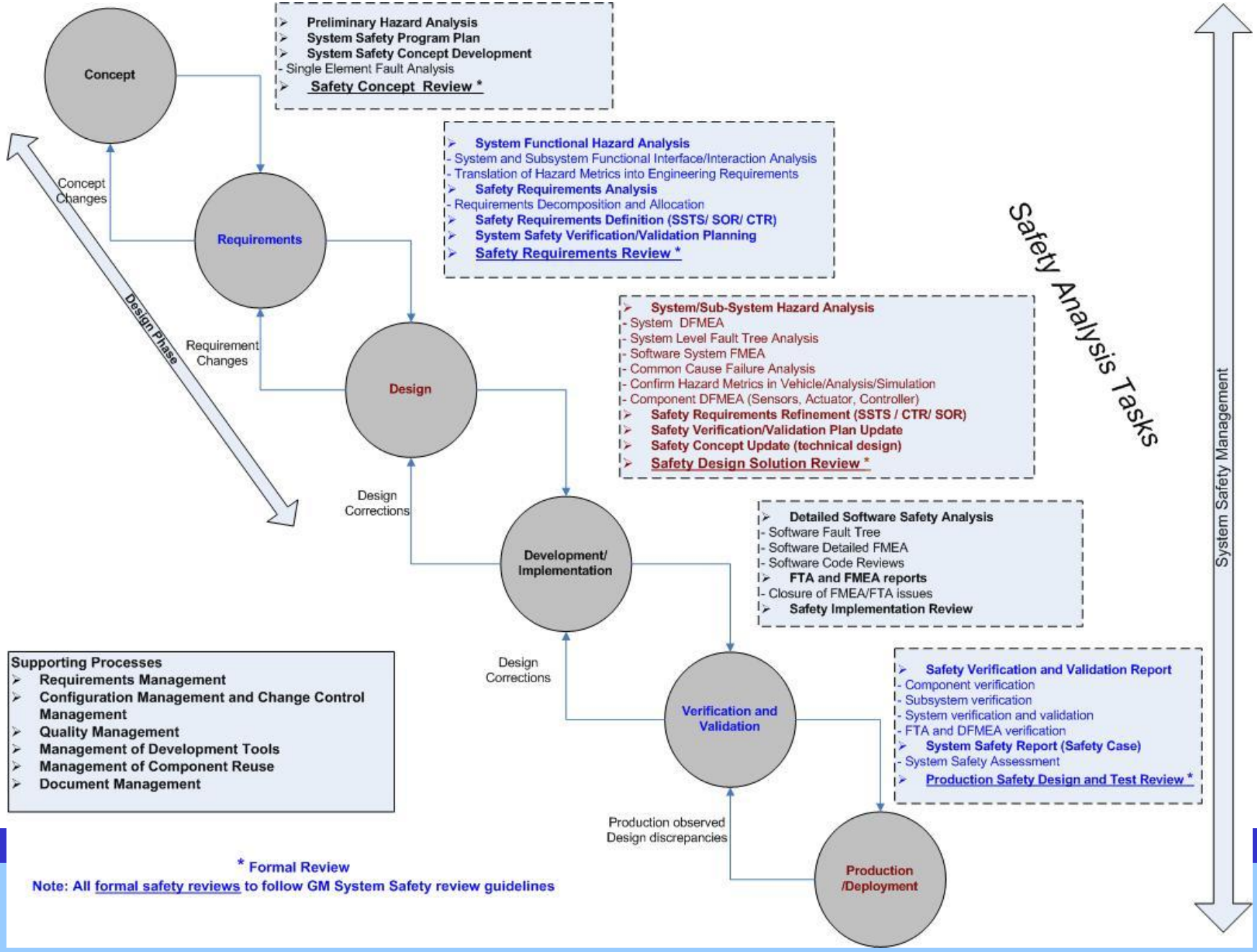
- Design Flaws
- Incorrect Requirement (s)
- Missing Requirement (s)
- Omission of Requirements

Failure of hardware devices including Sensors, Processors, Actuators, connectors, Communication Interfaces due to mechanical wear, ageing, stress

Example Potential Causes:

1. Incomplete understanding of the system behavior under all operating conditions
2. Engineering Process flaws
3. Management/Communication flaws

GM System Safety Engineering Process



- As part of continuous improvement of our process, we are open to evaluating any new technique that can help us improve the effectiveness and efficiency of the safety process
  - It is in this context that we decided to investigate STPA as applied to an embedded automotive control system
- We have applied STPA on a simplified Engine Control system and compared the derived safety requirements against those derived by following GM system safety process steps
- Two teams involved in the study
  - One performed the STPA and derived the safety requirements
  - Other followed the GM safety process to derive safety requirements
  - Both teams got together to compare the safety requirements objectively

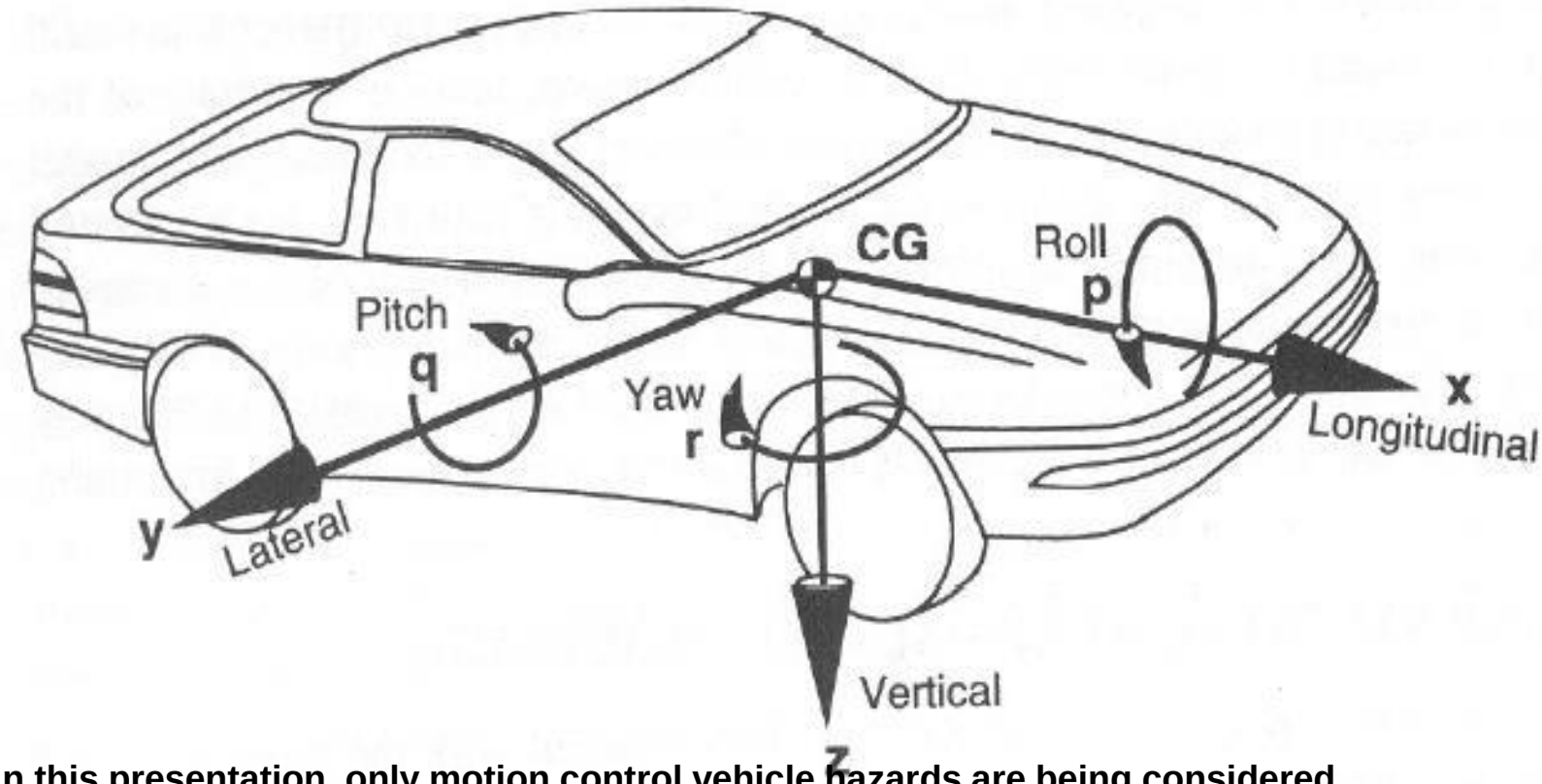
STPA Steps

- Identify Hazards
- Draw the control structure
  - Identify major components and controllers
  - Label the control/feedback arrows
- Identify Unsafe Control Actions (UCAs)
  - Control Table:
    Not given, Given incorrectly, Wrong timing,
    Stopped too soon
  - Create corresponding safety constraints
- Identify causal factors
  - Identify controller process models
  - Analyze controller, control path, feedback path, process

Source: STPA/STAMP Workshop #1, April 2012, MIT

Motion Control Vehicle Level Hazards (Example)

To identify Hazards, GM PHA process was followed:



Note: In this presentation, only motion control vehicle hazards are being considered

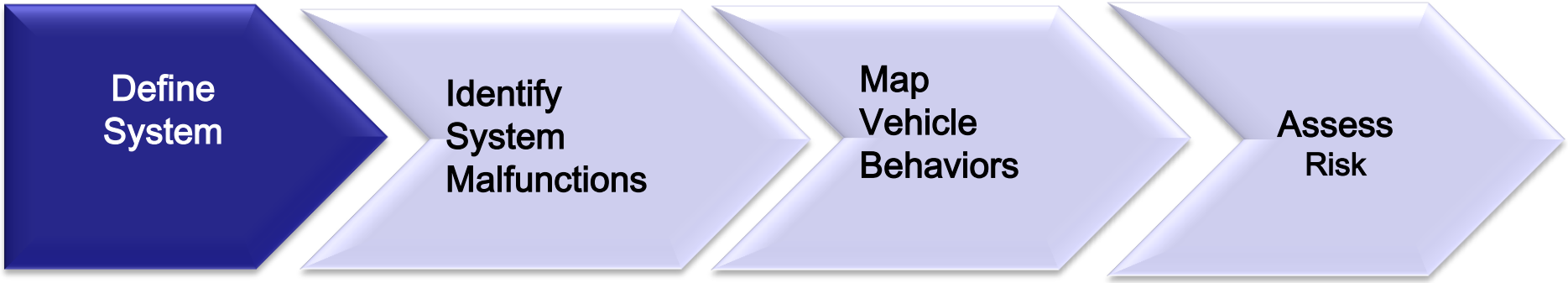
Source: SAE Vehicle Axes

Generic Vehicle Level Hazards

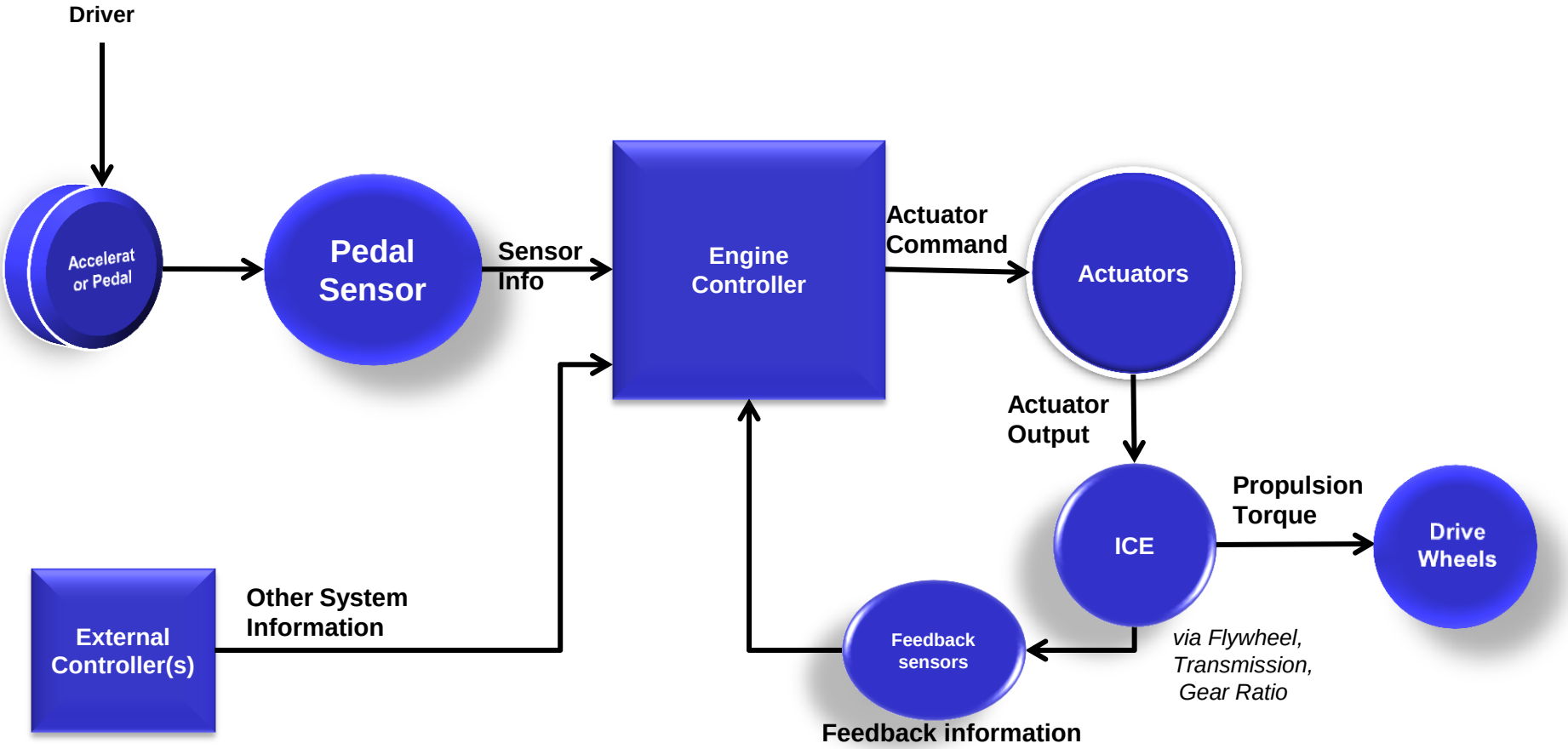
- Based on the 3 primary degrees of freedom of vehicle, the Table on the right shows the generic vehicle level motion control hazards that are possible
- Hazards are based on motion control properties that can be potentially affected by malfunctioning electrical/electronic control systems
- Not all of the hazards are applicable to all vehicle systems
- To identify the applicable hazards for a given vehicle system, GM's system safety process employs a HAZOP analysis to map malfunction behaviors to vehicle level hazards
- This is discussed in coming slides

Potential Vehicle Level Hazards (Example)
Unintended Longitudinal Vehicle Acceleration
Loss/Reduced Longitudinal Vehicle Acceleration
Unintended Travel in the Opposite Direction
Unintended Propulsion Engage (or Power flow)
Loss of Propulsion (or Power flow)
Unintended Longitudinal Vehicle Motion (Rollaway)
Loss of Longitudinal Vehicle Motion
Unintended Vehicle Deceleration
Loss/Reduced Vehicle Deceleration
Unintended Lateral Vehicle Motion
Loss of Lateral Vehicle Motion
Unintended Vehicle Yaw
Unintended Vehicle Vertical Motion/Roll

PHA: To identify system specific hazards



Simplified Engine Control System



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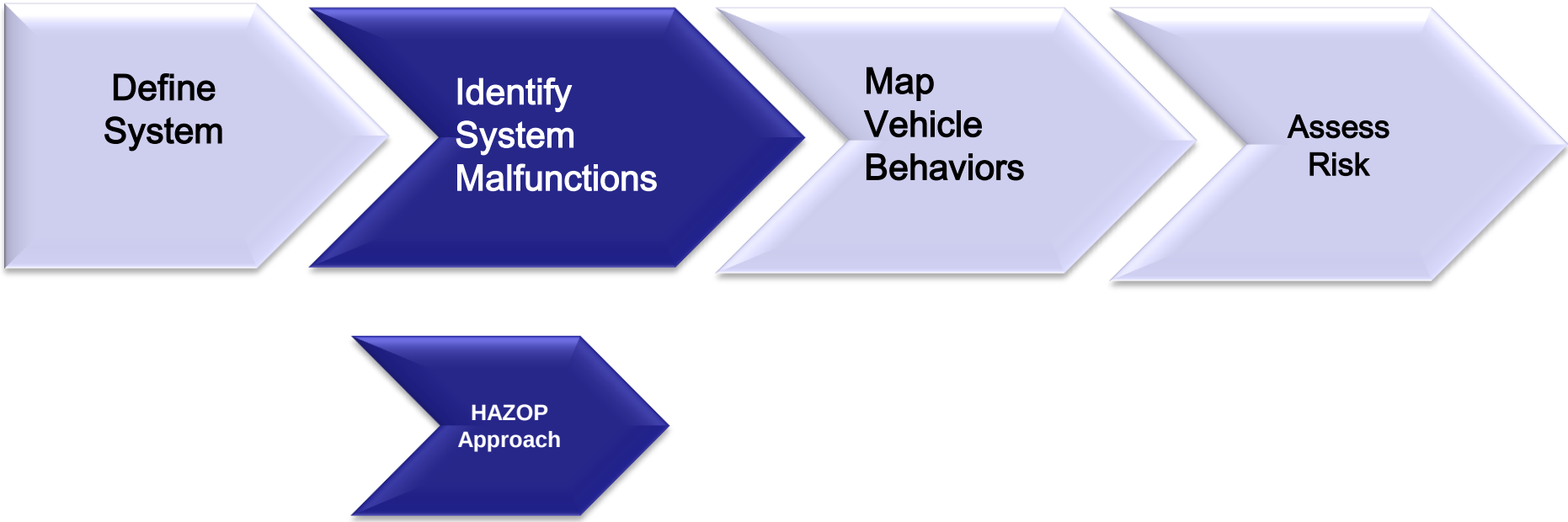


Identifying Malfunction Behaviors: HAZOP Methodology

GUIDEWORDS →

System Function Vs. Guidewords	Loss of Function	Incorrect Function -i (More than design intent)	Incorrect Function- ii (Less than Design intent)	Incorrect Function- iii (Wrong direction)	Unintended Activation (Incorrect Timing)	Locked/Stuck Function
Control Propulsion Torque	Loss of Propulsion Torque	Excessive Propulsion Torque	Reduced Propulsion Torque	-	Unintended Propulsion Torque	Stuck Propulsion (Stuck Throttle)

PHA: To identify system specific hazards

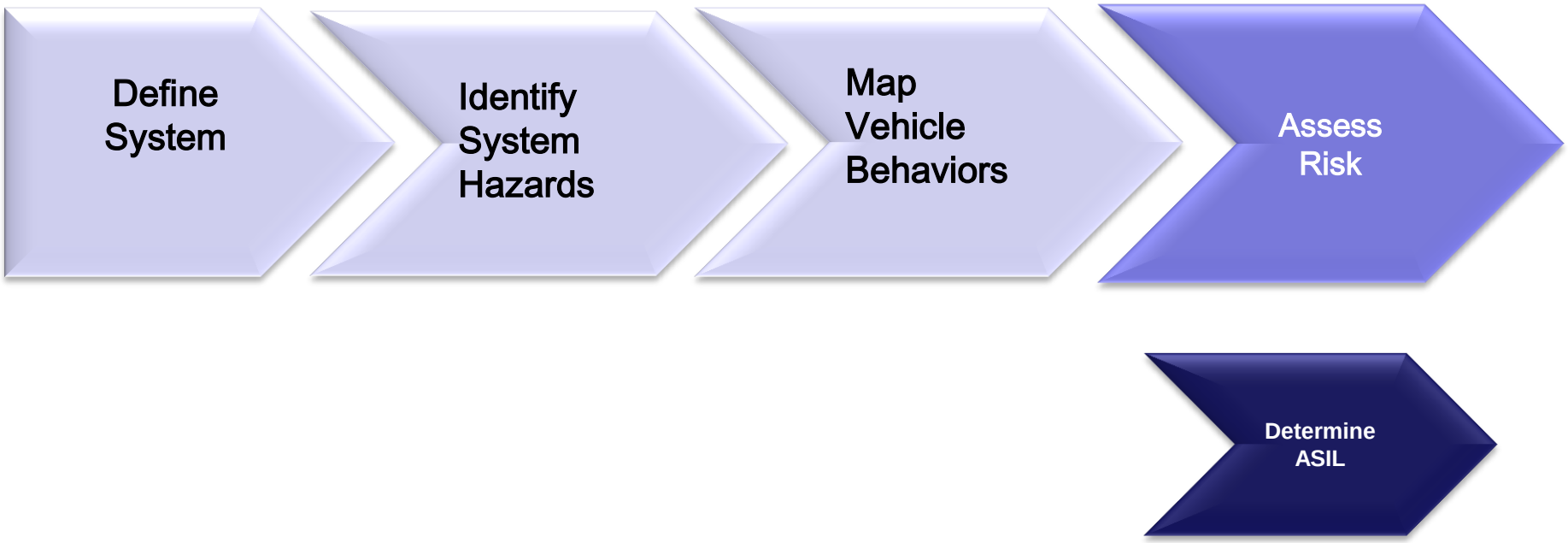


Map Malfunction Behaviors to Vehicle Hazards

- Hazards for Engine Control System (Example)

Malfunction Behaviors	Vehicle Hazards
Unintended Propulsion Torque	Unintended Acceleration
Excessive Propulsion Torque	
Stuck Propulsion Torque	
Loss of Propulsion Torque	Loss of Acceleration
Reduced Propulsion Torque	Reduced Acceleration
Unexpected Engine Start when vehicle is static	Access to Rotating Components during Service

PHA: To identify system specific hazards



Risk Assessment

- Per ISO26262, risk is expressed in terms of an **A**utomotive **S**afety **I**ntegrity **L**evel (ASIL)
  - ASIL = *function of* (S, E, C)
    - S = Severity of the Hazard
    - E = Likelihood of Exposure to the operating scenario
    - C = Controllability of the operator/involved people
      - Unable to avoid the mishap
- ASIL specifies the developmental process rigor, the required hardware and software integrity requirements for the safety-critical system
- For each identified hazard, a safety goal, and ASIL is specified. This is translated into one or more vehicle level safety requirements.
  - For example, for a propulsion system, a vehicle level safety requirement could be unintended longitudinal acceleration change at a vehicle level shall not exceed x g in y sec.; Design shall meet ASIL D integrity requirements for process and product

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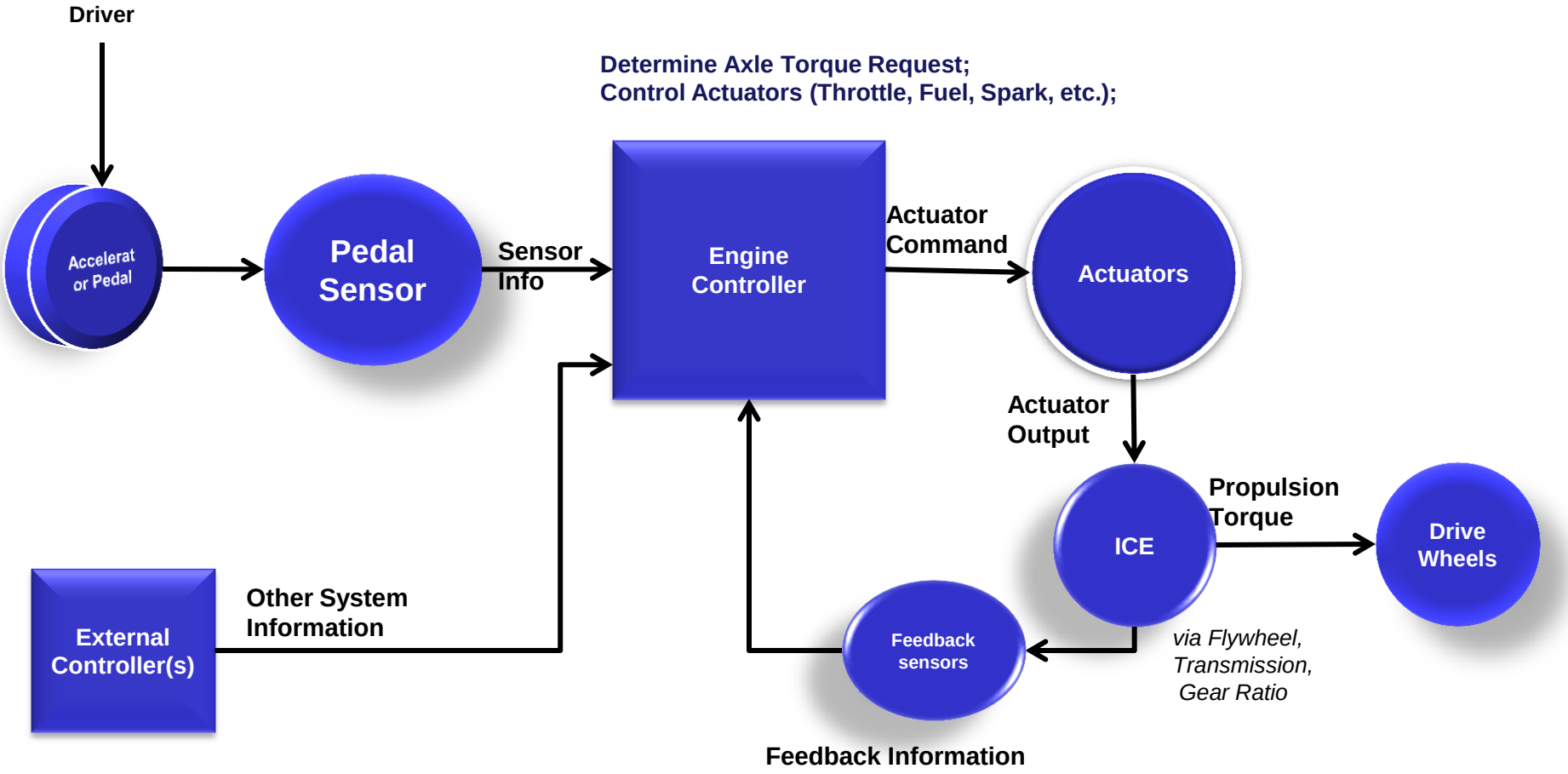
System Control Structure



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Unsafe Control Actions

Control Action	Action Required but not provided; Not providing causes a hazard	Unsafe Action Provided; Providing causes a hazard	Incorrect Timing Order	Stopped Too Soon
Determine Axle Torque Request	Axle Torque request and other relevant inputs not determined; Control system does not know what the current axle torque request is; Possibly uses the previous request or default(unknown) request; Potential for incorrect actuator command leading to unintended or excessive torque output- hazard.	Axle Torque request calculation incorrect; Control system miscalculates the Axle Torque request; Potential for incorrect throttle command leading to unintended or excessive torque output- hazard	Periodic Axle Torque Request computed too slow; Will lead to imprecise output from the control system; Output may not match input precisely. Potential for incorrect throttle command leading to unintended or excessive torque output- hazard	Axle Torque request determination stopped; If the Axle Torque request determination stops, and the system is not aware, then the effect is similar to pedal request not being calculated; Potential for incorrect actuator command leading to unintended or excessive torque output- hazard.
Command Engine Actuators	Actuator Control not performed; Control System does not control the actuators to the required position; Actuator may be stuck at a position and not changed; Potential for incorrect throttle command leading to unintended, excessive or stuck torque output- hazard	Control system opens the throttle wide when it should be closed; May be Control Throttle is stuck; Potential for incorrect throttle command leading to unintended, excessive or stuck torque output- hazard	Actuator control performed too late; May not match driver/axle torque request; Output will lag the driver/axle torque request if the control is delay; Potential for incorrect throttle command leading to unintended, excessive or stuck torque output- hazard	Actuator control stopped; Output may be zero when driver request is not; If the control propulsion Output stops, then the output is not controlled. System propulsion output could be reduced to zero. Loss of vehicle acceleration;

Defining Safety Constraints

Unsafe Control Actions	High Level Safety Constraints
Axle Torque request and other relevant inputs not determined;	The Control system shall determine the axle torque request periodically
Axle Torque request calculation incorrect;	The Control System shall not miscalculate the Axle Torque request
Axle Torque Request computed too slow;	Output Control shall be synchronized with Input request
Axle Torque request determination stopped;	System shall be made aware of the Axle Torque Command determination status
Actuator Control not performed;	System shall be able to control the actuator (Throttle, Spark, Fuel, etc.), when required;
Actuator Control performed when it should not;	Control system shall control the actuator (Throttle, Spark, Fuel, etc.) correctly in response to axle torque request;
Actuator control performed too late;	Actuator (Throttle, Spark, Fuel, etc.) Control shall be synchronized with axle torque request;
Actuator control stopped;	If the control propulsion output stops, System propulsion output shall be gradually ramped to zero with operator notification. Graceful transition to a safe state

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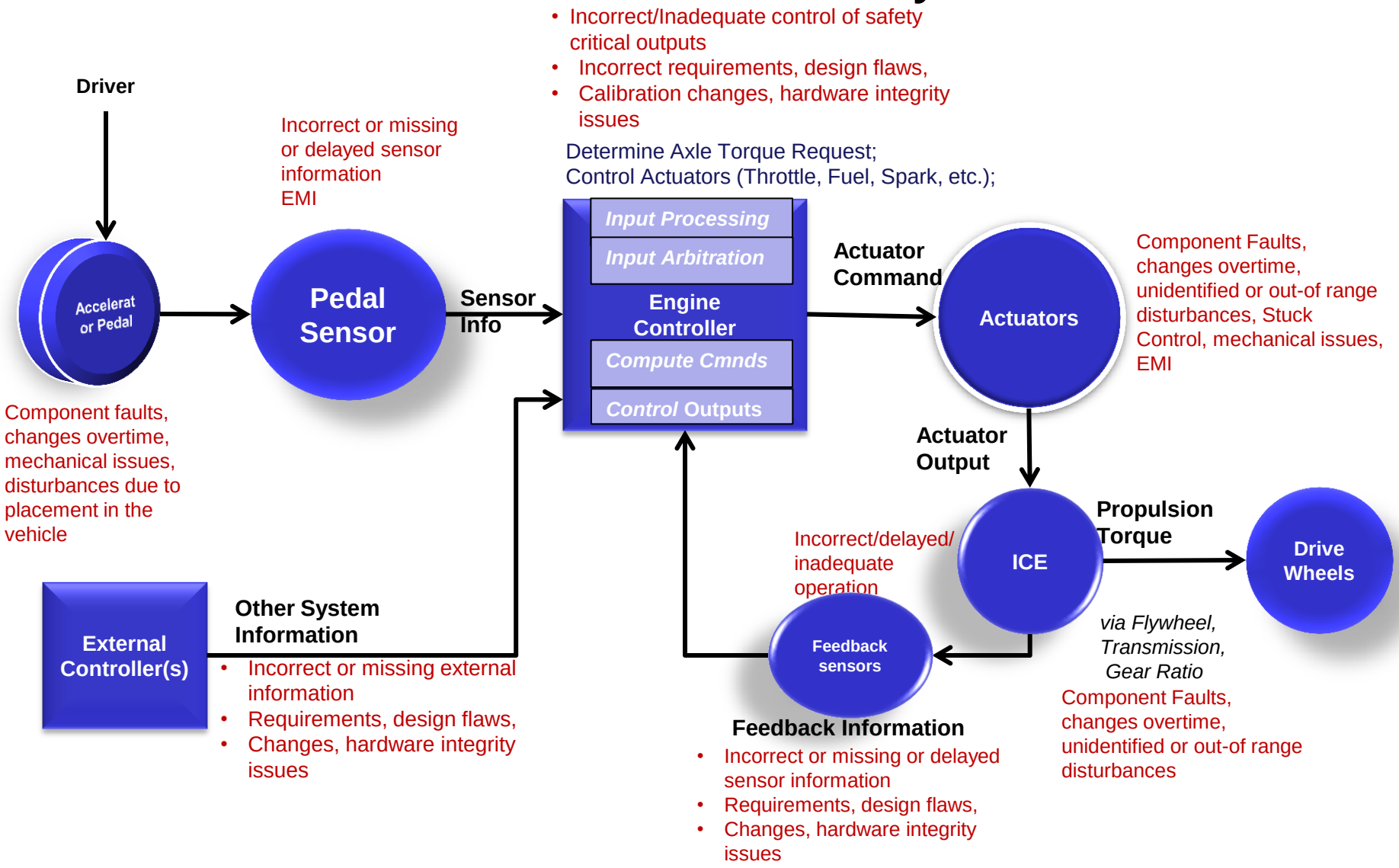
STPA Analysis: Causal Factors



STPA Analysis: Refined Safety Requirements

STPA Derived Safety Requirements
Control system shall compute periodically the Axle Torque request and other relevant inputs;
The Control System shall correctly calculate Axle Torque request based on all of it's inputs
Output control timing shall be synchronized with axle torque request; (Output should be in sync. with input)
Integrity of relevant feedback information shall be verified;
System shall be able to correctly control the actuator (Throttle, Spark, Fuel, etc.) when required; Actuator stuck shall be diagnosed;
Control system shall control the actuator (Throttle, Spark, Fuel, etc.) correctly in response to axle torque request;
Feedback information shall be diagnosed for integrity;
Actuator (Throttle, Spark, Fuel, etc.) Control timing shall be synchronized with Axle Torque Request; (Output should be in sync. with input);
Integrity of relevant feedback Information shall be verified to ensure actuator (Throttle, Spark, Fuel, etc.) control output is following axle torque request;
Hardware integrity metrics compliance for sensors, actuators, motor control and driver, i/o circuit, feedback information, processor and controller hardware circuit shall be met;
Process to check correctness of System, Software and Hardware requirements, design, implementation and V&V; Process to verify integrity checks during software changes, calibration changes; EMI Analysis; Ergonomics Human factors analysis for Pedal placement shall be performed.

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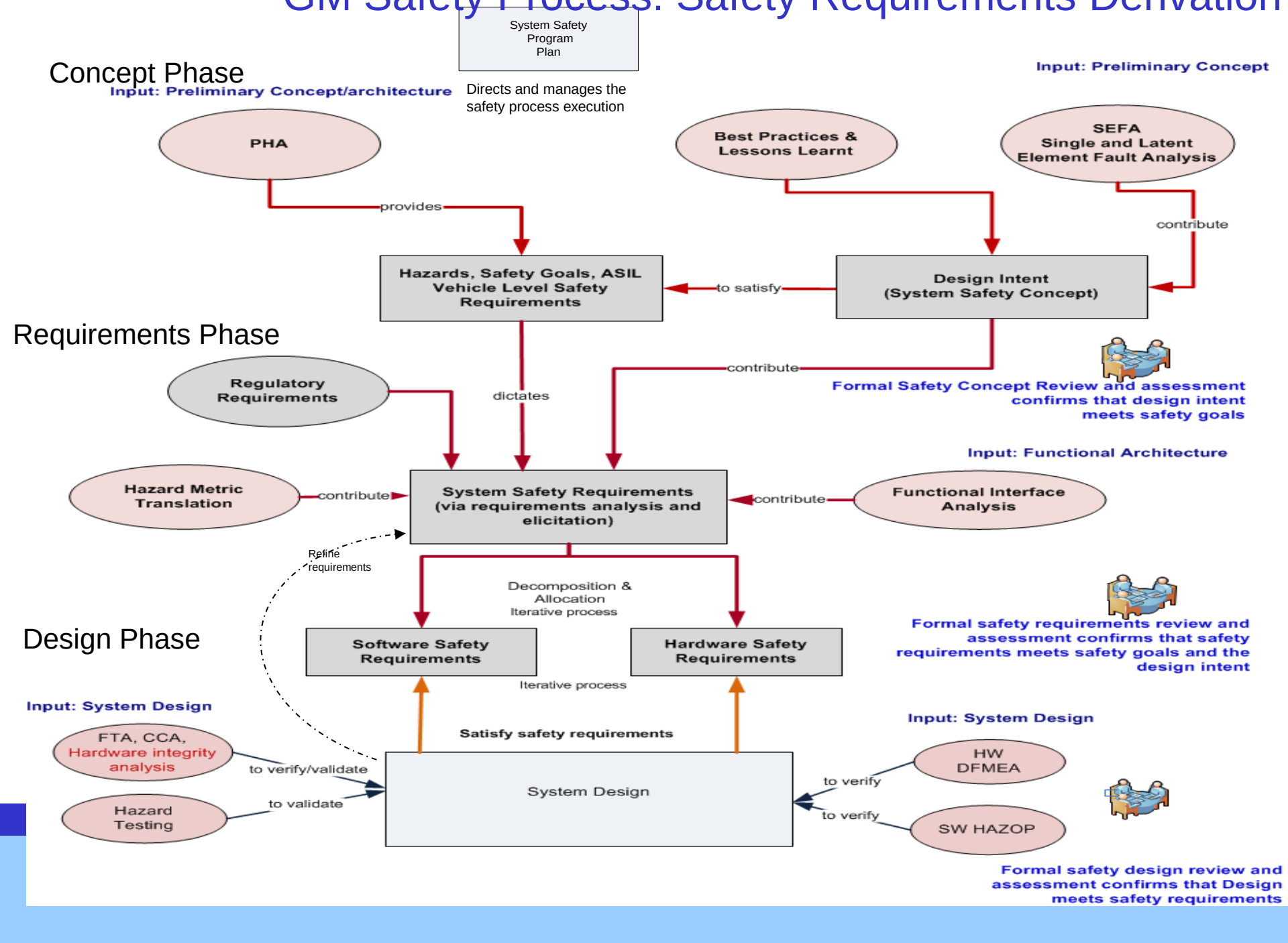
GM Safety Process: Safety Requirements Derivation



Example Safety Requirements Derivation

Requirement at a vehicle level

Unintended acceleration change shall not exceed x g within t ms ;

ASIL also specifies the process integrity requirements

Hazard Metric Translation for a given vehicle, control system

Requirement at a Control System level

Incorrect Axle Torque shall not exceed +/-y Nm within z ms

Requirements allocation to software and hardware

Function 1

Axle Torque Calculation

Function 2

Actuator Command Control

Integrity Requirements for Components

HAZOP is applied to functional interfaces to identify safety critical interfaces and interactions

- Sensor Inputs Integrity
- Controller Processor Integrity
- External Controller Input(s) Integrity
- Communication Integrity
- Control Outputs Integrity
- Control Feedback Sensors Integrity
- Actuator Component Integrity
- Power Supply Integrity

Tailored System FTA and Software functional HAZOP analysis (SAE ARP 5580) are used considering the control propagation paths to verify requirement completeness

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Analysis Results Summary

- The STPA derived requirements were compared to the those derived by the GM system safety process

- Overall safety requirements derived from the GM safety analysis activities were compatible with the requirements from STPA
  - This may be attributed to the reason that GM system safety process has HAZOP analysis, and tailored FTA approaches that considers the control function in it's analysis at different levels

- The safety team identified that there could be opportunity for further "specificity" in the detailed safety requirements
  - STPA derived requirements/constraints in terms of "unsafe control actions" were readily allocatable
    - Causal factors considers both systemic and random causes. This enables us to specify requirements to address all the causes
  - This opportunity to be further explored with specific recommendations developed by late 2013
    - Considering similar study using external resources in 2013

Conclusions

- STPA technique is valuable and different from other techniques such as traditional FTA and FMEA
- If FTA or FMEA focused only on the physical architecture without consideration to control system propagation paths and feedback mechanisms, it may be possible to miss some safety requirements
  - GM FTA approach is tailored to include control system propagation paths within the hardware and software architecture
  - HAZOP analysis of software architecture considers control propagation path
- Overall safety requirements derived from GM Concept and Requirements Phase safety analysis activities were compatible with the requirements from STPA
- GM safety team is continuing to study the benefits of incorporating STPA to enhance its safety engineering process
  - STPA inclusion could help verify completeness of safety requirements earlier in the process
  - Specific recommendations to be developed by late 2013

Acknowledgements

Thanks to the support of GM Engine Control Safety team members Rich Kulas and Tim Hartrey for supporting this study

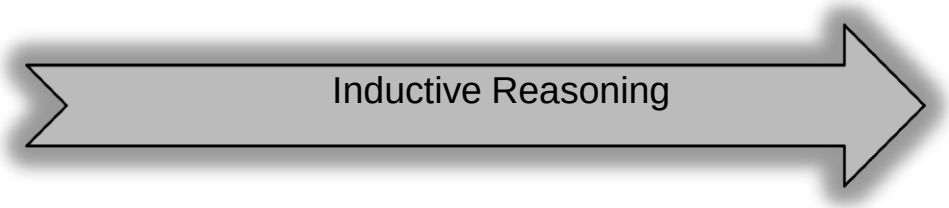
Thank You

Backup

Safety Analysis Techniques

FMEA

Start with the known causes



Possible effects

FTA

Possible causes



Start with the known Effects

HAZOP

Possible causes



Possible effects

- Hazard Operability (**HAZOP**) Approach: Use Guidewords to guide the analysis
  - Start with each system function and consider the following system behaviors
    - System function not provided when needed
    - System function provided when not needed
    - System function provided incorrectly when needed
      - Excessive- more than design intent
      - Inadequate- less than design intent
      - Different direction- in the opposite direction
    - System function locked/frozen

- Four basic guidewords for each software element
  - Fails to execute
  - Executes incompletely
  - Functionally erroneous
  - Executes with incorrect timing
    - Too early, too late, takes to long to complete

- Software interfaces are evaluated
  - Input errors - logically complete set
  - Output errors - logically complete set