A Model of Human Autonomy Interaction:
Implications for Human-Autonomy Teaming

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Autonomous Systems

- System autonomy
  - In development for a wide variety of systems
- Requires intelligent, robust, and reliable systems
  - Must overcome brittleness of past approaches
- Integration with human operators and decision makers

How Will we Best Combine Humans with System Autonomy?

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Level 0:
Fully Human

Level 1:
Some Assistance

Level 2:
Human must Monitor & Intervene

Level 3:
Fully Autonomous Some of the Time

Level 4:
Fully Autonomous

NHTSA

Status of Autonomous Vehicle Performance

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Human Drivers: Miles/Crash = 491,641 *2015 NHTSA
Miles/Fatal Crash = 95,128,092 *2015 NHTSA

Miles Driven per Disengagement**

Manufacturer	2015	2016	2017
Google/ Waymo	1,244	5,128	5,596
Delphi	41	17.5	22.4
Nissan	14	146	208
Mercedes-Benz	1.5	2.0	4.5

***Disengagement reports in CA*

Autonomous Vehicles would need to exceed the performance of human drivers to be safer on their own.

Until then, they require that Human drivers be alert and able to intervene when needed

Biggest Challenge: Human Oversight of Autonomy

- Automation may be useful for certain tasks

- But if we expect people to be able to successfully oversee the automation, they are likely to fail at this much too often due to loss of SA (either intentionally, or unintentionally)

Synergistic Human-Autonomy Integration

Human – Autonomy Integration that is Smooth, Simple, & Seamless…

Need Effective Synergy of the Human/Autonomy Team

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- Synergistic human & autonomy team is critical to success
  - Overseeing what system is doing
  - Intervening when needed
  - Sharing and offloading of tasks
  - Collaboration on functions
  - Coordinated actions

Informed Trust

Shared Situation Awareness

Factors that Affect Trust in Automation

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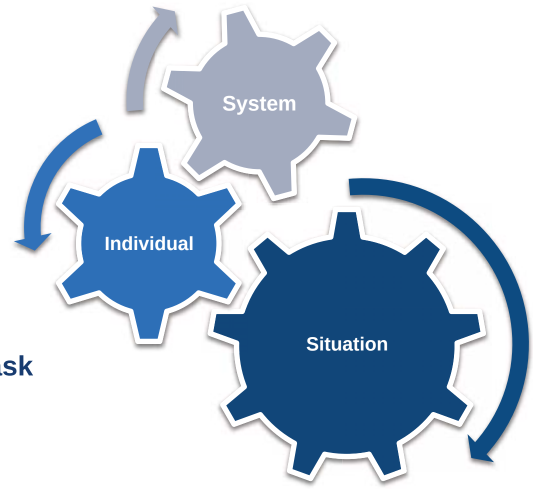
- System
  - Reliability
    - Actual
    - Subjective
    - Recency of Failure
  - System Validity
  - System Understandability
  - System Predictability
- Individual
  - Self-efficacy
    - Ability of self to perform task
  - Individual Differences
    - General Trust
    - Personal Characteristics
- Situational
  - Time constraints
  - Workload
  - Effort Required
  - Need for Attention to Other Tasks



Trust in Automation Challenge

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Appropriately Calibrated Trust

Dynamic & Situational

Informed Trust Requires SA

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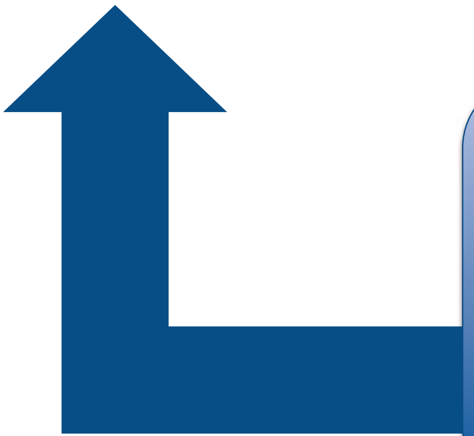
- **Oversight**
- **Intervention**



How much confidence do I have in the system?

- Generically
- Situationally
  - Is it working?
  - Is it getting good data?
  - Is it within its programmed envelope?
  - Will its actions meet my intended goals?

SA is critical to Autonomy Oversight & Interaction

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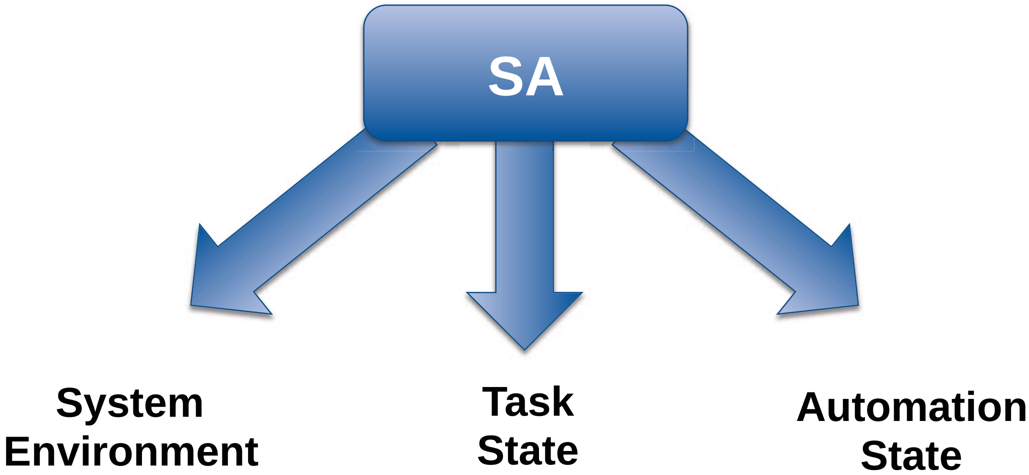

Often Poor Understanding of Automation State and Actions

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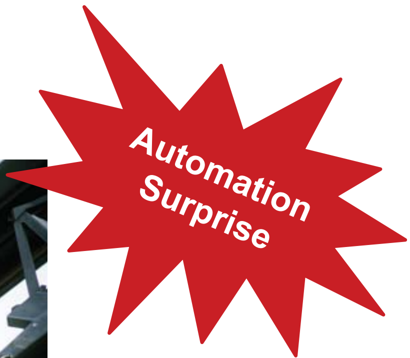
What's it doing?
Why did it do that?
What is doing now?



Ability to project behavior of system is key to successful team work

Will you be ready for the unexpected?

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Out-of-the Loop

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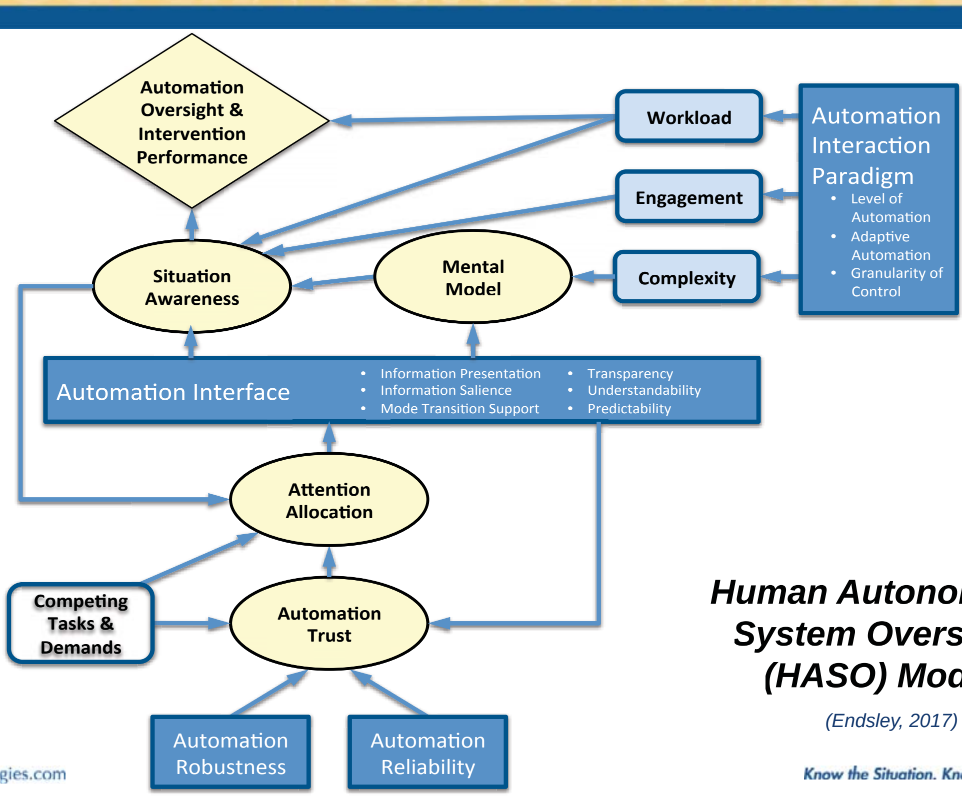
- Low SA on how the automation is performing
  - Slow to detect problems with system or automation
  - Slow to regain understanding of what it is doing and taking over manually
- Loss of Situation Awareness
  - Vigilance , Monitoring and Trust
  - Changes in information feedback
    - Intentional
    - Unintentional
  - Level of Engagement
    - Active vs. Passive processing

The Automation Conundrum

The more automation is added to a system, and the more reliable and robust that automation is, the less likely that human operators overseeing the automation will be aware of critical information and able to take over manual control when needed.

Attention Allocation | **Engagement**

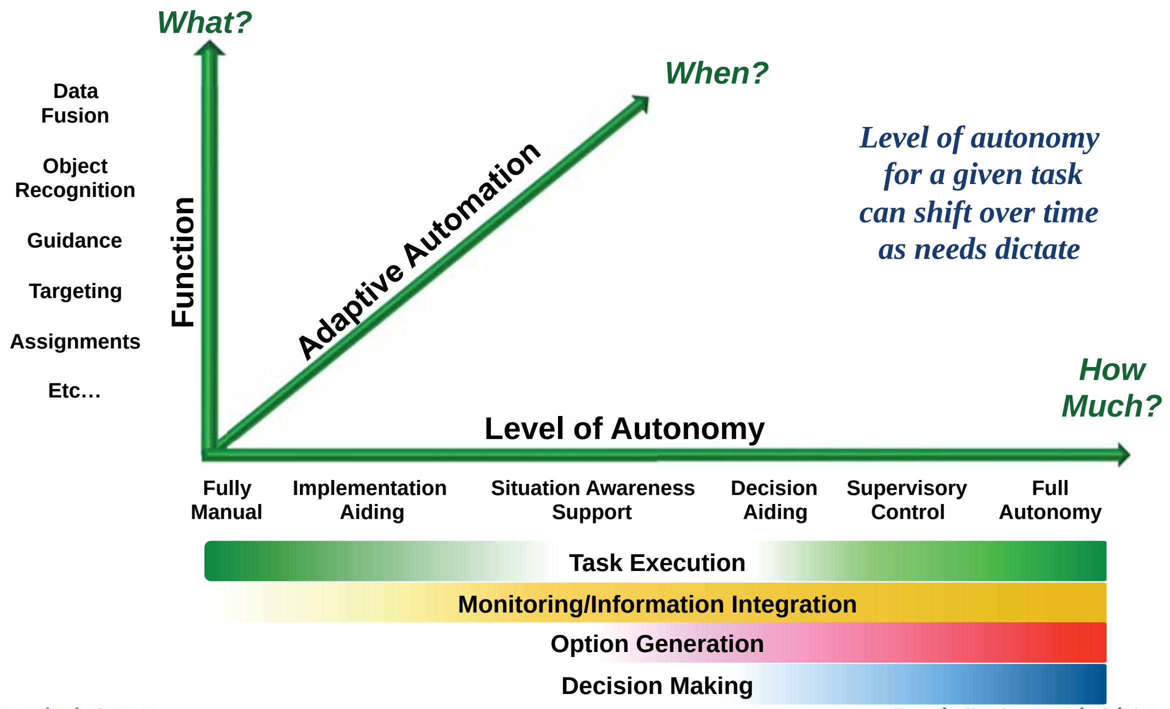
Effective Human-Automation Interaction



Human Autonomous System Oversight (HASO) Model

(Endsley, 2017)

Automation Interaction Paradigm: Choices in Automation Design



Levels of Automation

Processing Stage	Situation Awareness		Decision Making		Implementation
Kaber and Endsley (1997)	Monitoring & Information Presentation		Option Generation	Action Selection	Implementation
Parasuraman et al. (2000)	Information Filtering	Information Integration	Action Selection		Action Implementation

Situation Awareness → **Decision Making** → **Task Implementation**

Situation Awareness

- Significant benefit from systems that integrate information needed for comprehension (Level 2 SA) and projection (level 3 SA)
- Information filtering systems can limit level 3 SA (projection), negatively impacting performance
- Information cueing systems create good performance when correct but poor performance when wrong

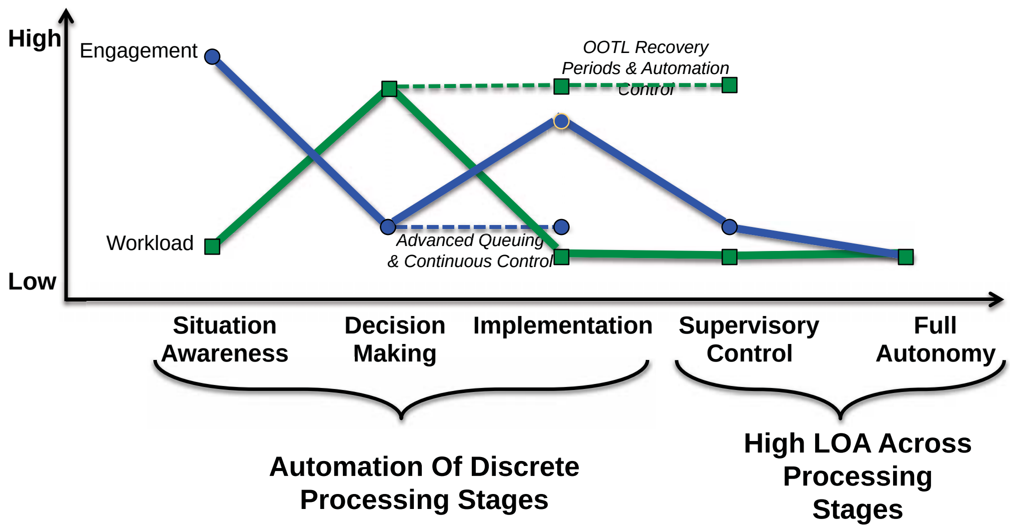
Decision Making

- Significant benefits when system is correct, but decreases performance when system is incorrect due to decision biasing
- Slower performance due to need to compare recommendations to system information
- Lower SA and increases in OOTL problems
- Option Selection less of an issue than Option Generation
- Critiquing systems, and contingency planning systems helpful

Task Implementation

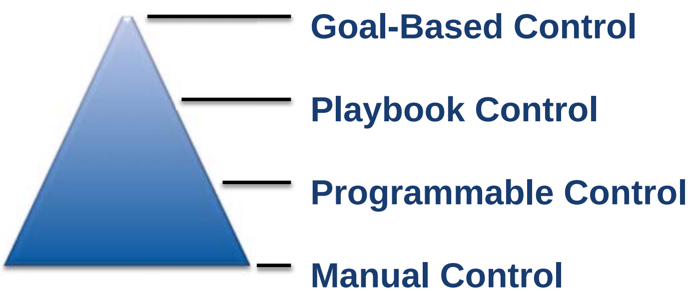
- Significant benefits to performance for routine, repetitive manual labor
- Manual workload may be lower overall, but Increases in cognitive workload at peak times and for systems low reliability
- Lower SA and significant OOTL problems for automation that employs advanced queuing of tasks and continuous control tasks

LOA Effects on Engagement & Workload



Human-Autonomy Interaction

- **Robustness**
  - The degree to which the autonomy can sense, understand, and appropriately handle a wide range of conditions
- **Span of Control**
  - From only very specific tasks for specific functions, up to autonomy that controls a wide range of functions on a system.
- **Control Granularity**
  - Level of detail in the breakdown of tasks for control



Supporting Operator SA – Automation Interface

- **Information Presentation**
  - **Information required clearly presented**
  - **Detailed guidelines on creating effective interfaces**
    - **Level 1, 2 & 3 SA; Confidence Level; Complexity; Alarms**
- **Information Salience**
  - **State of automation, modes, boundary conditions**
- **Mode Transition Support**
  - **To engage automation**
  - **Unexpected transitions to manual**
- **System Transparency**
  - **Why is it doing what it is doing?**
- **Understandability**
  - **What is it doing?**
- **Predictability**
  - **What will it do next?**

SAOD Automation Design Principles: Tesla Evaluation

Support Human Understanding of Autonomous Systems			
1	Automate only if necessary – avoid out-of-the-loop problems if possible	○	Combined ACC/Autosteer creates an out-of-the-loop issue and added complexity in predicting system behavior.
2	Use automated assistance for carrying out routine tasks rather than higher-level cognitive functions	◒	Key decisions regarding route selection and route following left to driver. Automation of many routine tasks like headlight and brights on/off, garage door operation, backing camera activation, locking/unlocking useful. Auto-braking inconsistent.
3	Provide SA support rather than decisions	○	Most decisions left to driver. Speed limit and lane departure warnings beneficial. Exceedance of speed limit needs continued display with more salient representation (e.g. red outline). Side collision warnings not salient.
4	Keep the operator in control and in the loop	○	Driver is in control of selection to use each automated feature. Driver engagement during Autosteer/ACC is low. New strategies are needed to incorporate the driver and improve engagement.
5	Avoid the proliferation of automated modes	⊖	Multiple modes and mode interactions create complexity and unexpected behaviors. Better integration of mode operations and deconfliction of mode activation/deactivation methods needed to improve mode operation and awareness.
6	Make modes and system states salient	⊖	Good display of current modes. Audio cues of unanticipated transitions to manual control lack needed salience. Unique audio cues also needed to alert driver to partial mode changes (e.g. Autosteer off, but ACC still on).
7	Enforce automation consistency	◒	Consistency in the terminology and information placement between modes was good. Some unexpected behaviors arose from mode interactions.
8	Avoid advanced queuing of tasks	⊖	Autosteer, ACC and Navigation all set up tasks to be carried out in advance which create the lowest levels of SA. Approaches that maintain operator involvement in the execution of tasks should be considered.
9	Avoid the use of information cueing	●	No information cueing provided
10	Decision support should create human/system symbiosis	N/A	No decision support systems provided
11	Provide automation transparency	○	Displays of the road and vehicles sensed by the system good for supporting shared SA with driver and provide projection of system actions. Improvements in supporting understandability of system actions and predictability of braking and speed changes are needed.

SAOD Automation Design Principles: Tesla Evaluation

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	Minimize Complexity of Autonomous Systems		
12	Ensure logical consistency across features and modes	○	Some unexpected behaviors arose from mode interactions, particularly as situations changed. Modes behaviors should be reviewed and modified to consider such interactions in context to conform to driver expectations.
13	Minimize logic branches	○	System complexity increased as new rules were added to the system. Minimize complexity by reducing the linkages and conditional operations contained in the autonomy, avoiding modes with their multiple-branch logic as much as possible.
14	Map system functions to the goals and mental models of users	○	A clear mapping between user goals and system functions should be present, for instance merging with traffic or exiting highways could be single step actions, rather than requiring multiple interactions with different modes and an understanding of how those interact.
15	Minimize task complexity	●	Actions to interact with the automation were simple and intuitive.
	Support Situation Awareness		
16	Integrate information to support comprehension of information (level 2 SA)	○	Display of lane and vehicles in front are good. Improved display of objects on the sides, blind spot, and rear of vehicle are needed. Improved display of exceedance of speed limits, obstacles below bumper, stationary vs moving objects on sides of cars are needed
17	Provide assistance for SA projections (level 3 SA)	○	Power and range projections good. Improved display to predict actions of autonomy needed, particularly those it can not handle. Improved display of future road hazards, traffic, and side collision warnings needed.
18	Use information filtering carefully	◒	Automatic replacement of information displays (e.g. presenting phone call information) covered only low priority data.
19	Support assessments of confidence in composite data	●	No confidence information associated with system provided.
20	Support system reliability assessments	●	Trust and effective judgments on when to intervene depend on an accurate assessment of system reliability for performing the task at hand. Interfaces should make explicit how well the autonomy is currently performing and its ability to handle upcoming or contemplated tasks.

Manned-Unmanned Teaming

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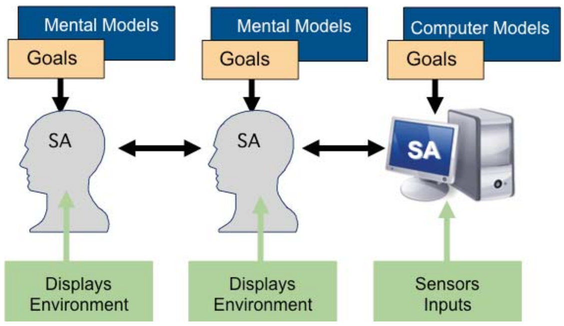
Will require:

- Flexible autonomy
  - Smooth transition of functions
- Simple operation
  - Low granularity of control (goal level)
  - High level of robustness
  - Wide span of operation
- Shared situation awareness
- Informed trust
- Computational models of SA and decision making

Future Systems Require

Shared SA between the system and the operators

- Understanding of its status
- How well is it functioning
- When interventions are needed and what kind
- How the system's status effects operator tasking and vice-versa



To Support Shared SA

Defines Interface Transparency Requirements

Model of Teammate

- Goals
- Functions/Tasks Assigned
- Strategies/Plans
- Tasks
  - Current Status
  - Ability to Perform Tasks
  - Impact of Tasks on
    - Other
    - System/Environment
    - Goals
  - Projected Actions
- Situation Knowledge

- Collaboration
- Function & Task Shifting
- Task Alignment
- Coordinated Action
- Information Sharing
- Deconfliction
- Progress Assessment

Conclusions

- System Autonomy is being developed for a wide variety of applications
- Need to develop robust, reliable and transparent autonomy
- For most systems Human-Autonomy Teaming will be critical to successful implementation
- To maintain SA and manageable workload requires careful design of
  - System interface
  - Automation paradigms
- Shared SA to provide effective manned-unmanned operations

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