



Architecting Effective Ground System Automation

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February 24, 2025





Today's Conversation

GSAW 2025 Architecting Effective Ground System Automation Tutorial

- Intelligence Age and its Brutal Facts
- What is Automation and considerations for its use?
- What are the Levels of Automation (i.e., manual, facilitated, human-in-the-loop, human-on-the-loop, and human-out-of-the-loop)?
- Using Model Based Architecting and Systems Engineering (MBASE) to choose level of automation for each activity
- What is involved in Intelligence Age Decisioning (i.e., OODA)?
 - Intelligence management (i.e., measurement, data, information, knowledge, wisdom, and intelligence)
 - Decision making (i.e., structured, semi-structured, and unstructured problems)
 - Decision implementation (i.e., simple independent, simple complex, complicated independent, and complicated complex)

Intelligence Age Decisioning is other than automating assembly lines

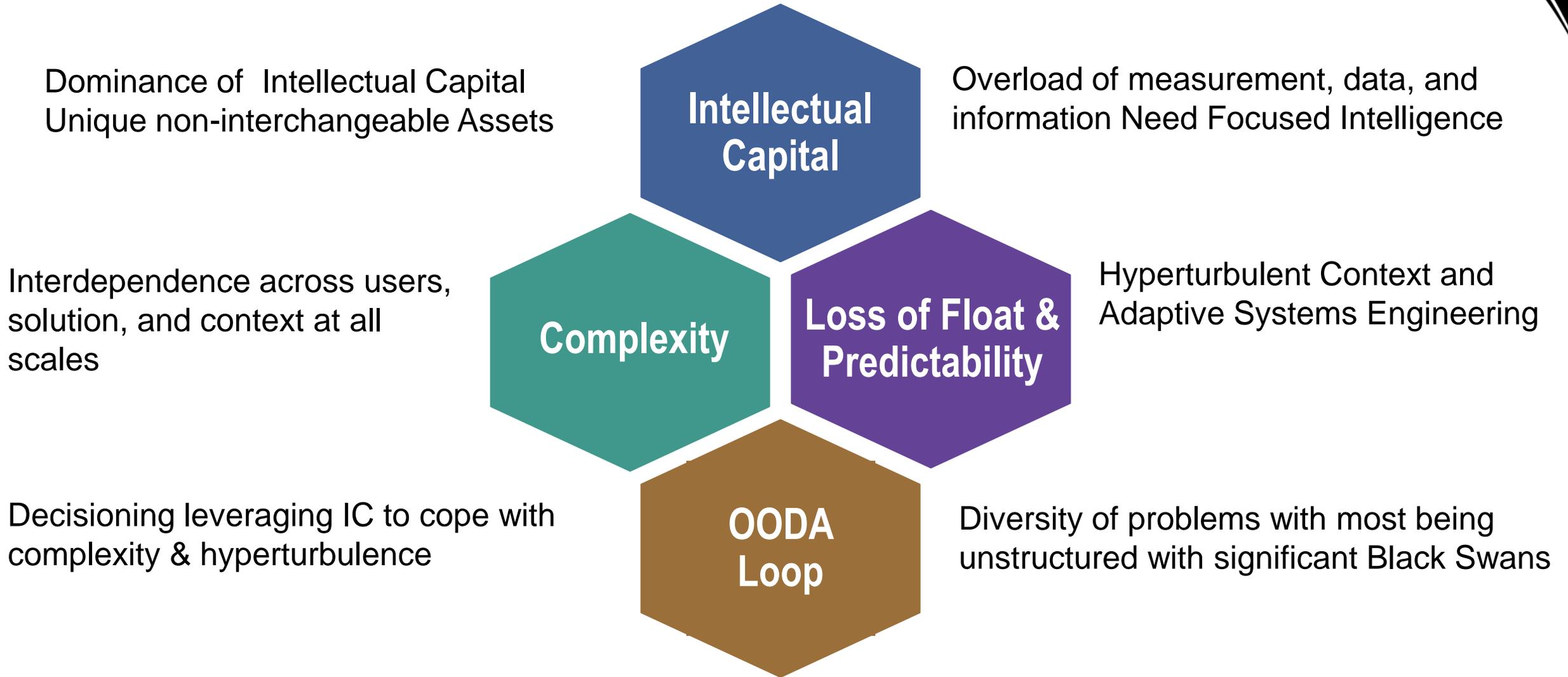


Instructor Biographies

GSAW 2025 Architecting Effective Ground System Automation Tutorial

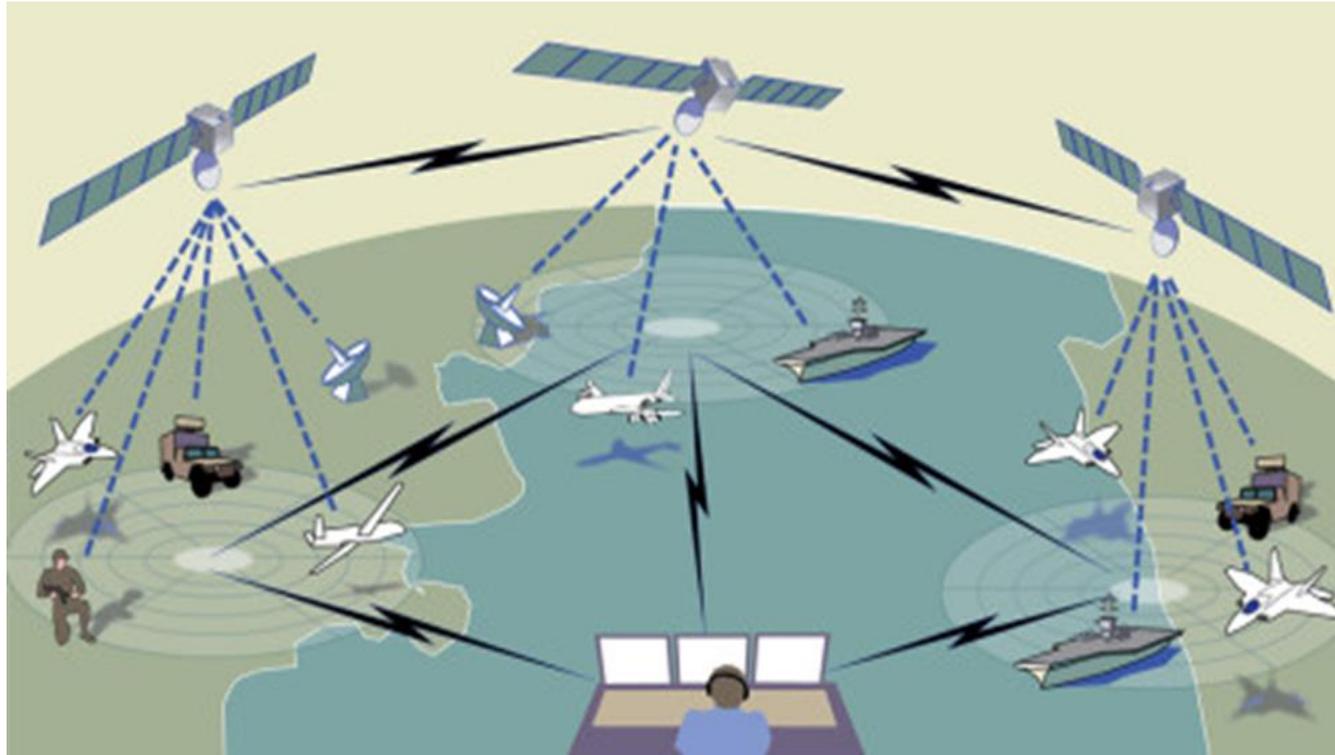
- **Mr. Popejoy is a Senior Project Leader at The Aerospace Corporation**
 - Over 30 years system-of-systems SE&A development experience at a national scale: satellite operations, space situational awareness, with professional papers on Responsive Space Operations, Space-Based Radar, & Positioning, Navigation, & Timing architectures
 - Currently leading AR&F Strategic Planning & Forecasting support for Project West Wing, NRO/AS&T, NGA, US Coast Guard, etc.
 - B.A. from Pitzer College in Political Studies
- **Dr. Vandergriff is a Senior Project Leader at The Aerospace Corporation**
 - Doctorate of Science in Engineering Management and Systems Engineering from George Washington University – dissertation “Unified Approach to Decision Support for Agile Knowledge-based Enterprises”
 - Complex Venture Architect with 39 years SE&A experience.
 - Publications: 2009 *In Search of Knowledge Management Pursuing Primary Principles Knowledge Management* textbook; the 2007 Aerospace Corporation’s *Mission Assurance Guide*; INCOSE’s 2005 *Complex Systems Engineering* tutorial; and the 1999 National Science Foundation’s *Photonics Curriculum*
 - Presentations for this conference are a synopsis of this research focused in the areas of automation, MBASE, and complexity theory insights.
- **Mr. Harkless was a Senior Engineering Specialist at The Aerospace Corporation**
 - Over 50 years of experience in System Engineering, with a specialty in Human-Systems Integration (HSI).
 - Current work includes defining levels of automation and the use of expert systems concepts to automate various customer’s ground systems.
 - 2009 Professional Paper: *Key Issues in HSI: Addressing Human Error and Automation in the Development and Operation of Large-Scale Technological Systems*.
 - Prior to joining Aerospace, HSI in a variety of industries including Northrop (Mission Data Processing & Technical Intelligence), Raytheon (automated air traffic control & air defense systems), Aerojet (satellite surveillance), and JPL (tracking & control systems for unmanned space flight operations).
 - B.S. from University of Southern California (combined Industrial Engineering, Education & Psychology).

Welcome to the Intelligence Age



Industrial Age assumptions about Physical Capital, Stovepipes, and Predictive Systems Engineering no longer hold

Architecting Effective Ground Systems



http://www.aerospace.org/wp-content/uploads/2012/05/clsp12p37_cyberspc-domain-444x236.jpg

Levels of Automation
Manual Control (MC)
Facilitated Control (FC)
Shared Control (SC) Human-in-the-Loop
Oversight Control (OC) Human on the Loop
Autonomous Control (AC) Human Override Only

- The Intelligence Age mission operations and analysis have challenging dynamic complex interactions with more demands on the ground Intellectual Capital assets.
- A tailored mix of automation levels enables an effective mix of IT and Intellectual Capital to address routine structured operations through the “black swan” unstructured operations needed by tomorrow’s systems.
- Selecting the right level of automation can be informed by Decision Science, Intelligence Management, and Complexity Theory

Ground solutions are no longer stovepipe assembly lines

What is Automation?



- Definitions
- Considerations for its use

Automation History



- Automation uses entities to manage, command, direct, or regulate other entities' behavior
- Automation uses tools to make humans more effective and/or efficient
 - A tool is any physical or software entity that can be used to achieve a goal, especially if the item is not consumed in the process
- Stone Age marks the era when Hominians first began manufacturing stone tools (the hand axe) - evidence dates back at least 2.6 million years
- Industrial Age Automation made production more efficient
 - Jacquard Loom – early machine automation
 - In 1801 Joseph-Marie Jacquard invented a mechanical loom which used holes punched in pasteboard punch cards to “automate” the weaving of patterns
 - It was the first machine to use punch cards, although not for computation
 - Assembly Lines – early production automation
 - 1947 Automation first coined by General Motors created an automation department
 - 1950s Assembly lines started using automation in feedback control (closed loop) production
- Intelligence Age Automation makes Intellectual Capital more effective
 - 1980s Expert Systems (ES) – Early Artificial Intelligence (AI) captures rules derived from experienced practitioners
 - 2000s Suggestive Sales – Amazon based on shopper big data recommending items of interest
 - 2010s Big Data Mining and Sensemaking



- **Each activity to be performed should be assessed to evaluate what level of automation is the best design (implementation) based on several factors**
 - *Activity Complexity*
 - *Activity Predictability*
 - *Activity Timeline*
 - *Criticality / Risk of failures*
 - *Activity Repetitiveness*
 - *Technology available ...*
- **Two common types of automation are feedback control and sequence control**
 - Feedback control senses the process and context to make calculated adjustments to ensure the activity is kept within some set parameter range (e.g., cruise control)
 - Sequence control performs a discrete set of operations usually based on preprogramed system logic with bounded predictable options (e.g., automated teller machine (ATM))
- **Activity automation can either be “closed loop” (i.e., with feedback) or “open loop” (i.e., no feedback)**
 - Feedback can be provided by a human, rules, or other artificial intelligence (AI) approaches
 - Most automation has some level of monitoring & control to override, shut down, or neutralize the automated system when undesired behavior is detected
- **Levels of Automation describes a mix of an activity’s tasks that are**
 - Allocated to the human,
 - Allocated to the system
 - Allocated to a mix of humans and systems

Ground solutions are no longer stovepipe assembly lines



- When Assets / Missions considered valuable - loss is not an option
 - Risk adverse management often chooses shared control for high risk / value activities
 - 24/7 staffing “required” to ensure proper response to disjunctive unknowable events
- Experience to date indicate Automation does not always achieve expected increase in performance and reduction of staff costs
 - Automation is not well understood or levels not tailored appropriately
 - Automation represented in CONOPs developed by staff unaware of technology capabilities and human factors involved leads to poor / incomplete requirements
- Properly tailored automation frees staffing to perform other duties but operator skill level needs to increase (industry 10+ years – government <2 years experience)
- Resource constrained context (more need than capability) drives need for High Cognitive planning and control of assets
- Levels of automation are tightly coupled with many factors (e.g., activity type, change coping context, acceptability of risk, operator skill level, acquisition ROI)
- Mission success requires stakeholder buy-in and understanding, clear adoption benefits, and use of experienced operators who can cope when automation fails

Based on Aerospace observations in previous studies 2004/5, 2007, 2012

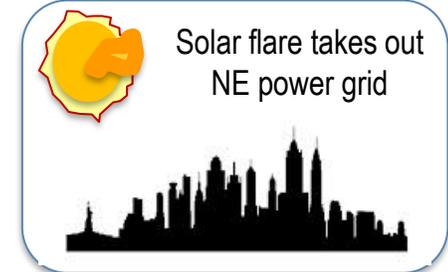
Automation Considerations



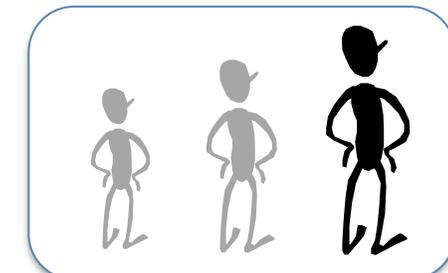
- Current technology unable to automate all potential activities
 - Human-level pattern recognition, language comprehension, and difficult problem solving (e.g., synthesis of sensory data)
 - Coping to dynamic context changes makes automation too costly and humans represent a more flexible cost effective solution
- Large investment to develop and upgrade – operational software and volume of products – verify, validate, accredit and approval process needs more rigor
 - Recurring Cost are the personnel needed to ensure that the entire system functions properly and maintain product quality
 - Minimize cascading failures and unexpected consequences
- Increasingly automated process has less and less labor to be saved or quality improvement to be gained
 - Diminishing returns and exhaustion of opportunities
 - Automation replaces junior level staff but leaves senior experience staff because they deal with anomalies
 - On the job training / experience becomes limited



Override Automation



Unintended Consequences



Loss of IC development

Lack of technology, complexity and emergence, and shrinking ROI

What are the Levels of Automation?



The question is not

“To automate or not”

But rather

“What mix of automation levels should be created?”

- A process is developed that produces desired behavior or products or services
- Ways to facilitate the human to improved productivity are introduced
- Ways to automate the processes are created, reducing error and increasing speed / productivity in repetitive processes,

Automation Level Examples



Automation Level decisions:

- Need for complex cognitive power to ensure activity success
- Technical feasibility to replace human capabilities (e.g., complex problem solving, pattern matching, responding to the unexpected)
- Automation ROI for developing automation and maintaining it
- Value gained from increased tempo and repeatability and reduced labor
- Acceptability of experience loss and responsiveness to uncertainty / change
- We must assess each activity for what level of automation is the best

Levels:

**Weaving
By Hand**

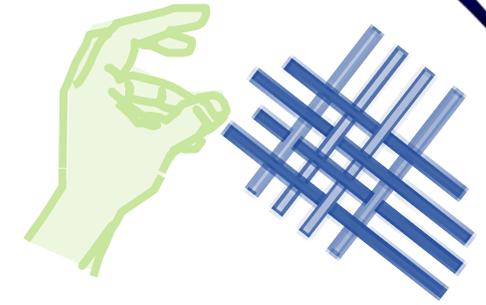
Manual

**Weaving
With Tools**

Facilitated

**Weaving
With Automated
Processes**

**Shared
Oversight
Autonomous**



To Automate or not to Automate . . .



- Level of automation to employ should be guided by
 - Compensate for human vulnerabilities (e.g., lack of speed and consistency, human errors)
 - Exploit human strengths (e.g., complex decision making, flexibility).
 - Level of uncertainty and risk is low - high levels of automation
 - Levels of uncertainty and risk are high – low levels of automation
 - Cost / impact of automation development and maintenance
 - Context /options rate of change (e.g., hyperturbulence) requires fast response
 - Context / options rate of change require constant updates
- Increasing levels of automation must address issues with
 - Loss of vigilance;
 - Loss of integrated situational awareness;
 - Degradation of operational skills;
 - Inability to cope with dynamic context changes;
 - Degradation of teamwork and communication.
- Designs should ensure the capabilities to overcome or counteract complacency, recover from failure, and provide a means of conflict resolution if loss of separation occurs.
- Automation helps complex technology cope with human error, but alone will not prevent it

Correct answer is a tailored automation levels mix across all the decision support needed.

Levels of Automation (LOA)



Levels of Automation		LOA Description
<p>Low</p> <p>1</p> <p>2</p> <p>3</p> <p>4</p> <p>5</p> <p>High</p>	Manual Control (MC)	Human performs all activities including monitoring, selecting option, and implementing it
	Facilitated Control (FC)	Human performs all the activities with limited automation of data input, manipulation, and implementation
	Shared Control (SC) <i>Human-in-the-Loop</i>	Both the human and the IT Assets generate options, the human controls selection; however, carrying out the actions is shared between the human and the IT Assets
	Oversight Control (OC) <i>Human on the Loop</i>	IT Assets generate list of decision options, IT Assets select the option informing human of selection, and it is turned over to the IT Assets to implement – human can override option selection within some time period if necessary
	Autonomous Control (AC) <i>Human Override Only</i>	At this level, the system selects the best option to implement and carries out that action - based upon a list of alternatives it generates - the system automates decision making in addition to the generation of options - the human mainly monitors the system and Halts / Alters workflow to avert catastrophic failures

MC Manual Control FC Facilitated Control SC Shared Control OC Oversight Control AC Autonomous Control

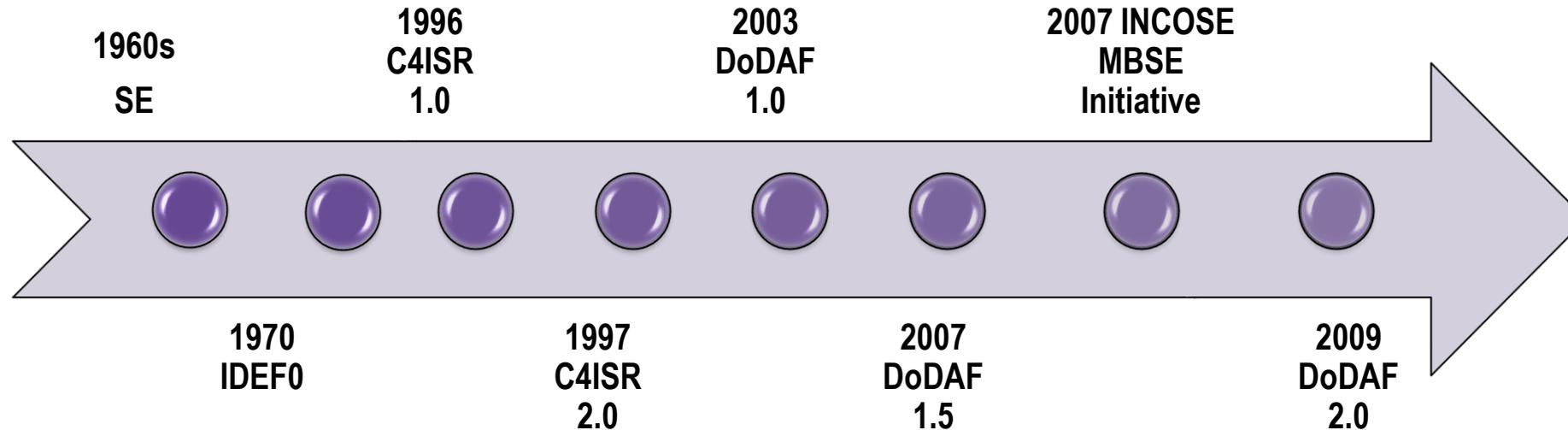
One needs to determine what level of Automation is required for each activity in a process

Selecting activity automation levels



- Using Model Based Architecting and Systems Engineering (MBASE)
 - *Focus acquisition to realistically specify solutions*
 - *Inform automation level trades based on latest insights*

Evolution of Functional Flows



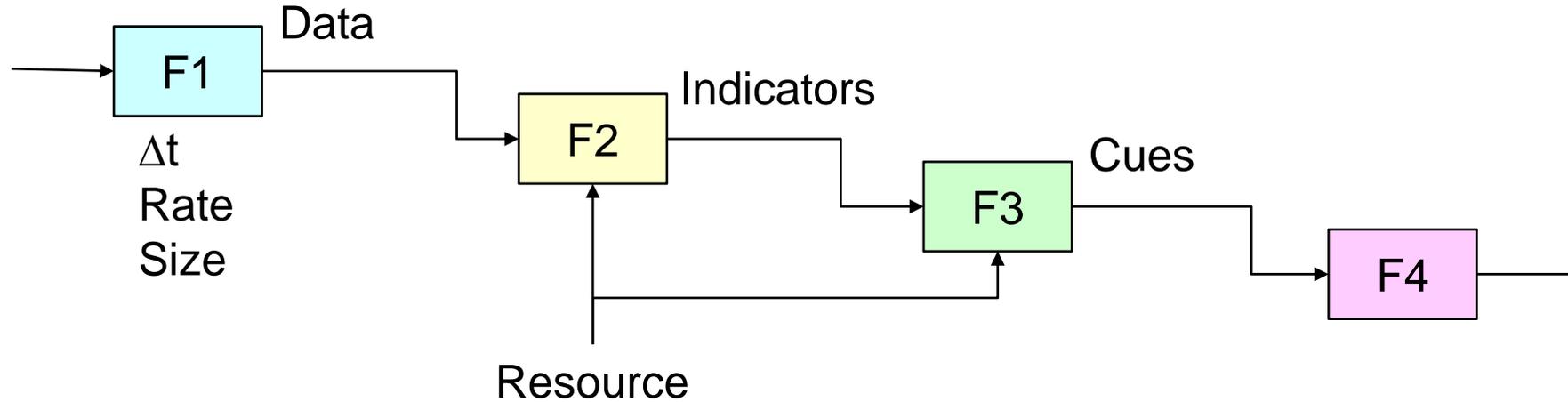
- 1970s saw development of the IDEF0 a function modeling methodology for the analysis, development, reengineering, and integration
- Architecture modeling continues to capture behavior modeling in SV-4s
- MBASE uses computers to simulate behavior and performance and can be used to examine benefits and needs for various automation levels

Automation level selection is supported by good functional modeling

Determine the Level of Automation Required



Is automation worth the savings realized in reducing time (production) or reducing workload (staffing) or increasing repeatability (reliability)



- Analyze activities (MBASE analysis) for LOA
- Review the available resources and abilities
- Determine the operating constraints
- Thoroughly review new innovations
- Review other factors that may exist at the time (e.g., cognition needed, risk involved, cost)
- Determine readiness for implementation
- Communicate benefits or payoff to be brought about by the change
- Ensure there is minimal resistance to change
- Ensure viable transition path to new automation level



Fitts List

- List is an evaluation matrix used to help determine the allocation of function between humans and machines
- Technique involves comparing capabilities of man and machine in terms of general task abilities, such as "data sensing," and "reacting to unexpected events"
- Published in 1951 by Fitts

Humans Excel In	Machines Excel In
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Store large amounts of information for long periods – and recall relevant facts at appropriate moment	Storing and recalling large amounts of information in short time periods
Ability to exercise judgement where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improving and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (e.g., infrared, radio waves)
Reacting to unexpected low-probability events	Doing many different things at the same time
Applying originality in closing problems	Exerting large amounts of force smoothly and precisely
Profiting from experience and altering course of action	Insensitivity to extraneous factors
Performing fine manipulation, especially where misalignment appears unexpectedly	Repeating operations very rapidly, continuously, and precisely
Continuing to perform when overloaded	Operating in environments that are hostile to man or beyond human tolerance
Reasoning inductively	Deductive processes

Activity - Human or Automation



Functional analysis identifies whether activities are best / cheapest done by humans or automation. Automated activities must be able to be overridden, shutdown, or neutralized when performance degrades or fails.

Decisioning Attribute	Prefer	Human	Computer
Static / Predictable Context	C	Bored – Prone to Variability	Able to predict & operate efficiently
Chaotic/Unpredictable Context	H	Copes w unexpected change	Unable to operate in
Structured Repetitive Decision	C	Bored – Prone to Variability	Consistent – Efficient
Semi-Structured Decisions	H/C	Humans deal with uncertainty	Deals w structure relies on human
Unstructured Decisions	H	Human adjusts & finds solutions	Unable to resolve
Failure Recovery	H	Capable of Recovery	Need Human Recovery
Explicit Knowledge/Intelligence	C	Memory Limit needs augmentation	Networks and search easily
Tacit Knowledge/Intelligence	H	Apply experience in new way	Limited Expert Systems capability
Static Workflow w defined options	C	Bored – Prone to Variability	Consistent - Efficient
Variable Workflow	H	Human respond to changes	Unable to resolve

References: Harkless, L.J., Dawes, S. M. (2009)

Exercise 1 – Automation Levels

A service recovery process

- Use Established Service Diagnostics
- Create Service failure indicators
- For known categories of service problems
- For unknown categories of service problems
- For known procedures for services problem resolution
- For new procedures for service problem resolution
- Capture metrics on service resolution (time, cost, etc. to resolve)
- Capture new service resolution procedures
- Update service failure, categories, and resolutions databases



Section 1 2 3 4 5 6 7 8 9



Identify
Service
Failure

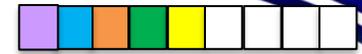
Classify
Service
Problem

Resolve
Service
Problem

Learn
Service
Resolution

1. List the activities to be performed to a granularity that automation level can be set
2. Draw activity flow
3. Assign level of automation to be used for that activity

How can we automate Intelligence Age Decisioning?



Section 1 2 3 4 5 6 7 8 9



- Decisioning combination of informing decisions, making decisions, and implementing decisions
- Challenging because of Hyperturbulent contexts with coupled systems, information overloads and conflict, and ever-quickenning tempo
- Decisioning repeats at many temporal & structural scales
- Decisioning is essential to all life's activities especially the creation and use of Intelligence
- Best served by application of the OODA Loop for Ground Systems

Intelligence Age Decisioning



- Intelligence is a prelude to all decision-making and action
 - Intelligence provides the understanding of the past, the awareness of the present, and the prediction of the future
 - Informed Decision Cycle is essential to effective application of Intellectual Capital for continuing success of a venture
- Decision Cycle is composed by 3 activities
 - Intelligence management integrated within the decision cycle is a process to get the right data, information, and knowledge to the right people at the right time so they can make the best decision and implement it successfully to meet an organization's objectives.
 - Decision-making is informed by an organization's Intellectual Capital, and is aided by appropriate intelligence management and computerized facilitation with problem definition, alternative generation, decision analysis, and decision communication
 - Decision implementation is informed by effective decision coordination, execution planning, and change feedback
 - It operates in a co-evolving context and venture - a process that performs and monitors a series of activities, actions, and functions that brings about the decision-makers chosen alternative

Good decisioning uses OODA Loops

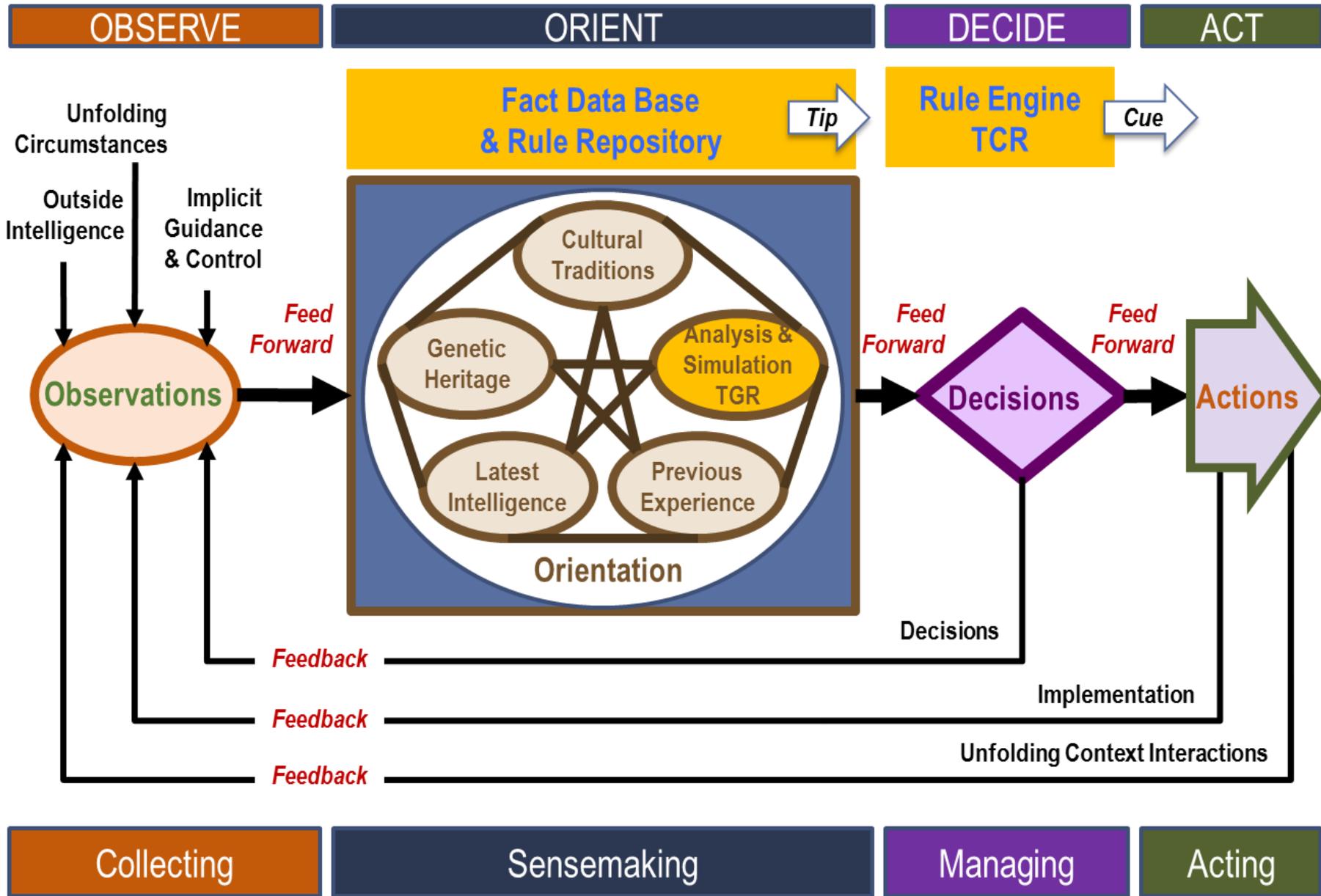
Dynamic Decisioning and the OODA Loop



- Dynamic Decisioning works in a high operational tempo with complex interactions and makes Intellectual Capital assets more effective
- Boyd asserted that all individual or organizational behavior can be depicted as a continual cycling through four steps: Observe, Orient, Decide, and Act (OODA) with feedback and feedforward
- OODA Loop, was originally developed for the dynamics of fighter combat – Pilot has capability to change speed and direction faster than foe
- Consciously applying the OODA Loop process yields an advantage over a competitor who is merely reacting to conditions as they occur, or has poor awareness
- Requires extensive use of Intellectual Capital to observe change, as well as, to orient the decision-based on the Social Capital culture and constraints
- Decision loops are repeated at many temporal and structural scales enabled by visualization



John Boyd's OODA Loop w Rules Overlay (Boyd, 1987)



Dynamic Responsive Intelligence Capability requires multiple nested OODA loops

Example of Indicators



- **Lagging Indicators:** warning lights show that some trigger has been reached
- **Coincident Indicators:** Monitor of current states of the car, its performance, and its context
- **Leading Indicators:** Warning of potential future events or conditions (usually short term predictions due to need for higher level of confidence)

Indicators are usually data or information translated into intelligence for the driver



OODA Self Awareness Using a “Dashboard”

Type	Description	Observe	Orient
Lagging	Warning / Triggers	Engine Light, Flat Tire Indicator	
Lagging	Monitor	Car Mileage	Road Map
Coincident	Warning / Triggers	Radar Detector	Speed Limit
Coincident	Monitor	Gas Gauge, Speedometer, Engine Temperature	Location / GPS, Back up Mirror, Windshield
Leading	Warning	Traffic congestion ahead	Miles before next turn
Leading	Monitor	Gas tank miles to go	Time to destination

Not exhaustive list but rather indicator type examples

Early detection and reaction provide significant benefits.

Intelligence Pyramid and its implications for automation



Section 1 2 3 4 5 6 7 8 9

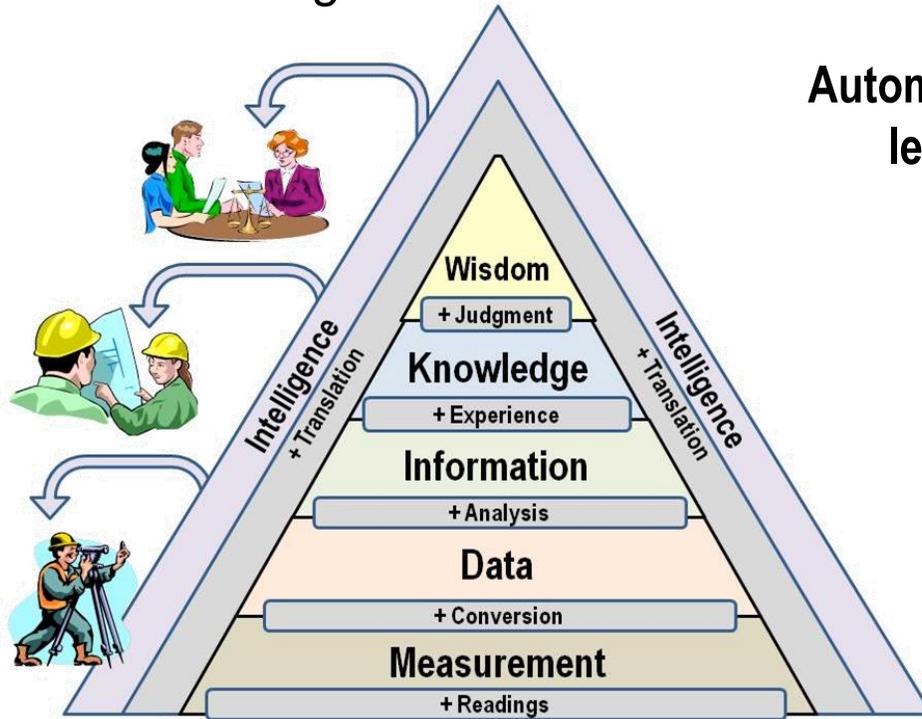


- Measurement
- Data
- Information
- Knowledge
- Wisdom
- Intelligence

Automation of Intelligence* Management



- Automation easy for Measurement / Data and is done today
- Harder for Information / Knowledge often requires human intervention
- Requires human judgment for Wisdom
- Varying Levels for Intelligence translation into users' frame of references



Intelligence Pyramid - IWKIDM

Automatability levels:

Low

High

	Examples
1	Quit following bear tracks
2	These are bear tracks
3	Tracklets – Big Data
4	Images - Large Data
5	Collect Data



* Intelligence is defined as the translation of WKIDM into a user's frame of reference



Information Glut or Overload*

Reasons for automation

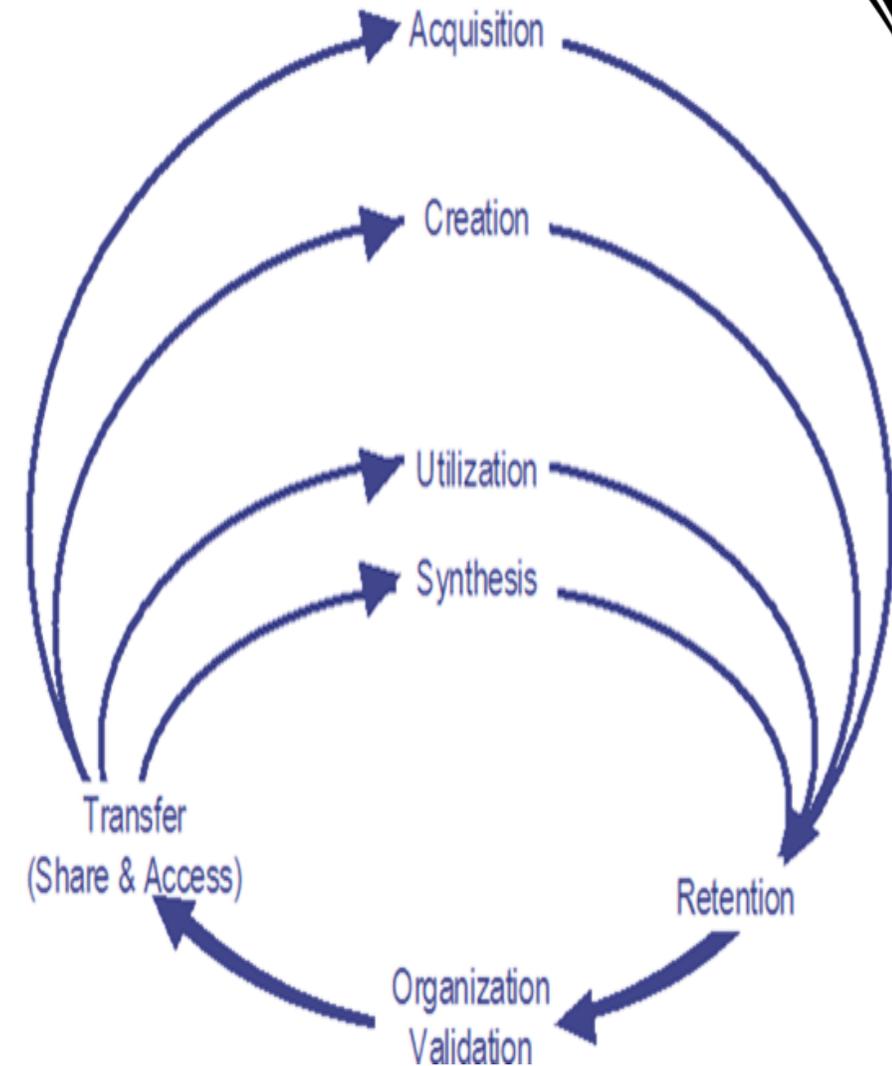
- Automation is one approach to overcoming the "**Information Overload**" experienced by humans when a system provides too many metrics at a rapid rate.
- The term refers to the difficulty a person can have understanding an issue and making decisions that can be caused by the presence of too much information.
- Factors that contribute to Information Overload are:
 - Human capability: personnel qualifications, experiences, attitudes
 - Information characteristics: quality, quantity, frequency, completeness, visualization
 - Activity and decision standardization, predictability, complexity
 - System capability: throughput, processing, human-machine interface (HMI)

Information Overload term was popularized by Toffler in *Future Shock*, 1970.

Intelligence Management (IM) Observe and Orient



- Requires Intelligence be acquired or created, used and synthesized, then retained, validated, and shared
- Automation has altered the role of operators from that of active controllers to executive monitors who must stay attentive to displays and make decisions requiring human interaction based on “Sensemaking” from the intelligence available to them
- Sensemaking can be automated through visualization and applying the right mix of human activities and automated activities



Automation of Sensemaking



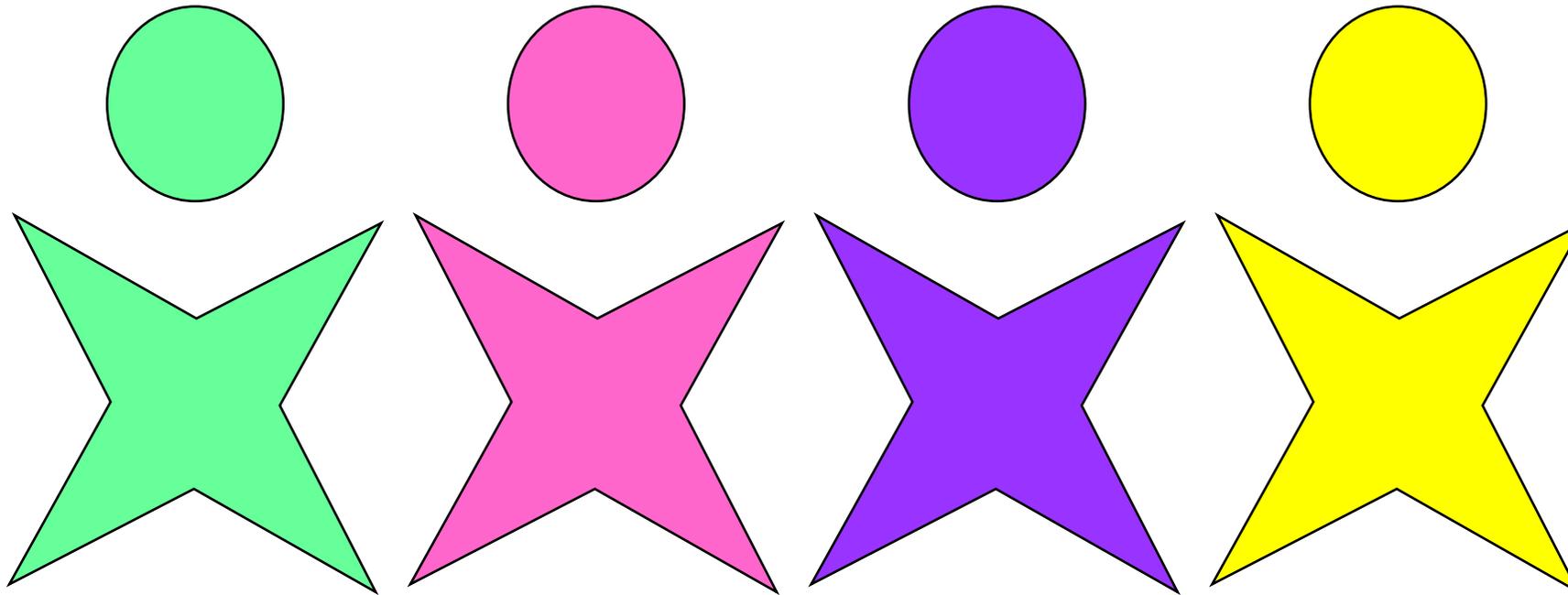
- Automation level driven by activities types involved and the WKIDM Intelligence Pyramid level
- Level of automation is guided by the need to exploit human strengths (e.g., complex decision making, flexibility) and compensate for human shortcomings (e.g., consistency / repetitive induced errors)
- Human-centered automation design is recommended (i.e., automate in support of human operators and with good human-machine cooperation)

(IM) Observe & Orient Activities	Measurement	Data	Information	Knowledge	Wisdom
Acquire / Create	AC	AC	SC	FC	MC
Synthesize / Use	AC	AC	OC	SC	MC
Retain / Validate	AC	AC	AC	OC	SC
Discover	AC	AC	AC	OC	SC
Transfer / Share	AC	AC	AC	AC	OC

MC Manual Control FC Facilitated Control SC Shared Control OC Oversight Control AC Autonomous Control



Break



Decision making problem types and automation implications



Section 1 2 3 4 5 6 7 8 9

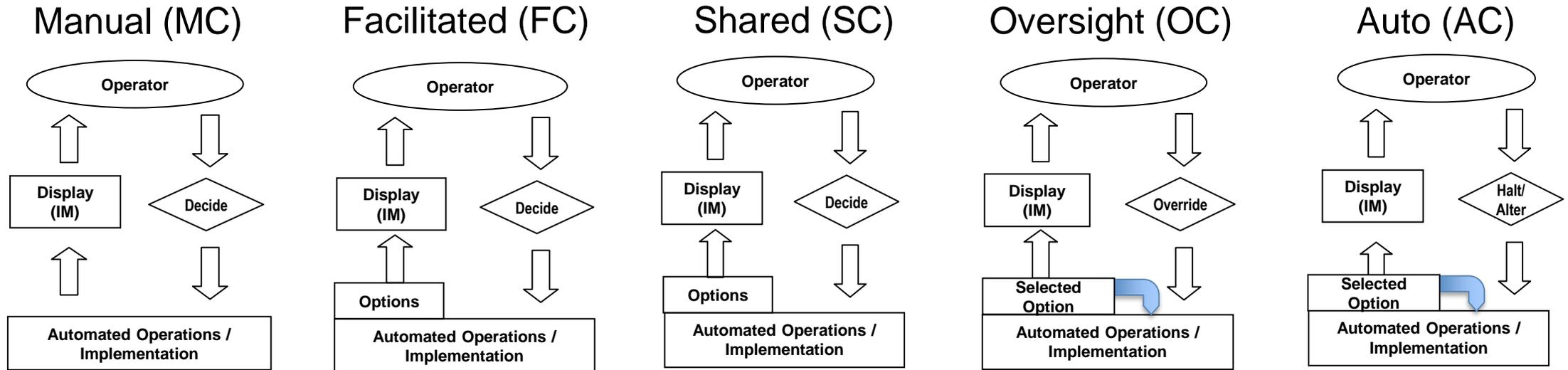
- Structured
- Semi-structured
- Unstructured

Decision Making (Decide)



- Interactive systems intend to identify problems, develop alternative solutions, make a decision, track / manage implementation, and learn for future support
- Ability to automate varies based on the type of decisions being made:
 - Structured
 - Decision-making uses routine procedure (i.e., interrelated sequential steps) or analyzed through algorithms and heuristics
 - Once a problem is solved it is used to define a procedure so next encounter uses same decision steps saving analysis time
 - Semi-structured
 - Problems have some easily defined parameters, but require some amount of judgment to make a good decision
 - Unstructured
 - Problems are usually unique, nonrecurring, and require significant human interaction and Intelligence Management to make a good decision
- Decision Constraints
 - A guideline explicitly directs the decision-maker about what can and cannot be done, and is used usually with well-structured problems to ensure consistency
 - A policy provides guidance by establishing parameters for a decision-maker's alternatives and can be used with any decision class

Decision Making Level of Automation (LOA)

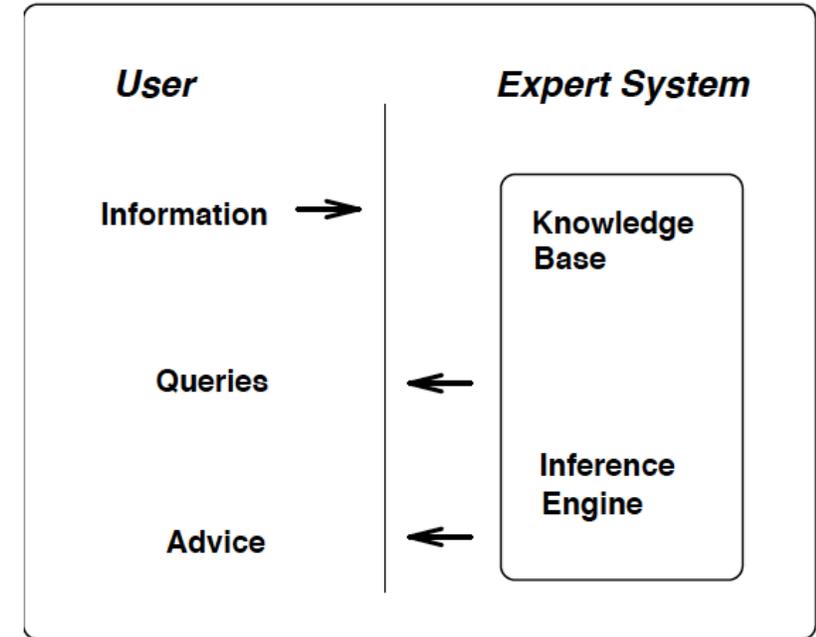


Function	Operator	System												
Monitor Operations	P	S	Monitor Operations	P	S	Monitor Operations	P	S	Monitor Operations	S	P	Monitor Operations	S	P
Generate Options	P		Generate Options	P	S	Generate Options	S	P	Generate Options	S	P	Halt/Alter	P	
Recommend Option	—	—	Recommend Option		P									
Select Option	P		Select Option	P		Select Option	P		Select Option		P	Select Option	P	
Implement Option		P												
Perform Operations		P												
Report Metrics		P												



Expert Systems and Rule Engines

- Like a human expert, an Expert System
 - Knows facts and procedural rules
 - Uses heuristics*
 - Justifies its conclusions
 - Is able to learn and absorb new knowledge
 - Applies new knowledge
- Expert System = Knowledge Base + Inference Engine
- A Knowledge Base stores facts (explicit knowledge) about the target environment
 - This is the job of a knowledge engineer, and is obtained mostly from domain experts
- The Inference Engine applies logical rules to the knowledge base and deduces new knowledge
- An Inference Engine is a mechanism that is able to observe patterns of facts and “infer” what should be done with the help of rules



* **Heuristics: a trial-and-error method of problem solving – not guaranteed to be correct all the time, but works much of the time**

Saskumir, Ramani, Raman, Anjanelua, Chandrasekar, (2007)



Automation of Decision Making

- Any real system will have many decision-making activities ongoing with various levels of human interaction and automation
- Decisions can range in type - structured, semi-structured, and unstructured
- Decision can be based on simple rules to very complex algorithms
- Risk aversion leads to Human in the Loop for high value assets / decisions
- DM LOA employed is guided by the need to exploit human strengths (e.g., complex decision making, flexibility) and compensate for human shortcomings (e.g., consistency / repetitive induced errors)
- Human-centered automation design is recommended (i.e., automate in support of human operators and with good human-machine cooperation)

Decision Making Activities	Structured	Semi Structured	Unstructured
Create Options	AC	SC	MC
Assess Options	AC	OC	FC
Select Options	AC	OC	FC
Communicate Option	AC	OC	SC

MC Manual Control FC Facilitated Control SC Shared Control OC Oversight Control AC Autonomous Control



Exercise 2: Typical Ground System Decision Types

For your Ground Systems

- List Several Structured Decisions and describe their LOA
- List Several Semi-structured Decisions and describe their LOA
- List Several Unstructured Decisions and describe their LOA
- Given the Table on Automation of Decision Making
 - Are there any LOAs that you disagree with? Why?

Decision implementation activities classes



- Simple independent
- Simple complex
- Complicated independent
- Complicated complex

Decision Implementation (Act)



- Industrial Age Automation focused on Decision Implementation (DI) and has mature automation examples
- Decision Science has identified seven DI categories ranging from communication, to performing activities, to assessing implementation
- DI activities performed are often referred to as *workflows*
- Workflow structure can be simple (a few activities) or complicated (many)
- The LOA possible for Decision Implementation varies based on the phase of the implementation ranging from communication to performing tasks to assessing implementation
- DI activities can be independent or complex (interdependent)
- Workflows composed of activities have differing levels of automation based on workflow structure and maturity and activity independence and maturity
- The LOA possible depends upon the activity category and the relationship of the activities.



Decision Implementation (DI) - Role of Automation

- Decision Science has identified seven DI phases:
 1. Communicating the decision – Provide the planner with the relevant knowledge to help them develop a plan.
 2. Planning implementation – Develop an actionable plan with schedule, resources, and products/services.
 3. Communicate the plan – Share with those who made the decision, impacted by the decision, and implementing the decision.
 4. Working the plan – Perform the outlined tasks.
 5. Monitoring implementation – Track the tasks, key performance indicators, and external environment.
 6. Evaluating implementation – Provide situational assessment and risk management.
 7. Learn from implementation – Capture and integrate lessons learned.
- DI Phases Observations
 - All phases require various IM to support implementation effectively
 - Phase 2, 6, and 7 often require Human Interaction / Intervention
 - Phase 1, 3, 4, and 5 often are more automatable
 - Guidelines and Policies need to be developed to guide role of automation

Without implementation, was a decision really made?

Workflow and Automation



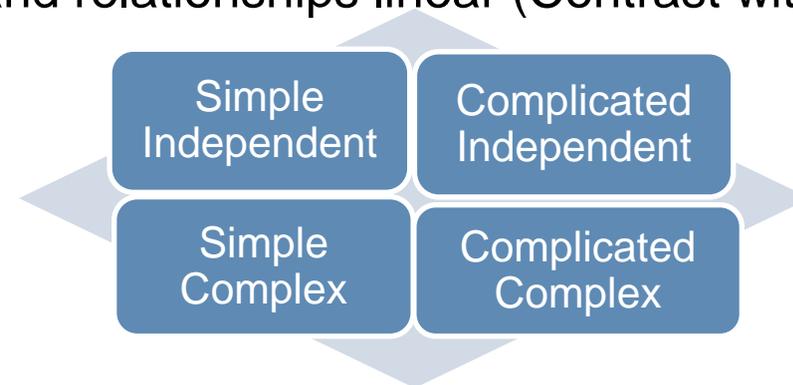
- Workflow is how work is organized
 - Composes and executes a series of tasks performed by humans / systems / services / applications.
 - Workflow is not limited to a linear “assembly line” like scripts
 - Workflow is fractal (i.e., can be composed of analytical functions, other workflows, and /or aggregated services at many scales)
- Workflow is documented in a human readable form, as well as a machine-readable form.
 - Rules are expressed in with the semantics / structure / syntax necessary to invoke machine workflow.
 - Created with drag and link analytic functions that interface software then interprets into machine readable
 - Visualized workflow is the translation of participant’s tacit knowledge of a task’s steps and constraints into explicit knowledge of the steps. (Polanyi, 1958) (Polyani, 1966)
 - Models of workflows allow the developer and user of the workflow to have insight into the process, to monitor its performance and anomalies, and to improve / optimize the workflow.
- In the development of workflow automation, the need for agile highly extensible responsive workflow that meets rapidly changing mission needs must be addressed.
 - Allows creation of “atomic” steps which can be replicated and repeated.
 - Often some atomic activities are performed in many workflows. These are often made into services to be developed once and used by many.
 - Just as with services, workflow production analytics and rules create “products” that describe various indicators based on observations.



Implantation Activity Structure

Complex, Complicated, Simple, Independent

- Complex in general usage is often used as the opposite of simple - Complex in specific technical usage is the opposite of independent while complicated is the opposite of simple
- Complicated is a class of closed systems while composed of large number of nested elements/ components/ interfaces whose functionality is decomposable and relationships linear
 - In today's systems, Complex is the difference between a myriad (Complicated) of connecting "stovepipes" and effective "integrated" solutions
- Independent Systems: A class of closed systems whose behavior is derived from uncoupled or loosely coupled elements/components with well-defined interfaces (e.g., often referred to as "stovepiped" systems.)
- Contrast this with complex systems that may be composed of complicated and/or simple systems
- Simple Systems: A class of closed systems composed of elements/ components/ interfaces whose functionality is decomposable and relationships linear (Contrast with complicated systems)



Implementation Structure Basics



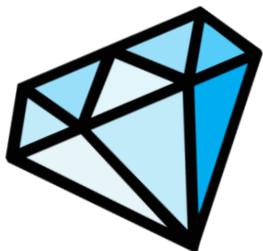
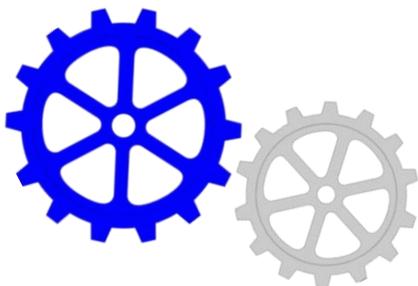
*Complicated is the opposite of simple
Complex is the opposite of independent*

Complicated



Independent

Complex



Simple

- Independent: A description of any entity that derives its properties from its components alone and can be decomposed / recomposed linearly being a sum of its parts.
Interchangeable Parts – Whitney & Colt
- Complex (technical term): A description of any entity that derives its properties from the highly coupled nature of its components and its context. The entity can be portrayed as “the whole is other than a sum of its the parts.” [Quote from Aristotle, 350 BC]
- Complicated: A description of an entity that is composed of many different types of components
- Simple: A description of an entity that is composed of one to a few types of components.

Structure impacts the LOA achievable



Some Implementation Workflow Structures

Simple or Complicated?

Complex or Independent?

- Fixed Sequence – Performs a defined set of activities
- Logical Sequence – Performs different activities depending upon various system states or inputs
- Feedback Control – Performs activities to maintain a stable state
- Discrete Process – Performs activities to create a discrete product
- Batch Process – Performs a defined set of activities without manual intervention.
- Interactive Process – Performs a defined set of activities with manual intervention
- Continuous Process –
- Applications having elements of discrete, batch and continuous process control are often called hybrid applications.

Automation of Decision Implementation



Decision Implementation Phases	Independent Simple	Independent Complicated	Complex Simple	Complex Complicated
1. Communicating the decision – Provide the planner with the relevant knowledge to help them develop a plan	AC	SC	SC	SC
2. Planning implementation – Develop an actionable plan with schedule, resources, and products/services	AC	SC	SC	SC
3. Communicate the plan – Share with those who made the decision, are implementing the decision and are impacted by it	AC	SC	SC	SC
4. Working the plan – Perform the outlined activities	AC	SC	SC	OC
5. Monitoring implementation – Track the tasks, key performance indicators, and external environment	AC	SC	OC	OC
6. Evaluating implementation – Provide situational assessment and risk management	FC	FC	FC	MC
7. Learn from implementation – Capture and integrate lessons learned	FC	FC	FC	MC

MC Manual Control

FC Facilitated Control

SC Shared Control

OC Oversight Control

AC Autonomous Control

Phase 2, 6, and 7 often require Human Interaction / Intervention, while Phases 1, 3, 4, and 5 often are more automatable - Guidelines and Policies need to be developed to guide role of automation



Exercise 3 – Typical Ground System Workflow

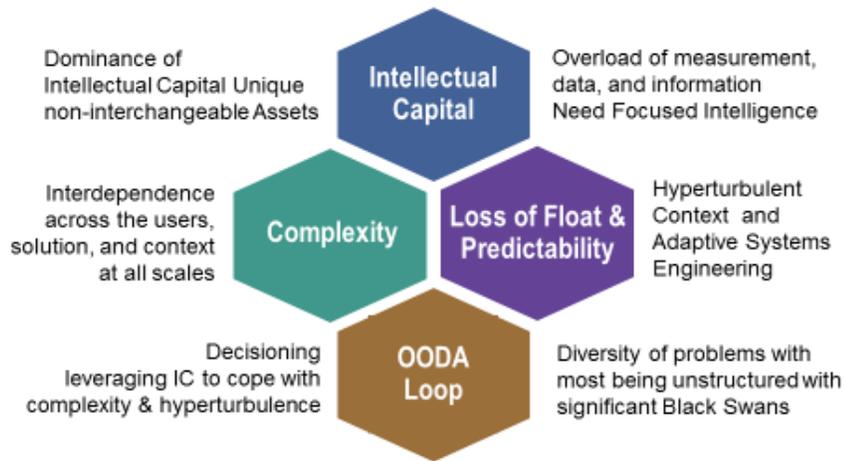
For your Ground Systems

- List Several Simple Independent workflows and describe their LOA
- List Several Complicated Independent and describe their LOA
- List Several Simple Complex and describe their LOA
- List Several Complicated Complex and describe their LOA
- Given the Table on Automation of Decision Implementation
 - Are there any LOAs that you disagree with? Why?

Architecting Effective Ground System Automation



Welcome to the Intelligence Age



Industrial Age assumptions about Physical Capital, Stovepipes, and Predictive Systems Engineering no longer hold

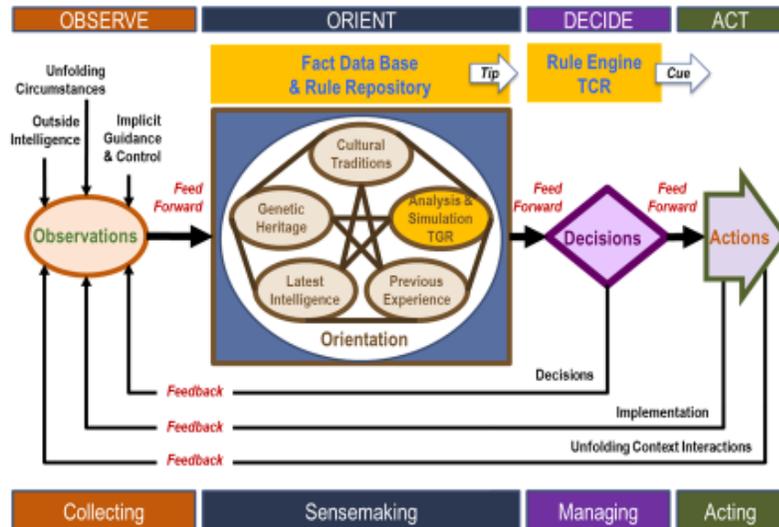
Levels of Automation (LOA)

Levels of Automation		LOA Description
Low	1 Manual Control (MC)	Human performs all activities including monitoring, selecting option, and implementing it
2	2 Facilitated Control (FC)	Human performs all the activities with limited automation of data input, manipulation, and implementation
3	3 Shared Control (SC) <i>Human-in-the-Loop</i>	Both the human and the IT Assets generate options, the human controls selection; however, carrying out the actions is shared between the human and the IT Assets
4	4 Oversight Control (OC) <i>Human on the Loop</i>	IT Assets generate list of decision options, IT Assets select the option informing human of selection, and it is turned over to the IT Assets to implement – human can override option selection within some time period if necessary
High	5 Autonomous Control (AC) <i>Human Override Only</i>	At this level, the system selects the best option to implement and carries out that action - based upon a list of alternatives it generates - the system automates decision making in addition to the generation of options - the human mainly monitors the system and Halts / Alters workflow to avert catastrophic failures

MC Manual Control FC Facilitated Control SC Shared Control OC Oversight Control AC Autonomous Control

One needs to determine what level of Automation is required for each activity in a process

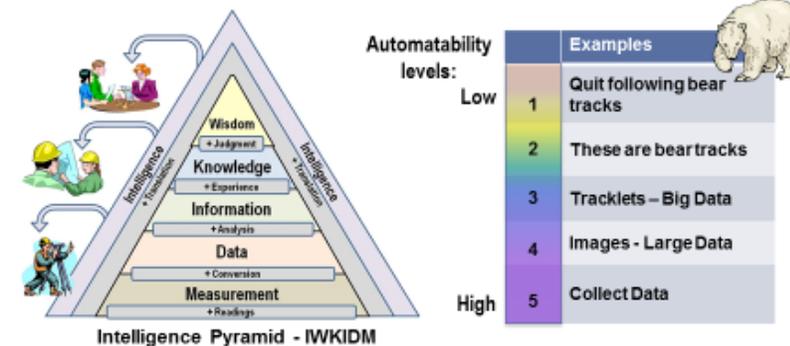
John Boyd's OODA Loop w Rules Overlay (Boyd, 1987)



Dynamic Responsive Intelligence Capability requires multiple nested OODA loops

Automation of Intelligence* Management

- Automation easy for Measurement / Data and is done today
- Harder for Information / Knowledge often requires human intervention
- Requires human judgment for Wisdom
- Varying Levels for Intelligence translation into users' frame of references



** Intelligence is defined as the translation of WKIDM into a user's frame of reference*





Thank you