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Modeling the Effects of Automation on Crew Workload for Software-Based Systems

GSAW 2013

March 20

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Outline

- Automation and Manpower
- Designing for Automation
- Functional Allocation
- Levels of Automation
- Workload Analysis
- Determining Crew Size
- Conclusions

Automation and Manpower

- Automation is achieved through the design of a machine that automatically performs tasks, previously accomplished by a human
- When designing a system, the automation of tasks doesn't always correlate directly with a reduction in manpower
  - The application of automation can lead to an increase in the complexity of tasks performed by the human[1]

1. Endsley, M. R. (1996). Automation and situation awareness. In R. Parasuraman & M. Mouloua (Eds.), Automation and human performance: Theory and applications (pp. 163-181). Mahwah, NJ: Lawrence Erlbaum.

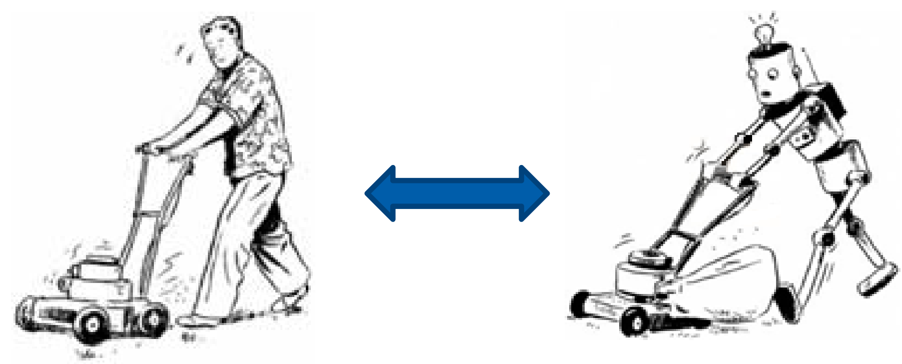
Designing for Automation

- The manning of highly automated, but more capable systems is a delicate balancing act
- The trade off between automation and manpower must be determined through analysis
  - "Manpower goals and parameters should be based on manpower studies and analysis. These studies and analyses should ensure that design options that reduce workload and ensure program affordability are pursued, and that lower-priority design features do not take precedence." (Defense Acquisition Guidebook, 6.3.1 Manpower)

Designing for Automation

- The analysis begins through the compilation of, and assignation of system functions/tasks to either the human or the machine
  - This analysis is called “functional allocation”
  - The goal is to optimize the contributions of both, as early as possible

- Performance of this analysis requires a set of known parameters
  - Completed detailed task analysis and functional flow diagrams
  - Known hardware and software technological limitations
  - Required performance in terms of speed and accuracy
  - Budget constraints



Functional Allocation

- The Fitts' List, derived from Fitts' Law (Fitts,1954), is a matrix that describes the inherent strengths of humans and machines
- The Fitts' List is employed to generate specific criteria to use for the functional allocation process

Human	Machine
Ability to react to unexpected, low-probability events	Performing routine, repetitive or precise activities
Ability to exercise judgment where events can not be completely defined	Performing complex and rapid computations with high accuracy
Improvising and adopting flexible procedures	Monitoring large amounts of data for sudden changes of state

Functional Allocation

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- The Fitts’ List criteria are weighted based on criticality, and each function/task is analyzed and assigned a score for each criteria as well as an overall human and machine score

	HUMAN						MACHINE							
Task description	**1 Ability to react to unexpected, low-probability events (Weight: 5)**		**2 Ability to exercise judgment where events can not be completely defined (Weight: 4)**		**3 Improvising and adopting flexible procedures (Weight: 4)**		**1 Performing routine, repetitive or precise activities (Weight: 4)**		**2 Performing complex and rapid computations with high accuracy (Weight: 5)**		**3 Monitoring large amounts of data for sudden changes of state (Weight: 4)**		**Total Score Human (out of 100)**	**Total Score Machine (out of 100)**
	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score		
Enable Communications	1	5	1	4	1	4	3	12	3	15	5	20	13	47
Monitor Status Data	1	5	1	4	1	4	5	20	5	25	5	20	13	65
Monitor Payload Data	5	25	3	12	5	20	1	4	1	5	3	12	57	21
Perform Upload	3	15	1	4	1	4	1	4	3	15	3	12	23	31
Perform Download	3	15	1	4	1	4	1	4	3	15	3	12	23	31

Levels of Automation

- Once the list of machine appropriate tasks has been generated, they must be analyzed for the application of automation
- Varying amounts of automation can be applied to each task, on a task by task basis, according to program needs or constraints
- Sheridan and Verplank's Scale of Human-Machine Task Allocation (SVL) is one method through which varying degrees of task automation can be defined

Levels of Automation

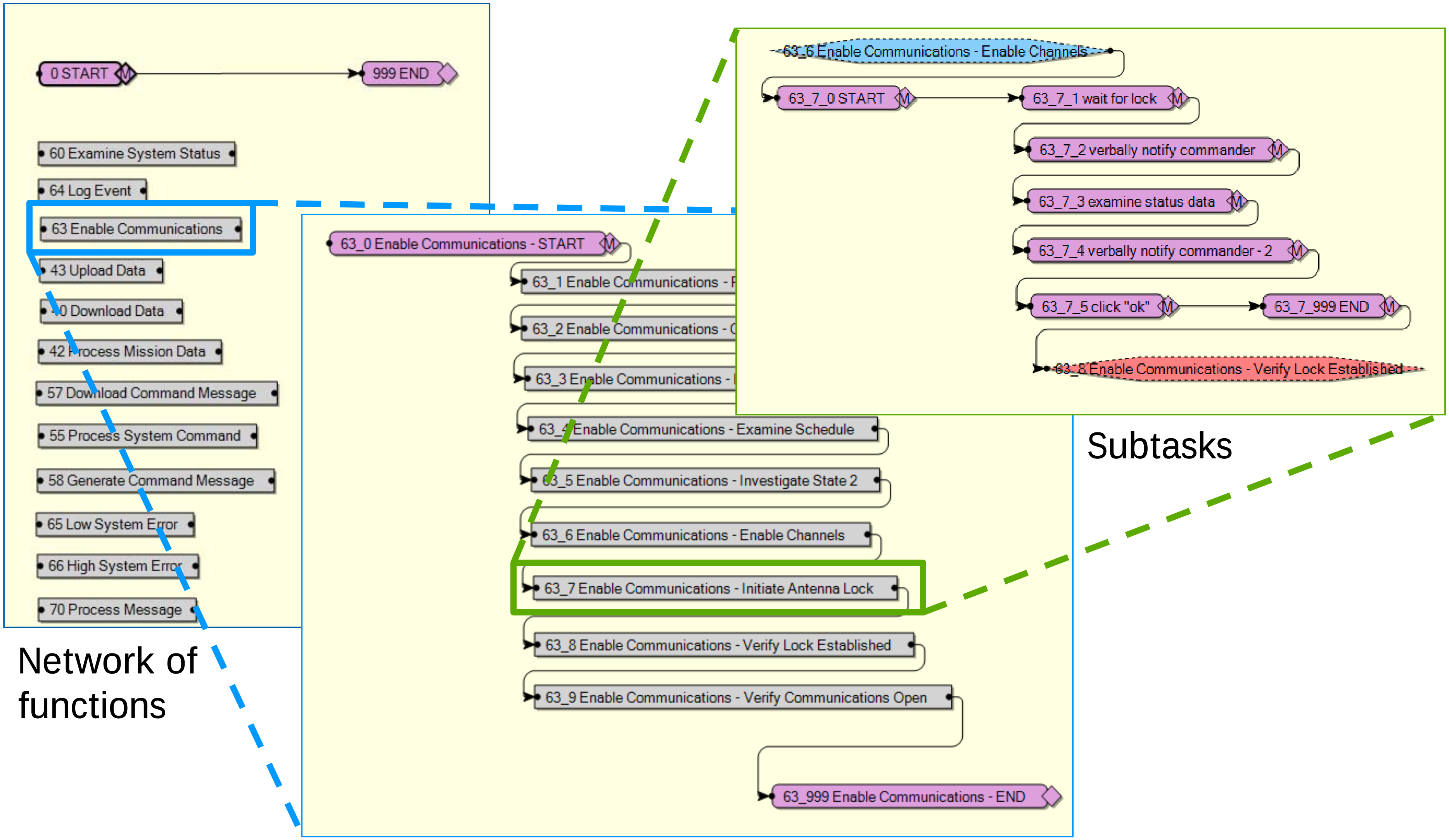
- The SVL defines 10 explicit levels of automation however, these can be grouped into 3 overall automation concepts

Sheridan-Verplank 10 Levels of Human-Machine Function Allocation	
1. The human does all the planning, scheduling, optimizing etc. and turns task over to computer for merely deterministic execution.	Human control-centered
2. Computer provides options, but human chooses between them, plans the operations, and then turn task over to computer for execution.	
3. Computer helps to determine options, and suggests one for use, which the human may or may not accept before turning task over to computer for execution.	
4. Computer elects options and plan actions, which human may or may not approve, computer can reuse options suggested by human.	Cooperative control
5. Computer selects action and carries it out if human approves.	
6. Computer select options, plans and actions and displays them in time for the human to intervene, and then carries them out in default if there is no human input.	
7. Computer does entire task and informs human of what it has done.	Machine control-centered
8. Computer does entire task and informs human only if requested.	
9. Computer does entire task and informs human if it believes the latter needs to know.	
10. Computer performs entire task autonomously, ignoring the human supervisor who must completely trust the computer in all aspects of the decision making.	

Workload Analysis

- Once we determine our automated tasks, taking into account our chosen levels of automation, the crew workload models can be built
- The Improved Performance Research Integration Tool (IMPRINT) is a software-based tool developed by the Army Research Labs (ARL), that models the amount of workload experienced by a crew, over a specific amount of time
- IMPRINT incorporates a network of functions and tasks consisting of detailed subtasks, scored for relative workload, into a cohesive, stochastic, temporally driven model that estimates workload for individual crew members

Workload Analysis



Subtasks

Network of functions

Tasks

Workload Analysis

- The IMPRINT workload model employs current workload analysis theories to provide workload scores for each subtask
- Visual, Auditory, Cognitive and Psychomotor (VACP) workload resource demand channels
  - Each subtask in the workload model is assigned a resource demand value from 0-7 for each resource demand channel
  - Resource demand values are added together when tasks are performed in parallel
- Most software system workload models will reveal heavy cognitive channel demands on operators

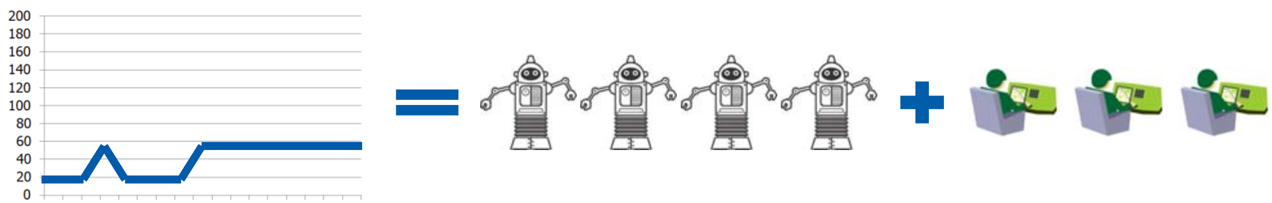
Cognitive Resource Demand Values (Examples)
1.0 Automatic (Simple Association)
1.2 Alternative Selection
4.6 Evaluation/Judgment – single aspect
5.0 Rehearsal
5.3 Encoding/Decoding, and Recall
6.8 Evaluation/Judgment – multiple aspects
7.0 Estimation, Calculation, and Conversion

Workload Analysis

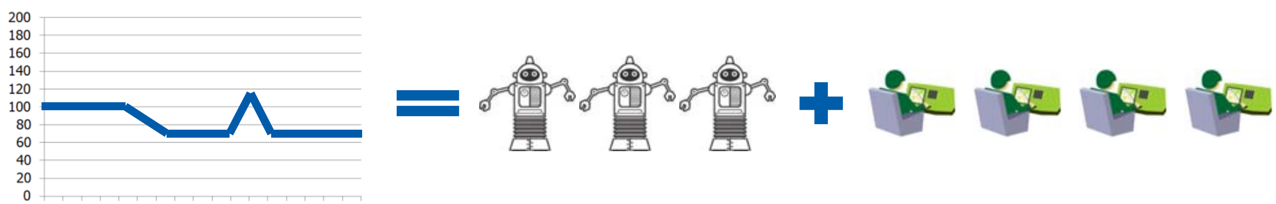
- In addition, some tasks performed in parallel may interfere with each other more or less based on the nature of the tasks
- Multiple Resource Theory (MRT) expands upon VACP by allowing for or preventing specific kinds of multi-tasking
    - For example, someone could more easily listen to the radio while typing, than trying to dial a phone while typing
    - Manifested in the model as resource demand value modifiers
- The IMPRINT model tracks total resource demand values for each operator during the programmed time period
- Total, modified workload values in excess of 60 indicate overload conditions and must be addressed
- Although not specifically addressed by the IMPRINT model, prolonged periods of low or no workload could point to underload conditions and should be considered as well

Determining Crew Size

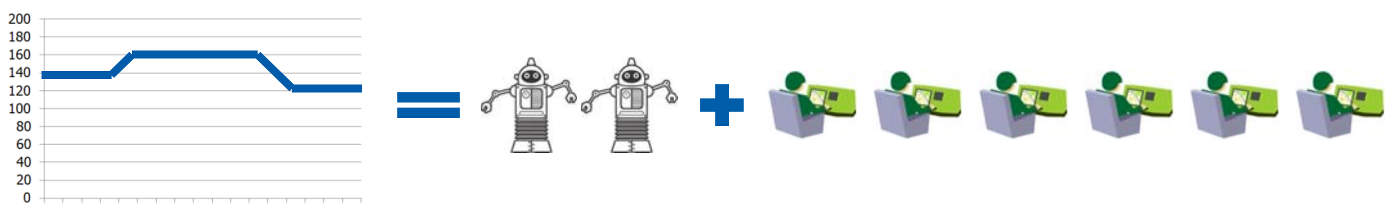
- Crew duties, and compositions are altered until a model is produced with acceptable workload levels
- It is possible to have multiple crew configuration options that may address specific system concerns, or varying levels of automation



Complexity	High
Flexibility	Low
Performance	High



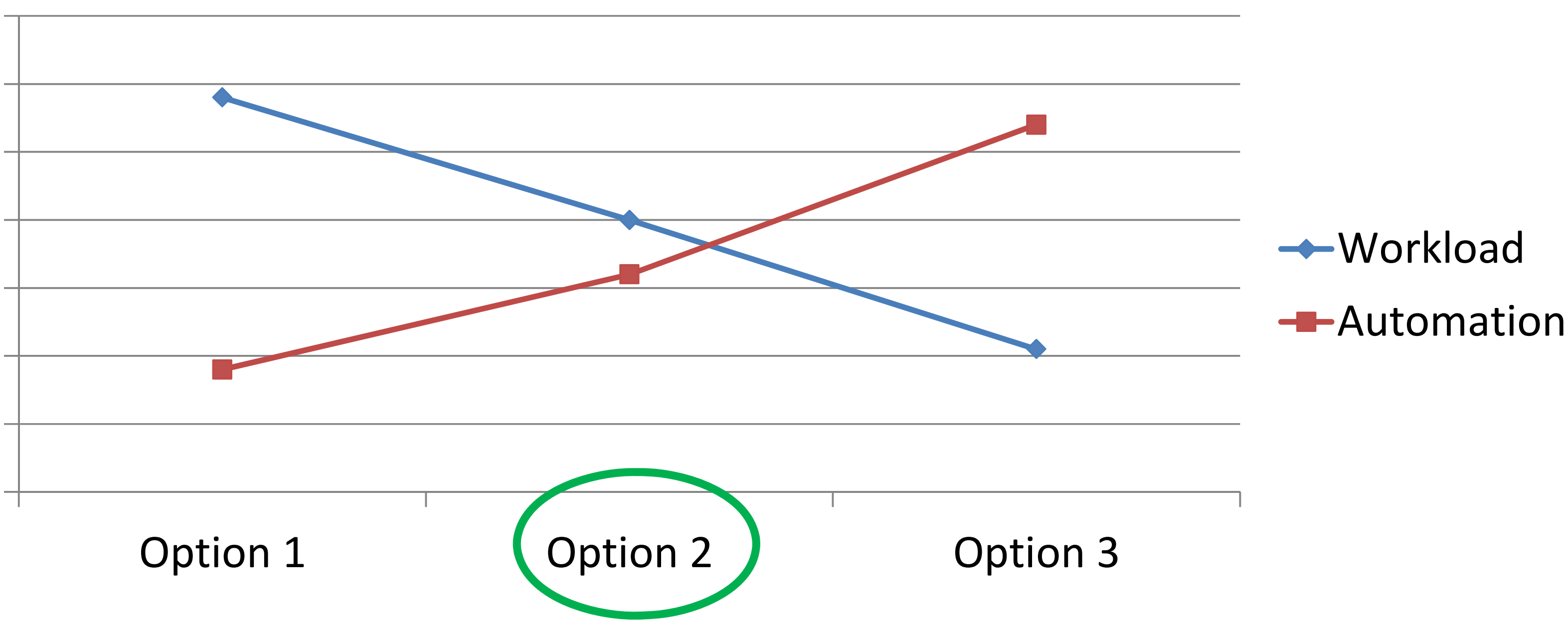
Complexity	Med
Flexibility	Med
Performance	Med



Complexity	Low
Flexibility	High
Performance	Med

Determining Crew Size

- Ultimately, crew workload and automation levels should be balanced to ensure that whatever crew size is selected, operators are:
  - Neither overloaded or underloaded
  - Provide benefit to the system
  - Are not present to “babysit” the machine



Determining Crew Size

- Other considerations must be taken into account when deciding on the amount of automation applied to the system

- Cost
  - The application of automation is expensive, as many software systems require complex algorithms in order to automate some of the more complex functions
  - Function automation must be balanced with crew size, as more crew members means more sustainment costs

- Performance
  - The ability to achieve performance parameters may hinge on the automation of specific system functions
  - Too many crew members, or automation of too many tasks, may produce underload conditions which could lead to decreased vigilance and increased operator error rates
  - Too few crew members, or automation of too few tasks, could lead to overload conditions, which can also lead to increase operator error rates

Conclusion

- We can model the effects of automation on crew workload just like we model workload with other types of systems
- There are some important considerations concerning which tasks are automated, and by how much
  - These decisions effect the workload of the crew directly
- After taking into account cost constraints, and minimum acceptable system performance, crew workload and automation should be balanced
  - Too little workload can sometimes be as detrimental as too much workload
- Finally, automation should be applied as a tool to allow the human operators the ability to focus more of their attention on the important details of the mission

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