Attention Allocation During Human-Autonomy Interactions: A Human-in-the-Loop Simulation Experiment on a Multi-Vehicle Management Task

Tetsuya Sato[1], Yusuke Yamani[1], Samia Islam[1], Michael S. Politowicz[1,2], & Eric T. Chancey[2]

Old Dominion University[1]

NASA Langley Research Center[2]

Advanced Air Mobility (AAM)

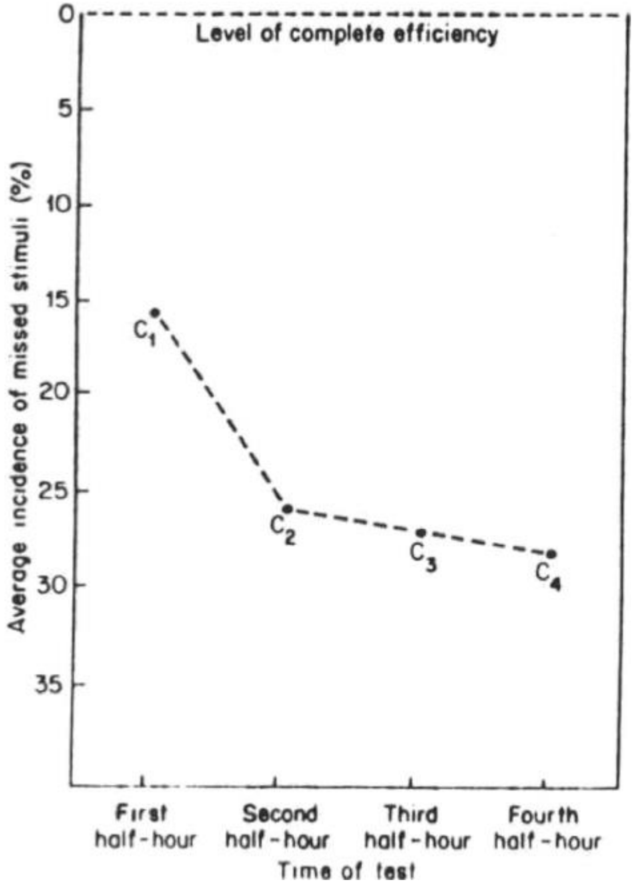
- AAM enables efficient transportation of goods and people in both urban and rural areas (National Academics of Sciences, Engineering, and Medicine, 2020)
- AAM is driven by increasingly autonomous systems.

Human-Autonomy Teaming (HAT)

- Autonomy is defined as "a machine that can carry out tasks independently and in conjunction with human interactions" (Demir et al., 2021, p. 696)
- AAM ecosystem requires successful human-autonomy teaming (HAT)
  - HAT refers to active and meaningful coordination between human(s) and / or increasingly autonomous agents in a task with a shared goal

Sustained Attention and AAM

- Implementing increasingly autonomous system shifts human responsibilities to passive monitor (Bainbridge, 1983)
- Human vigilance declines as quick as ½ hours (Mackworth, 1948; Molloy & Parasuraman, 1996; Warm et al., 2008)
- *Resource depletion theory* (Davies & Parasuraman, 1982) states that attentional performance decreases over time because cognitive resources are consumed faster than replenished.

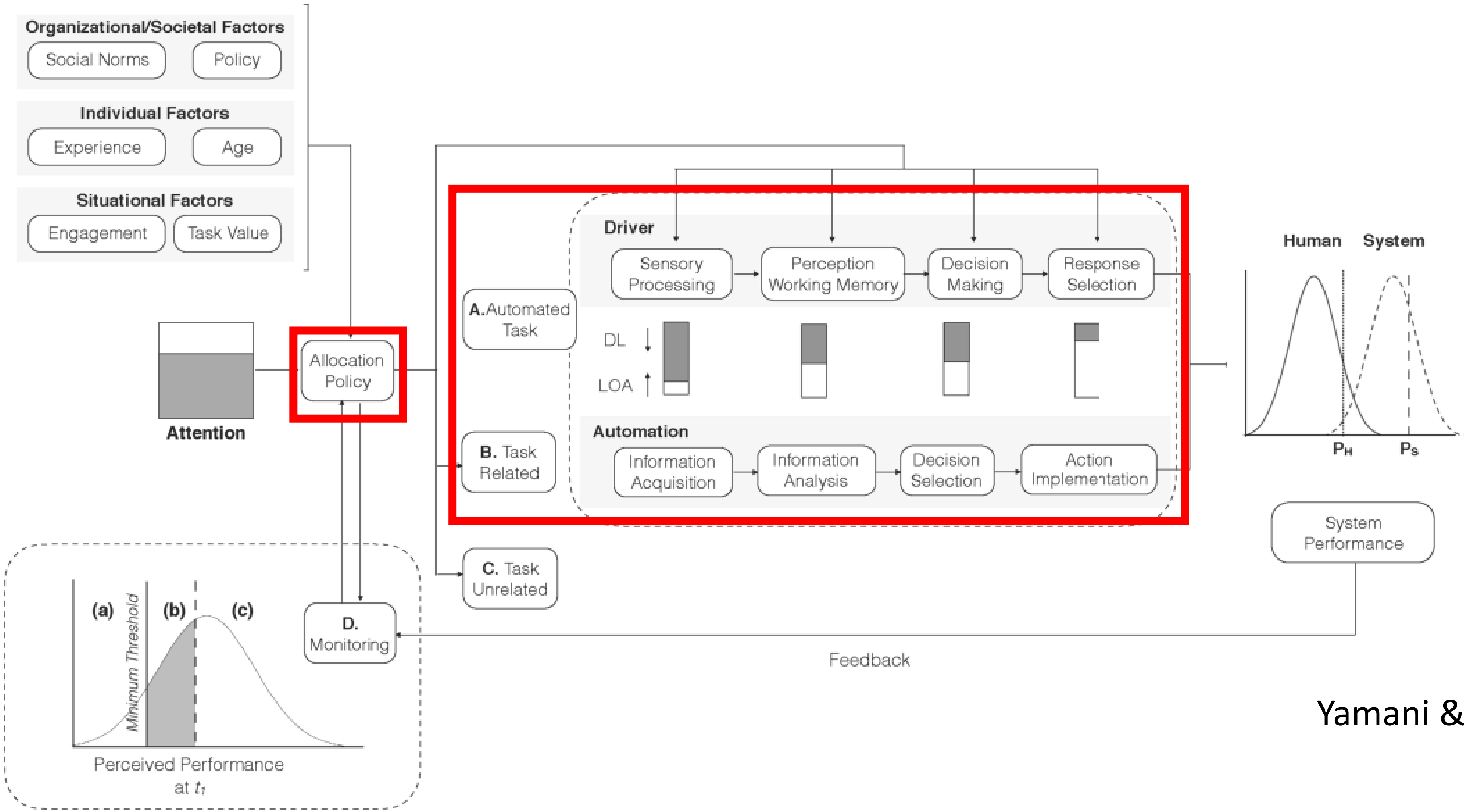


Mackworth (1948)

Research Question

In the AAM environments with varying levels of autonomy, what are factors that influence attentional performance over time in a multi-aircraft tracking task?

Theoretical Implications in HAT



Yamani & Horrey (2018)

Image Credit: Y. Yamani

Levels of Automation

Level 5: Executes a suggestion if human approves

Level 6: Human has limited time to veto before execution

Level 7: Autonomous, but always informs human of actions

Level 8: Autonomous, but does not always inform human

Level 10: Autonomous

Sheridan & Verplank (1978)

Image Credit: NASA

Hypotheses (Yamani & Horrey, 2018)

1. Increasing the levels of automation of the multi-agent planning (MAP) task will free up attentional resource, supporting system monitoring task performance
2. Operators will show a steeper performance decline in the MAP task when they have fewer vehicles equipped with higher levels of autonomy.
3. Operators' performance in the MAP task will also decline when they have more vehicles equipped with lower levels of automation.

Experimental Design

- Participants
  - 40 undergraduate students from Old Dominion University
- Tools and Apparatus
  - Human-Autonomy Teaming Task Battery (HATTB)
  - Tobii Pro Eye Tracker
- Independent variables:
  - Levels of automation: High (level 6 automation) vs. low (level 5 automation)
  - Number of aircraft (1 vs. 4 vs. 8 vehicles)
- Dependent variables:
  - Percentage dwell time (PDT), subjective workload, and HATTB task performance

Human-Autonomy Teaming Task Battery (HATTB)

- NASA's software application that evaluates participant's ability to concurrently perform predefined tasks that simulate AAM operation.
  - Multi-Agent Planning (MAP) Task
  - System Monitoring Task
- HATTB can simulate various levels of automation in each task

Multi-Agent Planning (MAP) Task

- Goal: Navigate the aircraft that you are responsible to its target destination without colliding with other aircraft.

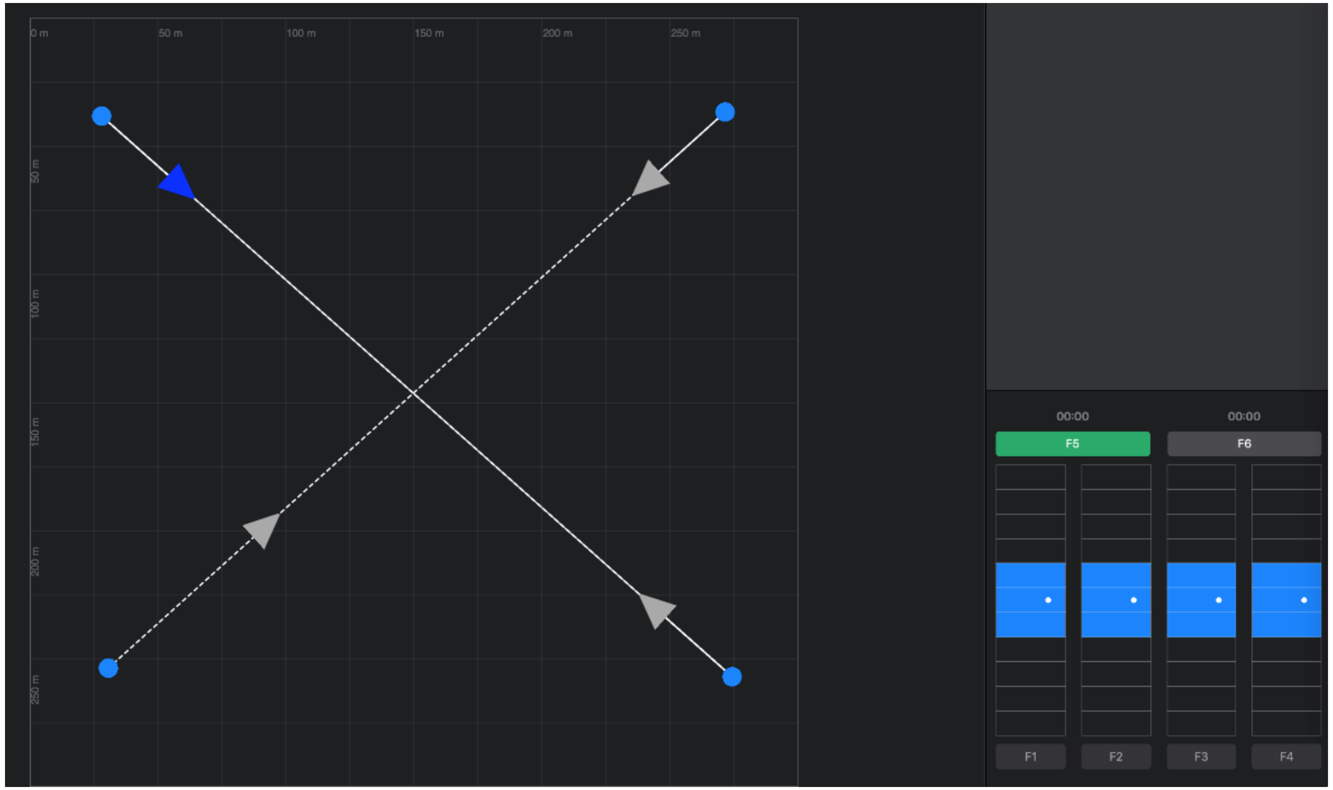


Image Credit: NASA

System Monitoring Task

- Goal : Monitor the fluctuation of four gauges that represent the pressure and temperature of the participant's aircraft.

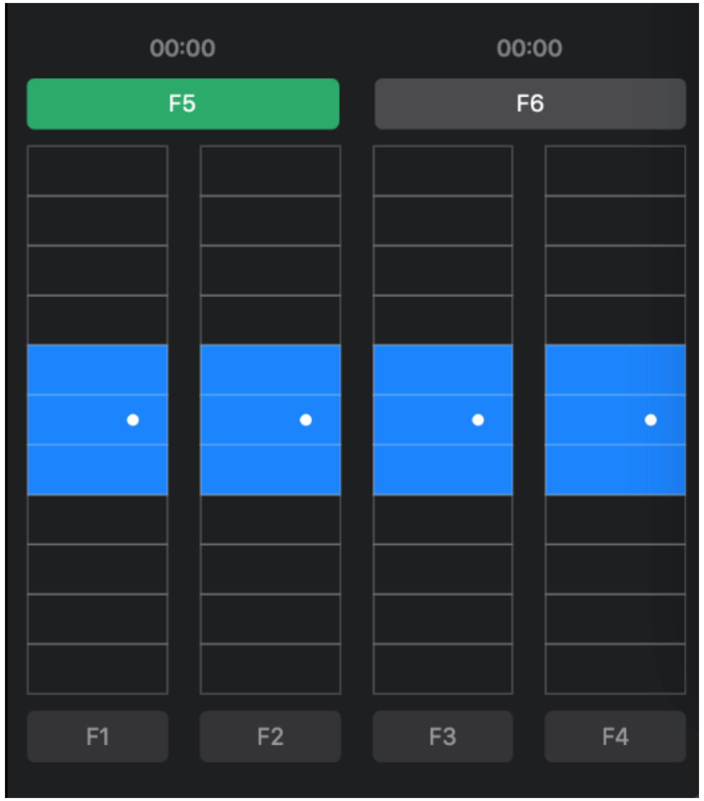


Image Credit: NASA

Procedure

1. Complete informed consent and demographics form
2. Visual screening test
3. Randomly assign participants to high or low group
4. Practice session
   - Perform each task individually for 5 minutes
5. Experimental session
   - Perform two 20-minute experimental blocks
   - Complete subjective questionnaire at the end of each experimental block

Dependent Measures

- HATTB Task Performance
  - MAP task
    - Error rate: the proportion of events that involve a collision
  - System monitoring task
    - Error rate: the proportion of events that participants executed incorrectly
    - Response time (RT): time between the onset of an event and the participant's initial response
- Percentage dwell time (PDT)
  - Proportion of time that participants fixated on certain areas of interest
- Subjective Measures
  - NASA-TLX (Hart & Staveland, 1988)

Planned Statistical Analyses

- Mixed Bayesian Analysis of Variance (Wetzels et al., 2012)
  - PDT
  - Subjective workload
  - HATTB task performance
- Measure of evidence in the default Bayesian analysis is B_{10}
  - $B_{10} < 1/3$
    - Data substantially support the model **without** the effect of interest (the null hypothesis)
  - $B_{10} > 3$
    - Data substantially support the model **with** the effect of interest (the alternative hypothesis)

Conclusion of Planned Experiment

- Our current research focuses on
  - Attention allocation strategies during vigilance decrement in HAT
    - Analysis of eye movement allows online measure of attention allocation
  - Effects of vigilance decrement on HAT
  - Effects of task interruption and task switching on HAT
- Current Research
  - Provides theoretical understanding of the mechanisms that underlie attentional performance in HAT
  - Provides practical implications for facilitating effective HAT in AAM operation

Acknowledgement

NASA

SIGMA XI
THE SCIENTIFIC RESEARCH SOCIETY

Contact Information

- Tetsuya Sato: tsato003@odu.edu
- Dr. Yusuke Yamani: yyamani@odu.edu
- Samia Islam: samiaislam112@gmail.com
- Michael S. Politowicz: michael.s.politowicz@nasa.gov
- Dr. Eric T. Chancey: eric.t.chancey@nasa.gov

Reference

Bainbridge, L. (1983). Ironies of automation. *Automatica, 19*, 775-779.

Davies, D. R., & Parasuraman, R. (1982). The psychology of vigilance. Academic Press.

Demir, M., McNeese, N. J., Gorman, J. C., Cooke, N. J., Myers, C. W., & Grimm, D. A. (2021). Exploration of teammate trust and interaction dynamics in human-autonomy teaming. *IEEE Transactions on Human-Machine Systems*, *51*, 696-705.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139-183). North-Holland.

Mackworth, N. H. (1948). The breakdown of vigilance during pro-longed visual search. Quarterly Journal of Experimental Psychology, 1, 6-21.

Molloy, R., & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. Human Factors, 38(2), 311-322.

National Academies of Sciences, Engineering, and Medicine. (2020). *Advancing aerial mobility: A national blueprint*. National Academies Press.

Sheridan, T. B., & Verplank, W. L. (1978). Human and computer con-trol of undersea teleoperators. Massachusetts Inst of Tech Cam-bridge Man-Machine Systems Lab.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance re-quires hard mental work and is stressful. Human factors, 50, 433-441.

Wetzels, R., Grasman, R. P., & Wagenmakers, E. J. (2012). A default Bayesian hypothesis test for ANOVA designs. *The American Statistician*, *66*, 104-111.

Yamani, Y., & Horrey, W. J. (2018). A theoretical model of human-automation interaction grounded in resource allocation policy during automated driving. International Journal of Human Factors and Ergonomics, 5(3), 225-239.