Key Issues in Human Systems Integration: Addressing Automation in the Development and Operation of Large-Scale Technological Systems

Ground System Architectures Workshop (GSAW) Workshop

Automation Agenda

- What is Automation?
- Automation in Complex Technological Systems
- Human Error and Automation
  - *Levels of Automation*
  - *Situation Awareness*
  - *Human Information Processing*
- Techniques to guide automation decisions

Automation and Human Operator Role

- Complexity of large-scale technological systems increasingly drives the use of automation
- The human operator's role in modern high-technology systems is, increasingly that of a systems monitor, systems manager and decision maker
- Automation is a double-edged sword, it has eliminated some sources of error but introduced new sources
- Paradoxically automation can often increase the impact of human error
  - *automation merely shifts the location of human error from the 'operator' to the designer, the maintenance personnel, and the supervisor who must deal with automation problems and failures. (Reason, 1990)*
- Automation can help complex technological cope with human error, but it alone will not prevent human error occurrences

What are we trying to accomplish?

Can these warfighters?

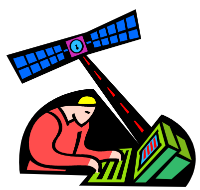
With this training?

Using this equipment?

Under these conditions?

TIME PRESSURE

24/7 ops



STRESS

Weather

Accomplish their mission?

Questions on Automation

What's all this fuss about automation?

How do I make trades about automation?

Will automating my system eliminate all human error?

Will automating my system always result in reductions in staffing?

Will automating my system reduce individual operator workload?

Can't I just automate everything and let the operator figure out what automation they want to use?

What trades about automation should I consider?

When in doubt, automate?

Just because something can be automated should it be?

How does the human know what the automation is doing?

How should levels of automation and task allocation be determined for a system?

Avoiding Automation Surprises

- Automation opens up new ways for system breakdown
  - *Wrestling with automated systems*
- Invites new forms of human error
  - *Mode confusion – why is it doing this now?*
- Change tasks and add tasks for the human
  - *“I can’t fly anymore, but I can type 50 words per minute now”*

What drives the decision to automation?

Integration of users across system lifecycle represents 40-60% of life-cycle costs

* Increased demands on operators – new missions, CONOPS, tactics
* Increased volume and rate of information
* Reduced manpower projections - number and experience
* Changing human roles – control of multiple platforms, multi-mission tasking

Is Automation the Answer?

Automation and Human Operator Role

- The human operator's role in modern high-technology systems is, increasingly that of a systems monitor, systems manager and decision maker
- Automation is a double-edged sword, it has eliminated some sources of error but introduced new sources
  - *In some cases these new errors result in consequences that are more severe than those eliminated by the automation (Weiner and Nagel, 1988)*
  - *In some cases, automation has created the situation where small errors are tuned out, but opportunities for large errors are created*
  - *As Weiner states, "some glass cockpits have clumsily used automation that creates bottlenecks where pilots are least able to deal with them – during high workload periods" (Weiner 1988, Hughes and Dornheim, 1995, p. 52)*

Automation

Advantages:

- Eliminates human error and limitations
- Capitalize capabilities of human operator and machine

Disadvantages:

- Computer cannot make judgments
- Computer systems not always reliable to issue alert
- Alerts may be misinterpreted
- De-skill the operator
- Isolates operator from control process
- May lead to degraded failure-recovery

Automation in Complex Technological Systems

- Paradoxically automation can often increase the impact of human error
  - *automation merely shifts the location of human error from the 'operator' to the designer, the maintenance personnel, and the supervisor who must deal with automation problems and failures. (Reason, 1990)*
- Automation can help complex technological cope with human error, but it alone will not prevent human error occurrences
- Providing insight into the human error consequences resulting from a particular system design enables designers to choose between alternative designs that includes levels of automation

The goal is a system design that reduces the frequency of human errors,
reduces the severity of the consequences of human error,
and enables recovery from human errors (error-tolerant systems)

Trust in Automation

- Will the operator trust that the machines determines, selects and executes tasks properly?
- What is the result of the operator not trusting the machine, what operator actions will this lead to and how will they affect system performance?
- How should a designer build a system that encourages trust in automation?

Sheridan (2002)

Challenges with Human Centered Automation

1. Allocate to the human the tasks best suited to the human, allocate to the automation the tasks best suited to it.	→	Unfortunately there is no agreement on how best to do this.
2. Make the operator a supervisor of subordinate automatic control system(s).	→	*F*or many tasks direct manual control may prove best.
3. Keep the human operator in the decision and control loop	→	Humans can handle only control tasks of bandwidth below one Hz.
4. Maintain the human operator as the final authority over the automation	→	This is not always the safest way. There are many systems where the human is not to be trusted.
5. *Make the human operator's job easier, more enjoyable, or more satisfying through friendly automation.*	→	Operator ease and enjoyment are OK if system performance is not compromised.
6. Empower the human operator to the greatest extent possible through flexibility of interface or through automation.	→	The operator may feel a false sense of empowerment.
7. Support trust by the human operator.	→	The challenge is to engender the right amount of trust, not too little or too much. Both pose serious problems.
8. Give the operator information about everything he or she should want to know	→	The problem here is that too much information will surely overwhelm.
9. Engineer the automation to minimize human error and response variability	→	Error is a curious thing. Darwin taught us about requisite variety years ago. A good system tolerates some error.
10. Achieve the best combination of human and automatic control, where best is defined by explicit system objectives.	→	Don't we wish we always had explicit system objectives!

Adapted from Sheridan (2002)

10 Levels of Automation

Sheridan and Verplank (1978) defined the following ten levels of automation:

1. The human performs the entire task (no automation)
2. The computer aids the human with options
3. The computer aids the human with options and suggests one
4. The computer selects an action and human chooses whether or not to perform the action
5. The computer selects an action and performs the action, if approved by the human
6. The computer selects an action and performs the action, unless the human stops execution within a given amount of time
7. The computer selects and takes action and informs the human after the fact
8. The computer selects and takes action and informs the human if prompted
9. The computer selects and takes action and decides what information the human should receive
10. The computer selects and takes action and decides what information the human should receive and if the human should receive any information (fully automated)

Levels 1-10 show a progression from no automation to a fully automated system or low to high automation.

Levels of Automation - Simplified

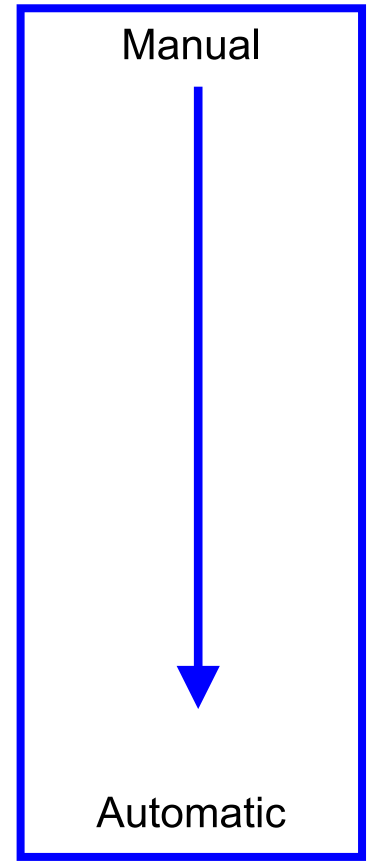
- The computer offers no assistance: the human must do it all
- The computer suggests alternative ways to do the task
- The computer suggests one way to do the task, and

  …..executes that suggestion if the human approves, or

  …..allows the human a restricted time to veto before automatic execution, or

  …..executes automatically, then necessarily informs the human, or

  …. executes automatically, and informs the human only if asked
- The computer selects and executes the task, ignoring the human



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Factors to Consider

- Determining appropriate levels of automation requires investigating:
  - *System performance*
  - *What task assignment results in optimal task performance*
  - *Humans are naturally better at some tasks and machines are naturally better/faster at others*
- Operator performance during automation failure
  - *With a highly automated system, can the user manually recover from a failure?*
- Perceived subjective workload levels
  - *Is operator workload decreased with automation?*
- Situation awareness (SA)
  - *It is critical to consider SA when automating a system or part of a system?*
- Why is it so important to carefully identify the Levels of Automation?
  - *Overcoming weaknesses of Human/Machine*
  - *Taking advantages of strengths of Human/Machine*
  - *Considering these can result in the design of a system with optimal levels of automation*

References

Department of Defense (DoD). (1999). *Human Engineering*, MIL-STD-1472F, 23. August 1999.

Endsley, M. (1988). Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON), 789-795. New York: IEEE

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*. 37(1), 32-64.

Endsley, M.R., Bolte, B., and Jones, D.G., (2003). *Designing for Situation Awareness: An Approach to User-centered design*. New York & London: Taylor and Francis

Endsley, M.R., and Kaber, D.B., (1999). Level of Automation Effects on Performance, Situation Awareness and Workload in Dynamic Control Task. *Ergonomics*. 42, (3)., p. 462-492.

Fitts, P. M., (Ed.). (1951). *Human Engineering for an effective air-navigation and traffic-control system*. Columbus Ohio: Ohio State University Research Foundation.

Hughes, D., and Dornheim, M.A. (1995). Accidents Direct Focus on Cockpit Automation. *Aviation Week & Space Technology*. January 23, 1995, 52-54.

Salvendy, G. (1997). *Handbook of Human Factors and Ergonomics*. New York. John Wiley & Sons, Inc.

Sarter, N.B., and Schroeder, B. (2001). Supporting Decision Making and Action Selection under Time Pressure and Uncertainty: The Case of In-Flight Icing. *Human Factors.* Vol. 43, No. 4, 573-583 (2001)

References

Sheridan, T. (2002). *Humans and automation: System design and research issues*. Santa Monica, CA, and New York: Human Factors and Ergonomics Society and Wiley

Sheridan, T.B., and Verplank, W.L., (1978). *Human and computer control of undersea teleoperators*. (Man-Machine Systems Laboratory report). Cambridge: MIT

Van Cott, H.P. and Kinkade, R.G. (1972). *Human Engineering Guide to Equipment Design.* Washington, D.C., American Institute for Research, McGraw-Hill

Weiner, E.L., & Nagel, D.C., (Eds). (1988). *Human Factors in Aviation*. San Diego: Academic.

Wickens, C.D. and Hollands. J. (1999). *Engineering Psychology and Human Performance*. New York: Pearson

Wickens, C.D. (2008). *Function allocation and the degree of automation.* Presentation to the Rocky Mountain Chapter of the Human Factors and Ergonomics Society.

Woodson, W.E., Tillman B., and Tillman P. (1992). *Human Factors Design Handbook*. New York. McGraw-Hill.

References

ANSI/HFS 100 (2007). *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* (2007)

A Manager's Guide to Reducing Human Errors: Improving Human Performances in the Chemical Industry, CMA, 1990

Braddock, R. (1958). An extension of the "Lasswell Formula". *Journal of Communication*, 8, 88-93.

Casey, Steven. (2006). *The Perilous Plunge*. In The Atomic Chef and Other True Tales of Design, Technology, and Human Error. Aegean Publishing, Santa Barbara, CA. pp. 224-235.

Chapanis, A., and LIndenbaum, L.E., (1959). A reaction –time study of four control-display linkages. *Human Factors*, Volume 1, No. 4 1-7.

Chaparro, A., Croff, L.S. (2001). *Human factors survey of aviation technical manuals phase 1*. Washington, DC: U.S. Department of Transportation.

Chaparro, A., Croff, L.S. (2001). *Human factors survey of aviation technical manuals phase 2*. Washington, DC: U.S. Department of Transportation.

Cheaney, E.S., and Billings, C.E., (1981). Application of the epidemiological model in studying human error in aviation. NASA Ames Research Center. Moffett Field, CA

Cooper, S.E., Ramey-Smith, A.M., Wreathall, J., Parry, G.W., Bley, D.C., Luckas, W.J., Taylor, J.H., and Barriere, M.T. (1996). *A technique for Human Error Analysis (ATHEANA) – technical basis and method description. NUREG/CR-6350*, United States Nuclear Regulatory Commission, Washington, D.C.

Cushing, S. (1995) Pilot-Air Traffic Communication- It's not (only) what you say, it's how you say it. *Flight Deck*, Winter 1995/6.

Dekker, Sidney (2005). *Ten questions about human error: a new view of human factors and system safety*. New York. Routledge.

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References

Dupont, V., Bestgen, Y. (2006). Learning from technical documents: The role of intermodal referring expressions. *Human Factors*. Vol. 48, no. 2, pp. 257-264

Endsley, M. (1988). Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON), 789-795. New York: IEEE

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors. 37(1), 32-64.

Endsley, M.R., Bolte, B., and Jones, D.G., (2003). Designing for Situation Awareness: An Approach to User-centered design. New York & London: Taylor and Francis

Endsley, M.R., and Kaber, D.B., (1999). Level of Automation Effects on Performance, Situation Awareness and Workload in Dynamic Control Task. Ergonomics. 42, (3)., p. 462-492.

Ernst Mach (1905), Erkenntnis und Irrtum (Knowledge and Error, English edition, 1976), Netherlands: Dordrecht, Reidel

Fitts, P.M. (1954) The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47, 381-391.

Grayson, R.L. and Billings, C.E. (1981) Information Transfer Between Air Traffic Control and Aircraft: Communication Problems in Flight Operations, Information Transfer Problems in Aviation Systems. NASA Rep. TP-1875 , NASA Ames Research Center. Moffett Field, CA.

Helmreich, R.L. and Merritt, A.C. (1998) *Culture at Work in Aviation and Medicine*. Ashgate Publishing: Aldershot.

Johnson, R.C., Thomas, D.L., Martin, D.J. (1977). *User acceptance and usability of the C-141 job guide technical order system-Final Report*. Brooks Air Force Base, TX: Air Force Human Resources Lab.

Hollnagel, Woods and Leveson. (2006). *Resilience Engineering: Concepts and Percepts.*

References

Meshkati, N. (1991). Human Factors in Large-Scale Technological Systems; Accidents: Three Mile Island, Bhopal, Chernobyl., Industrial Crisis Quarterly, 5, 133-154

Meshkati, N. (1991). Integration of Workstation, Job and Team Structure design in complex human-machine systems: A framework. International Journal of Industrial Ergonomics, 7, 111-120

McCoy, W.E. and Funk, K.H. (1991). Taxonomy of ATC Operator errors based on a model of human information processing. In R.S. Jensen (Ed), Proceedings of the Sixth International Symposium on Aviation Psychology, 29 April to 2 May, Columbus, Ohio.

Miller,G.A. (1956) The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

MIL-STD-1472F - Department of Defense *Design Criteria Standard: Human Engineering*, Department of Defense, (2003)

Norman, D. (1998, 2002) *The Design of Everyday Things*. New York. Basic Books.

Perrow, C. (1984). Normal Accidents. Living with High-Risk Technologies. New York. Basic Books

Rasmussen, Jens., Pejtersen, A. M., and Goodstein, L.P., (1994). *Cognitive Systems Engineering*, John Wiley & Sons, New York, New York.

Rasmussen, Jens. (1983). *Skills, Rules and Knowledge; Signals, Signs and Symbols and other distinctions in human performance models.* IEEE Transactions on systems, man and cybernetics. Vol. SMC-13, No. 3, May/June 1983.

Reason, James (1990). *Human Error.* Cambridge University Press.

Reason, J., and Hobbs, A. (2003). Managing Maintenance Error. A Practical Guide. Burlington, VT: Ashgate.

Reason, J, "Human error: models and management," BMJ 2000; 320:768-770

References

Smith, Timothy P. (2005). *Human Factors Review of Restraint Failures on Mobile Amusements Rides*. Division of Human Factors, U.S. consumer Product Safety Commission. *http://www.cpsc.gov/LIBRARY/FOIA/FOIA05/os/amusrest.*

Spurgin, A.J., Lydell, B.D., Hannaman, G.W. and Lukic, Y. (1987). *Human Reliability Assessment: A Systematic Approach*. In Reliability '87, NEC, Birmingham, England.

Swain, A.D. (1982). Modelling of response to nuclear power plant transients for probabilistic risk assessment. Proceedings of the 8th Congress of the International Ergonomics Association, Tokyo, August, 1982.

Swain, A.D. and Guttmann, H.E. (1983). A handbook of human reliability analysis with emphasis on nuclear power plant applications. NUREG/CR-1278, USNRC, Washington, DC 20555.

Vesper, J.L. (2003). *Writing Procedures That Contribute to Performance.* Learning Plus Inc., Rochester, N.Y. Vincente, Kiln J. and Rasmussen, Jens. (1988). *A Theoretical Framework for Ecological Interface Design*. Riso Report M-2736, August 1988. ISBN 87-550-1459-3. Riso National Laboratory, DK-4000 Roskilde. Denmark.

Vicente, Kim. (2006). The Human Factor. Revolutionizing the way people live with technology. New York & London, Routeledge.

Welford, A.T. (1960) The measurement of sensory-motor performance: Survey and re-appraisal of twelve years progress. Ergonomics, 3, 189-230.

Wickens, C. (1984). Engineering Psychology and Human Performance. Columbus, OH, USA: Charles E. Merrill.

Wickens, C. (1992). Engineering Psychology and Human Performance (Second Edition). New York: Harper-Collins.