On Regarding C2 Systems & Users as Fallible ePartners

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Outline

Goal:
• To propose research programme into fallibility in C2, C2 systems, & users

Structure:
• Motivation
• 21st century C2 systems
• Fallibility of C2 systems & users
• Managing fallibility
• Applying ePartner approach
• R&D and experimentation needed
Introducing myself

Qualifications:
• BSc Aeronautical Engineering, Bristol, UK
• Defence Fellowship (Masters), Brunel, UK
• PhD Artificial Intelligence, Maastricht, NL

Experience:
• 1966-87: Royal Air Force officer, UK & SG
• 1987-2004: Consultant, Atos Origin, NL: Dutch-French ICT company
• 2001-date: Professor, U. Pretoria, ZA: Computer Science Department
• 2004-date: Professor, NLDA, Breda, NL: Operational ICT & Communications
Motivation

NCW tenets ("value chain"):  

- Better networks
- Better sharing
- Better understanding
- Better decisions
- Better effects
- Better actions
- Effects superiority
- Agile, improved tempo
- Decision superiority

But what if information being shared is erroneous?

Robust
More secure
More extensive
Knowledge superiority
Information superiority

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21st century C2 systems (1)

Traditional C2:

• Based on rational decision making:
  N.B. rational = choosing best immediate outcome
  Option selection is central
  PRO: optimal
  CON: needs perfect information; no time pressure

• Organizational decomposition:
  Hierarchy; specialisations; stove-pipes
  PRO: simple to implement
  CON: wicked problems are not decomposable

• Restricted communication:
  Technological & security restrictions
  Reporting chain; need to know principle
  PRO: minimise comms links; control information flow
  CON: delay; learn jargon; informal comms poorly supported

Raiffa, 1968
21st century C2 systems (2)

Information-age C2:

• Rational -> naturalistic decision making:
  - Situation assessment central
  - Based on knowledge & experience
  - PRO: agile; satisficing
  - CON: open to error; fails in novel situations

• Decomposition -> networked organization:
  - Information sharing (push, smart pull) central
  - PRO: wicked problems handled collaboratively
  - CON: complicated to implement; sharing intent

• Restricted -> free communication:
  - Information flows to nodes that can process it
  - PRO: fast; self-organizing
  - CON: bandwidth; culture; conflicts need-to-know

Klein, 1999
21st century C2 systems (3)

C2 systems

Sense-making & Decision-making

Understanding

Situation Awareness

Situation Assessment

Battlespace Management

Battlespace Monitoring

Operating Environment

Command Intent

Information Domain

Generation & Dissemination of Orders

Physical Domain

Synchronization

Cognitive & Social Domain

Alberts, 2001

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21st century C2 systems (4)

Military Command Team Effectiveness (CTEF):

- Mission framework
- Task
- Organisation
- Leader
- Team member
- Team

**CONDITIONS**

**PROCESSES**

**OUTCOMES**

- Task focused behaviours
- Team focused behaviours
- Task outcomes
- Team outcomes

**Task model**

(Task model (eg OODA))

**Team model**

- AAR
- Process adjustment loop
- Conditions adjustment loop
- Organisational learning loop

Essens et al, 2005 (NATO RTO HFM-087)

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Fallibility of C2 systems & users (1)

Fallibility:

• Environment
• Hardware & software:
  Platform
  C2 system
• Human users
• Organization / system
• Propagation of errors through network
Fallibility of C2 systems & users (2)

Environment - complexity & uncertainty:

- Characteristics of environment:
  - Goals & task ill-defined, change over time, & may conflict
  - Conditions dynamic
  - Multiple players
  - Closed loop between actions & feedback
  - Real-time
  - Time stress
  - High stakes
  - Decision makers are experts
  - Organizational goals & norms

- Wicked problem:
  - Incomplete, contradictory, changing requirements
  - Solution to one problem creates another problem

Klein & Klinger, 1991
Rittel & Webber, 1973
Fallibility of C2 systems & users (3)

Hardware & software:

- **Hazard rate**
  - Infant mortality phase
  - Random failure phase
  - Wear-out phase

- Maintenance / requirements change
- Hardware
- Software

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Fallibility of C2 systems & users (4)

Human user errors:
- Mistake:
  Error made during planning
- Slip (action) / lapse (memory):
  Error made during execution

Research into human error:
- Mostly into slips & lapses:
  Phenotypes:
  - How slips appear when expressed as actions
  Genotypes:
  - Mechanisms assumed to be cause of slips
- Mistakes usually have more severe consequences
- Some into deliberate violation of rules / SOPs

Norman, 1981

Norman, 1993

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Fallibility of C2 systems & users (5)

Organizational / system errors:
• Person versus system approach to error
• System errors:
  Operational constraints
  Resource constraints
  Vague policies
  Culture
  Groupthink
  Normalization of deviance
  Organizational drift / mission creep

Reason, 2000
Janus, 1983
Vaughn, 1996
Snook, 2000
Fallibility of C2 systems & users (6)

Network resilience:
• Robust to removal of random nodes
• Removal of highly-connected nodes is devastating

Error propagation:
• Epidemiological processes:
  Diseases, viruses, rumours:
  • Regard erroneous information as disease, virus, or rumour
  Original models assumed fully-connected networks
  Partly-connected networks give disease clusters
  In power-law networks diseases always propagate:
  • Internet shown to be power-law network
• Controlling error propagation:
  Vaccination of highly-connected nodes most effective
  Problem is knowing which nodes are highly-connected

Newman, 2003

Callaway et al, 2000

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Managing fallibility (1)

Defence in depth:
- Swiss cheese model

High reliability organizations (HROs):
- Preoccupation with failure
- Reluctance to simply interpretations
- Sensitivity to operations
- Commitment to resilience
- Deference to expertise

Crew Resource Management (CRM):
- Aviation analogue
- Threat & error management model (TEMM)
- Cultural influences

Reason, 2000
Weick & Sutcliffe, 2001
Helmreich, 2000
Managing fallibility (2)

Latent threats
Scheduling, vague policies, culture: national, organisational, professional

Immediate threats
Environmental, organisational, individual, team/crew, & PUC factors

Threat management strategies & countermeasures

Error management

Error → Detection & response → Induced PUC state → Management of PUC state → Inconsequential → Adverse outcome

Helmreich, 2000
Applying ePartner approach (1)

Human partners:
- Come to know each other’s qualities & foibles
- Anticipate other partner’s needs & behaviour
- Adjust support for partner depending on situation
- Detects & mitigates other partner’s errors

Set of partners:
- Complex Adaptive System

*Morowitz & Singer, 1995*
Applying ePartner approach (2)

ePartner concept:
- User & system as partners:
  Instead of supervisor-subordinate or even master-slave
- Requires additional capabilities of system:
  Sensing mental state:
    - Facial expression & voice analysis
    - Physiological measures
  Sensing context
  Modelling user’s cognitive task load
  Multi-modal HCI

Neerincx, 2003a/b
Applying ePartner approach (3)

Applying ePartner concept to C2 systems:
- Incorporate sensors
- Input information regarded as potentially erroneous:
  Fault detection, isolation & recovery (FDIR) in each node
- Manage fallibility using TEMM
- CRM training for users

Space analogue:
- Astronaut-rover teams on Mars
- MECA project:
  For European Space Agency
  See www.CrewAssistant.com
R&D and experimentation needed (1)

Research:

- **Human error in C2:**
  What are threats, types of error, & countermeasures in C2?
- **C2 system connectivity:**
  Do C2 networks follow power law?
- **Erroneous planning:**
  Do human planners make errors? Why? What do they look like?
- **Operationalizing Wieckian sensemaking:**
  How do experts make sense of novel situations?
  Can this be turned into algorithm / decision support?
- **Cognitive engineering:**
  How can cognitive engineering be adapted to C2 systems?
- **Surprising the enemy:**
  Can we harness Murphy’s law to exploit enemy errors?
- **Widening concept of security:**
  What are the commonalities between security & RAMS?
R&D and experimentation needed (2)

Experimentation:
- Structure of C2 systems:
  How can C2 networks be structured to maximise difficulty for enemy to identify key nodes & links?
- Interaction between ePartners & users:
  How do ePartners & users interact?
  What should be included in user education & training?

Development:
- Test-bed:
  Develop test-bed with failure/error injection
  Extend test-bed to become training environment
- C2 system architectures:
  Develop failure-/error-tolerant C2 system architecture
Any questions?