AI-ENABLED AUTONOMOUS CASUALTY EVACUATION IN LARGE-SCALE COMBAT OPERATIONS: LESSONS LEARNED AND FUTURE RESEARCH DIRECTIONS

Lessons Learned From Modern Large-Scale Combat Operations

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Disclosure
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KEY CONCLUSIONS

Modern Warfare

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New Operational Problems

↓

Volunteer Innovation

↓

Technological Evolution

↓

Need for AI

↓

Future Autonomous Medical Systems

- Route Optimized ✓
- Threat Detection ✓
- GPS Denied ✓
- Communication Denied ✓
- Autonomous Mode ✓
- Casualty Monitoring ✓

The future of casualty evacuation lies in **intelligent autonomous systems** rather than increasingly complex remote-controlled vehicles.

MODERN BATTLEFIELD

A NEW OPERATIONAL REALITY

Key Challenges

- FPV drones
- Electronic warfare
- Persistent surveillance
- GPS denial
- Thermal imaging

TECHNOLOGY EVOLUTION

The Evolution of Casualty Evacuation on the Modern Battlefield

1. HUMAN EVACUATION

- High risk to personnel
- Slow and exhausting
- Limited by terrain, exposure and endurance
- Not scalable

2. VOLUNTEER INNOVATION

- Grassroots ingenuity
- Low-cost solutions
- Rapid field adaptation
- Single-use or limited capability

3. REMOTE-CONTROLLED UGV

- Removes operator from danger
- Limited by radio range and EW
- Susceptible to detection and jamming
- Payload and autonomy still limited

4. FIBRE OPTIC CONTROL

- Immune to EW and jamming
- Secure, reliable command link
- Lightweight fibre optic tether (thin line)
- Extended range via fibre tether

5. AI-ASSISTED SYSTEMS

- AI enhances navigation and obstacle avoidance
- Improved situational awareness
- Health monitoring integration
- Human remains in the decision loop

6. FULLY AUTONOMOUS SYSTEMS

- No human in the loop
- Operates in GPS-denied, EW-contested environments
- Dynamic route planning and threat avoidance
- Continuous casualty monitoring and care

LOW — CAPABILITY & AUTONOMY — HIGH

REDUCED RISK TO PERSONNEL	FASTER EVACUATION	RESILIENT TO EW AND JAMMING	CONTINUOUS CARE AND MONITORING	ADAPTIVE AND SCALABLE	MISSION EFFECTIVENESS

THE FUTURE OF CASUALTY EVACUATION LIES IN **INTELLIGENT AUTONOMOUS SYSTEMS** RATHER THAN INCREASINGLY COMPLEX REMOTE-CONTROLLED VEHICLES.

TECHNOLOGY EVOLUTION

1. HUMAN EVACUATION
2. VOLUNTEER INNOVATION
3. REMOTE-CONTROLLED UGV
4. FIBRE OPTIC CONTROL
5. AI-ASSISTED SYSTEMS
6. FULLY AUTONOMOUS SYSTEMS

First Generation

Volunteer-Built Systems

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Russian Volunteer Cart

Manually built by volunteers.
Radio-controlled. Used for battlefield evacuations.

Ukrainian Volunteer Cart

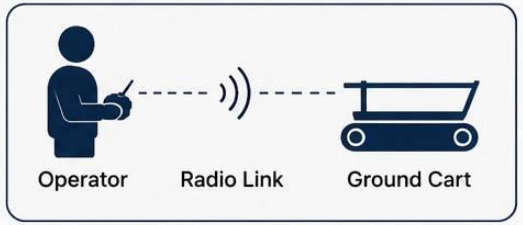
Manually built by volunteers.
Radio-controlled. Used for battlefield evacuations.

Advantages

- Low cost
- Rapid deployment
- Reduced rescuer exposure

Limitations

- Radio-dependent
- Operator-dependent
- No autonomy



FIRST GENERATION:

VOLUNTEER-BUILT SYSTEMS

1. Russian volunteer cart
2. Ukrainian volunteer cart

ELECTRONIC WARFARE

The New Battlefield Constraint

STARLINK-ENABLED SATELLITE-CONTROLLED EVACUATION PLATFORM

Representative Ukrainian Armed Forces system for casualty evacuation under electronic warfare conditions

Low-cost, adaptive unmanned ground systems can support casualty evacuation when communications and mobility are degraded by electronic warfare.

KEY SPECIFICATIONS

Operating weight:	~772 lb
Range:	up to 24.9 mi
Top speed (loaded):	2.5 mph
Top speed (unloaded):	4.7 mph
Drive power:	2 × 2.0 hp
Battery capacity:	300 Ah
Communications:	Analog, ELRS, LTE, Starlink
Cameras:	Digital, front and rear
Dimensions (H × W × L):	54.3 × 44.1 × 53.5 in

SATELLITE-ENABLED ROBOTIC CASUALTY EVACUATION PLATFORM

Representative Ukrainian Armed Forces unmanned ground system for casualty evacuation under electronic warfare conditions

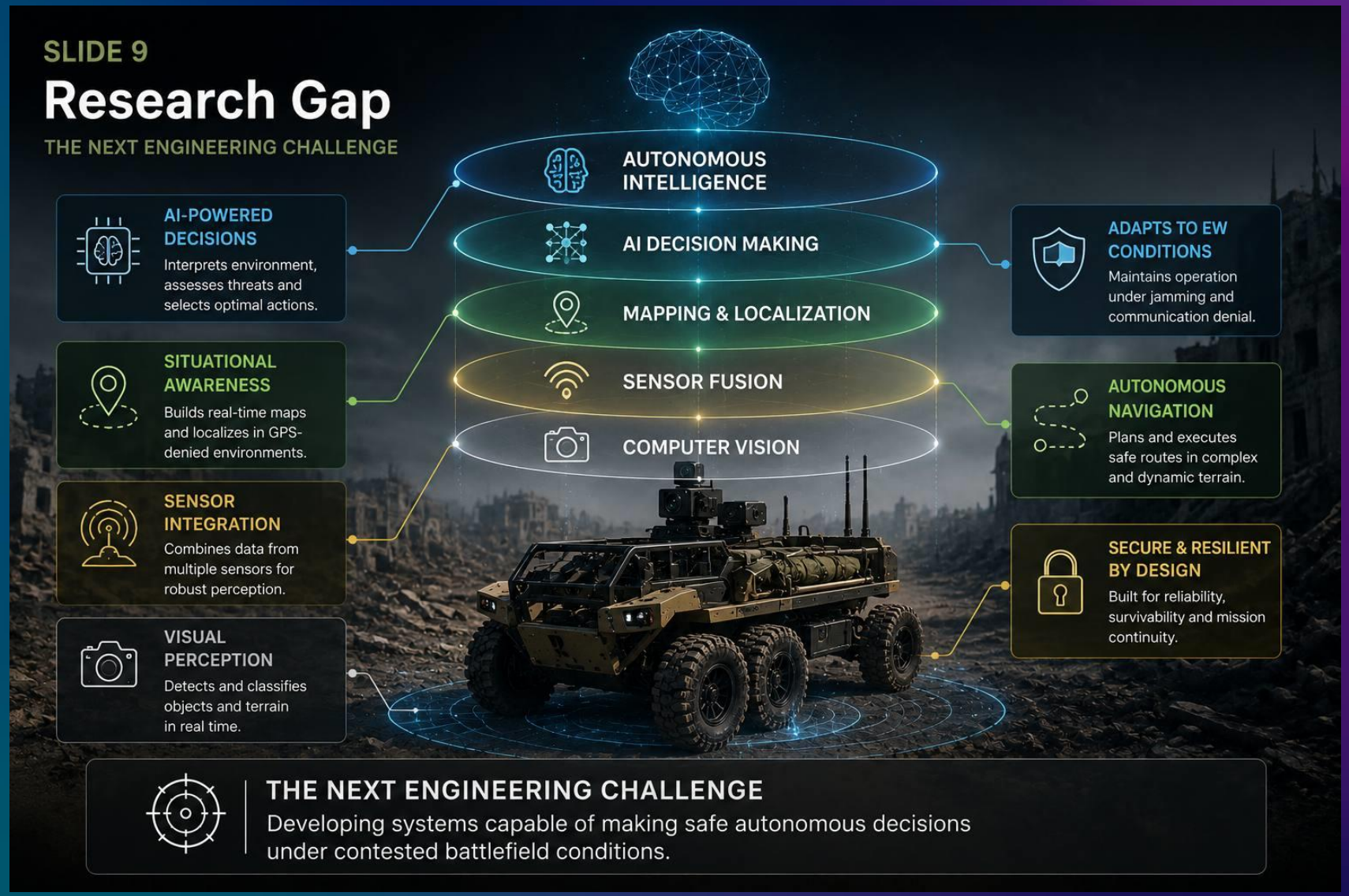
FIBER-OPTIC CONTROL

Radio → Fiber-Optic → AI Autonomy

SLIDE 9

Research Gap

THE NEXT ENGINEERING CHALLENGE



THE NEXT ENGINEERING CHALLENGE

Future breakthroughs will depend primarily on autonomous intelligence rather than further mechanical improvements.

SLIDE 10

Proposed Research Direction

AI-CENTERED AUTONOMOUS CASUALTY EVACUATION

1 **ARTIFICIAL INTELLIGENCE**
Perception, learning and reasoning

2 **MISSION PLANNING**
Goal generation, resource allocation, and constraints

3 **NAVIGATION**
Localization, path planning, and obstacle avoidance

4 **THREAT ASSESSMENT**
Detect and analyze threats and risks in real time

5 **MEDICAL SUPPORT**
Patient monitoring, stabilization, and health management

6 **ADAPTIVE DECISION MAKING**
Re-plan, reprioritize, and respond to changing conditions

7 **TEAM COORDINATION**
Coordinate with multiple assets and operators

8 **COMMS & DATA MANAGEMENT**
Secure comms, data fusion, and network resilience

9 **EXECUTION & CONTROL**
Mission execution and real-time supervision

AUTONOMOUS BY DESIGN
AI orchestrates the full mission from planning to execution.

HUMAN-MACHINE TEAMING
Operator remains in the loop for oversight and exception handling.

SCALABLE & MODULAR
Architecture supports future capabilities and platform growth.

SAFE & RELIABLE
Designed for reliability, resilience and mission continuity in contested environments.

THE VEHICLE BECOMES A PLATFORM.
AI BECOMES THE MISSION COMMANDER.

PROPOSED RESEARCH DIRECTION

AI-CENTERED AUTONOMOUS CASUALTY EVACUATION

SLIDE 11

AI System Architecture

Conceptual Research Framework

AI CORE

Mission Intelligence Engine

Fuses multi-domain data, reasons about mission objectives, and drives adaptive autonomous decision-making.

NAVIGATION

Localization, path planning, terrain analysis, and obstacle avoidance.

THREAT ANALYSIS

Detects, classifies, and prioritizes threats using multi-sensor fusion.

MEDICAL AI

Assesses casualties, prioritizes care, and recommends interventions.

COMMUNICATIONS

Maintains secure links, shares data, and ensures network resilience.

MISSION PLANNING — Generates mission plan, allocates resources, and sets execution strategy.

EMERGENCY RECOVERY — Detects failures, reroutes assets, and maintains mission continuity.

CONTINUOUS LEARNING — Learns from mission outcomes and updates models for future performance.

ARTIFICIAL INTELLIGENCE BECOMES
THE CENTRAL MISSION MANAGEMENT SYSTEM.

AI-CENTRIC MISSION MANAGEMENT

AI becomes the central mission management system.

INTEGRATED MULTI-DOMAIN DATA

Unified processing of navigation, threat, medical, and comms data.

ADAPTIVE & RESILIENT

Adapts to dynamic conditions and recovers from disruptions.

SECURE & RELIABLE

Built with security, redundancy, and fault tolerance in miind.

SCALABLE ARCHITECTURE

Modular design supports future capabilities and platform growth.

AI SYSTEM ARCHITECTURE

Conceptual Research Framework

SLIDE 12

Autonomous Navigation

Beyond Remote Control

AI EVALUATES • ADAPTS • EXECUTES

1. **MISSION** — Receive mission objectives and constraints.
2. **TERRAIN ANALYSIS** — Analyze terrain and environment using sensors and maps.
3. **THREAT ANALYSIS** — Detect and assess threats and potential hazards.
4. **SAFE ROUTE GENERATION** — Compute optimal routes that balance safety and efficiency.
5. **CONTINUOUS REPLANNING** — Monitor changes and dynamically adjust the plan.
6. **MISSION COMPLETION** — Arrive at objective and confirm mission success.

CONTINUOUS FEEDBACK LOOP

AI EVALUATES

- ✓ **TERRAIN** — Slope, roughness, obstacles, traversability.
- ✓ **FPV RISK** — Probability of FPV drone detection and engagement.
- ✓ **THERMAL EXPOSURE** — Heat signature and exposure to thermal sensors.
- ✓ **EW ACTIVITY** — Electronic warfare threats and signal interference.
- ✓ **NATURAL COVER** — Vegetation, structures and concealment.
- ✓ **ALTERNATIVE ROUTES** — Multiple route options evaluated in real time.

NAVIGATION BECOMES A CONTINUOUS DECISION-MAKING PROCESS RATHER THAN SIMPLE VEHICLE CONTROL.

AUTONOMOUS NAVIGATION

Beyond Remote Control

SLIDE 13

AI-Assisted Medical Support

INTELLIGENT CARE IN THE FIELD

1. **CASUALTY** — Detect and identify casualty and severity.
2. **VOICE DIALOGUE** — Establish voice communication and collect information.
3. **AI ASSESSMENT** — AI analyzes vital signs, symptoms and context.
4. **DECISION SUPPORT** — AI recommends actions and treatment priorities.
5. **CONTINUOUS MONITORING** — Continuously tracks patient status and response to care.
6. **MEDICAL TEAM HANDOVER** — Securely transfer data and hand over to medics.

AI VITAL ASSESSMENT

Heart Rate	112 bpm
Respiration	24 /min
SpO_2	93 %
Blood Loss	Moderate
Consciousness	Alert Alert / Oriented
Pain Level	6 /10

AI RECOMMENDATION

- Control bleeding
- Pain management
- Monitor vitals
- Prepare for extraction

DATA SECURELY SHARED WITH MEDICAL TEAM

ARTIFICIAL INTELLIGENCE SUPPORTS MEDICAL DECISION MAKING
WITHOUT REPLACING CLINICAL JUDGMENT.

RESEARCH TOPICS

VOICE INTERACTION
Natural, reliable communication in noisy and stressful environments.

CONSCIOUSNESS ASSESSMENT
Detecting level of consciousness and cognitive status.

BLEEDING ASSESSMENT
AI-based estimation of bleeding severity and physiological impact.

DECISION SUPPORT
Evidence-based recommendations for life-saving interventions.

REMOTE MEDICAL GUIDANCE
Real-time expert guidance through secure communication.

FUTURE MODULAR MEDICAL INTEGRATION
Plug-and-play medical modules for scalable capabilities.

AI-ASSISTED MEDICAL SUPPORT

INTELLIGENT CARE IN THE FIELD

SLIDE 14

Adaptive Mission Management

DYNAMIC RESPONSE TO CHANGING CONDITIONS

REAL-TIME INPUTS

MISSION STATUS
Progress, objectives, constraints.

THREAT CHANGES
New threats, level, location, type.

COMMUNICATION STATUS
Link quality, availability, jamming, outages.

VEHICLE STATUS
Health, energy, sensors, payload, mobility.

CASUALTY STATUS
Condition, priority, stability, risks.

AI DECISION ENGINE

SITUATION ANALYSIS
Fusion of multi-source data and contextual understanding.

ADAPTIVE REASONING
Predict outcomes, evaluate risks and opportunities.

PRIORITY OPTIMIZATION
Balance mission success, safety and resource usage.

AI MAY CHOOSE TO

CONTINUE
Proceed with the current mission plan.

PAUSE
Temporarily hold operations and reassess.

HIDE
Move to concealment or reduce visibility.

CHANGE ROUTE
Replan path to improve safety or efficiency.

SWITCH COMMUNICATION
Change channel, network or communication mode.

RETURN
Abort mission and return to base.

REQUEST ASSISTANCE
Call for support or additional resources.

CONTINUE AUTONOMOUSLY
Operate independently without external input.

OUTCOME

MISSION ADAPTED
Objectives adjusted to current conditions.

RISK MITIGATED
Threats reduced, safety improved.

RESOURCE OPTIMIZED
Energy, time and assets used effectively.

MISSION SUCCESS
Achieve goals while protecting lives.

MISSION EXECUTION BECOMES **ADAPTIVE** RATHER THAN PREDETERMINED.

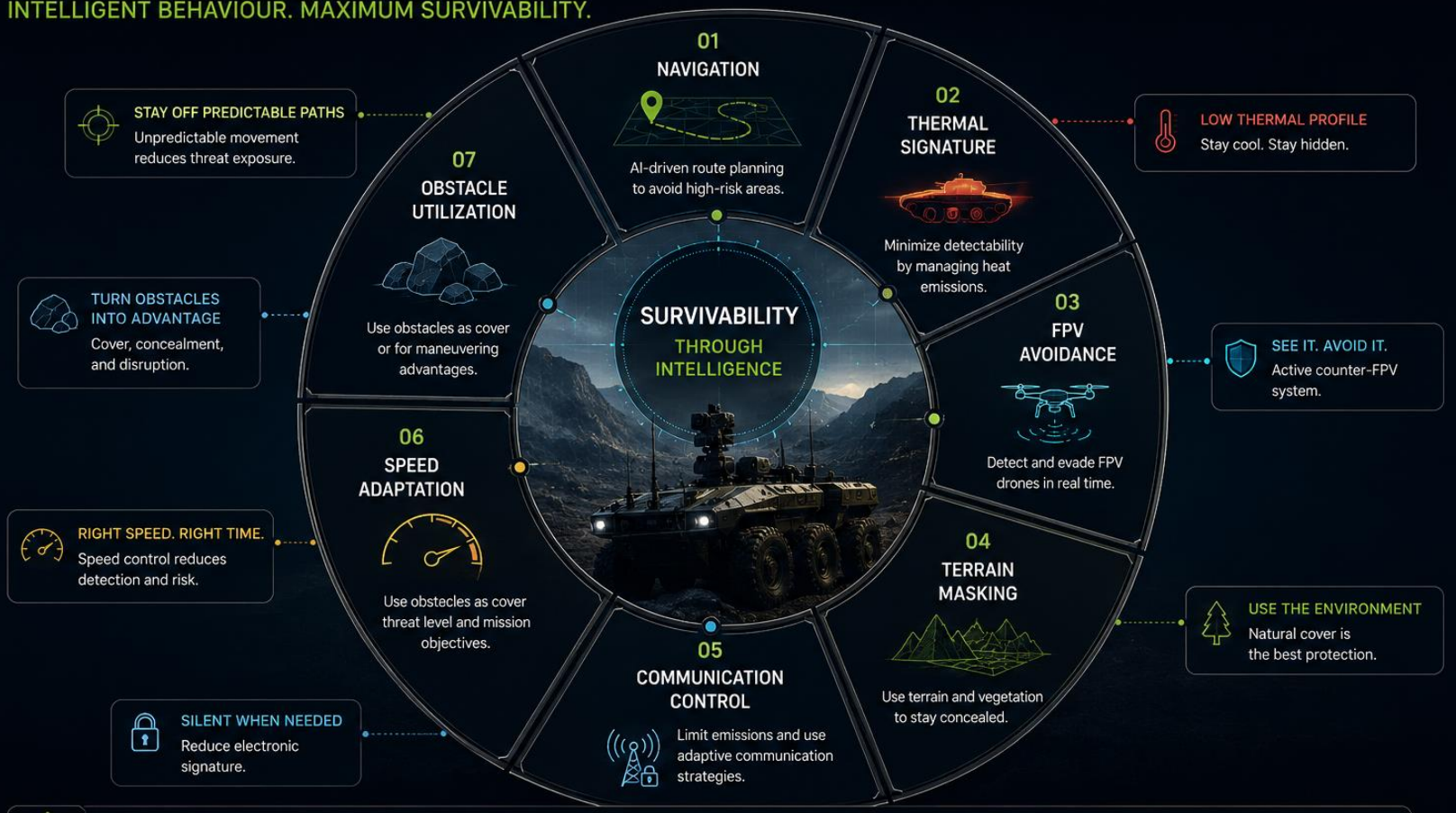
ADAPTIVE MISSION MANAGEMENT

DYNAMIC RESPONSE TO CHANGING CONDITIONS

SLIDE 15

Survivability Through Intelligence

INTELLIGENT BEHAVIOUR. MAXIMUM SURVIVABILITY.



STAY OFF PREDICTABLE PATHS
Unpredictable movement reduces threat exposure.

LOW THERMAL PROFILE
Stay cool. Stay hidden.

TURN OBSTACLES INTO ADVANTAGE
Cover, concealment, and disruption.

SEE IT. AVOID IT.
Active counter-FPV system.

RIGHT SPEED. RIGHT TIME.
Speed control reduces detection and risk.

USE THE ENVIRONMENT
Natural cover is the best protection.

SILENT WHEN NEEDED
Reduce electronic signature.

FUTURE SURVIVABILITY DEPENDS MORE ON INTELLIGENT BEHAVIOUR THAN ON ARMOUR ALONE.

SURVIVABILITY THROUGH INTELLIGENCE

INTELLIGENT BEHAVIOR.
MAXIMUM SURVIVABILITY

SLIDE 16

Communication Hierarchy

FROM CONNECTED TO COMPLETELY AUTONOMOUS

HIGH RELIANCE ON COMMUNICATION

PARTIAL COMMUNICATION

NO RELIANCE ON COMUNICATION

01 OPERATOR RADIO

Direct voice and data link with human operator.

EXAMPLES: VHF/UHF Radio · Voice Comm · Data Link

RELIABILITY: ●●●●○ HIGHEST

02 FIBRE OPTIC

High-bandwidth, low-latency secure data connection.

EXAMPLES: Tactical Fibre · Encrypted Data · High Bandwidth

RELIABILITY: ●●●○○ HIGH

03 AUTONOMOUS MODE

Mission execution with intermittent or limited communication.

EXAMPLES: Intermittent Link · Store & Forward · Local Coordination

RELIABILITY: ●●○○○ MEDIUM

04 SILENT AI MISSION

No communication. AI makes all decisions independently.

EXAMPLES: No Emissions · Onboard AI · Mission Execution

RELIABILITY: ●●○○○ LOW

05 NO COMMUNICATION POSSIBLE

Complete comms blackout. Operate to mission end-state.

EXAMPLES: GPS-Denied · Comms Jammed · Mission Completion

RELIABILITY: ●○○○○ LOWEST

COMMUNICATION GRADUALLY BECOMES OPTIONAL RATHER THAN MANDATORY.

FUTURE AI SYSTEMS PRIORITIZE MISSION SUCCESS EVEN WHEN COMMUNICATION IS IMPOSSIBLE.

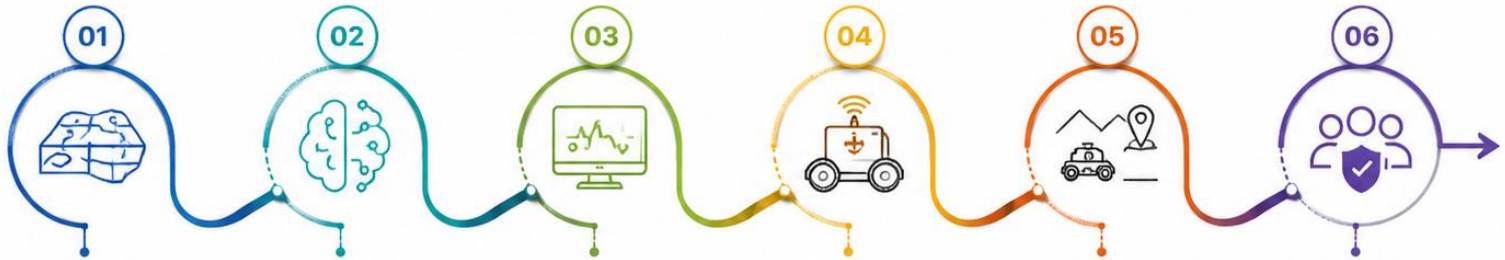
COMMUNICATION HIERARCHY

FROM CONNECTED TO COMPLETELY AUTONOMOUS

SLIDE 17

Future Research Roadmap

A MULTIDISCIPLINARY RESEARCH PROGRAMME
RATHER THAN A SINGLE ENGINEERING PROJECT.



01 BATTLEFIELD ANALYSIS

- Study real-world evacuation scenarios
- Threat modelling
- Environmental characteristics
- Mission requirements definition

02 AI ALGORITHMS

- Path planning and replanning
- Threat detection and avoidance
- Decision-making under uncertainty
- Multi-agent coordination
- Medical decision support

03 SIMULATION

- High-fidelity environment modelling
- AI and system simulation
- Scenario testing
- Performance evaluation
- Iterative improvement

04 PROTOTYPE

- Hardware development
- Sensor integration
- Embedded systems and autonomy
- Safety and reliability testing
- System validation

05 FIELD EVALUATION

- Real-world trials
- Mission performance assessment
- Human factors evaluation
- Robustness testing
- Feedback collection

06 OPERATIONAL INTEGRATION

- Doctrine and procedure development
- Training and usability
- Logistics and support
- Large-scale deployment
- Continuous improvement

DEFENCE STUDIES | ARTIFICIAL INTELLIGENCE | ROBOTICS & AUTONOMY | MEDICAL SCIENCES | COMMUNICATIONS ENGINEERING | SYSTEMS ENGINEERING

MULTIDISCIPLINARY COLLABORATION IS THE KEY TO FUTURE SUCCESS.

THE GOAL: SAVE MORE LIVES, COMPLETE MORE MISSIONS, WITH LESS RISK.

FUTURE RESEARCH ROADMAP

A MULTIDISCIPLINARY RESEARCH PROGRAM RATHER THAN A SINGLE ENGINEERING PROJECT

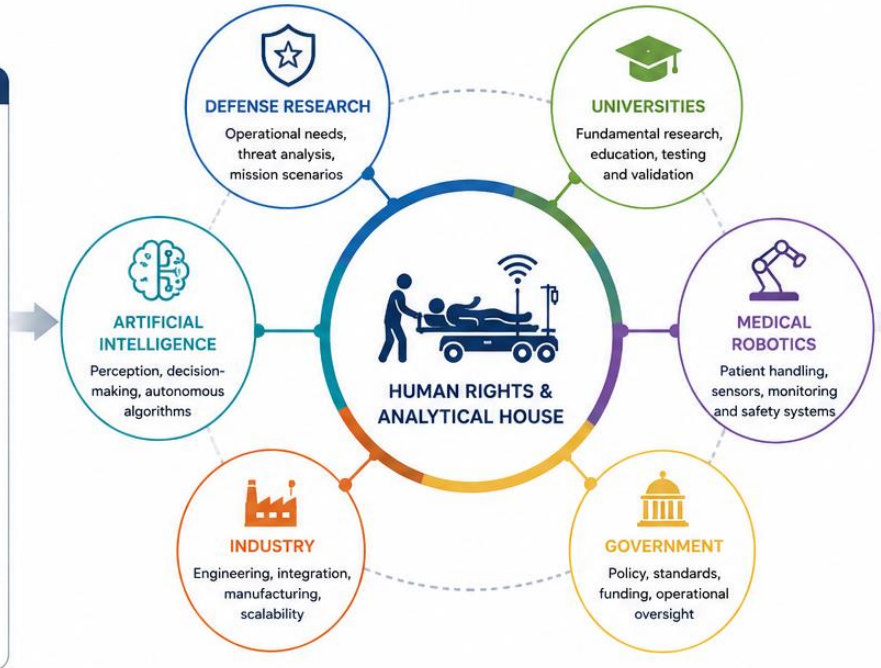
SLIDE 18

Research Collaboration

COLLABORATION ACROSS DISCIPLINES IS ESSENTIAL
FOR THE NEXT GENERATION OF CASUALTY EVACUATION SYSTEMS.

WE BRING TOGETHER

- **Defense Research** — Mission expertise, doctrine & requirements
- **Universities** — Research excellence, innovation & talent
- **Artificial Intelligence** — Advanced algorithms, machine learning
- **Medical Robotics** — Patient care technology, robotic systems
- **Industry** — Engineering capability, reliability & production
- **Government** — Strategic guidance, standards & funding



WE WORK TOGETHER ON

- **JOINT RESEARCH** — Multi-disciplinary teams solving real-world challenges
- **PROTOTYPE DEVELOPMENT** — Rapid iteration, integrated solutions
- **FUTURE GRANT PROGRAMS** — Building the foundation for long-term impact

COLLABORATION ENABLERS

- **Shared Vision** — Common goals for human-centred missions
- **Open Communication** — Transparent exchange of knowledge
- **Integrated Teams** — Bringing diverse expertise together
- **Ethical & Legal** — Human rights, safety and compliance
- **Continuous Learning** — Adapting and improving together

TOGETHER WE CAN DELIVER INTELLIGENT, RELIABLE AND HUMAN-CENTRED CASUALTY EVACUATION SOLUTIONS.

RESEARCH COLLABORATION

COLLABORATION ACROSS DISCIPLINES IS ESSENTIAL FOR THE NEXT GENERATION OF CASUALTY EVACUATION SYSTEMS

SLIDE 19

Key Conclusions

THE FUTURE OF CASUALTY EVACUATION LIES IN INTELLIGENT AUTONOMOUS SYSTEMS RATHER THAN INCREASINGLY COMPLEX REMOTE-CONTROLLED VEHICLES.

INTELLIGENCE. AUTONOMY. COMPASSION.
TOGETHER WE CAN SHAPE THE FUTURE OF CASUALTY EVACUATION.

KEY CONCLUSIONS

THE FUTURE OF CASUALTY EVACUATION LIES IN INTELLIGENT AUTONOMOUS SYSTEMS RATHER THAN INCREASINGLY COMPLEX REMOTE-CONTROLLED VEHICLES.

SLIDE 20

Thank You

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Why This Research Matters

Intelligent autonomous casualty evacuation systems have the potential to save more lives, reach more people and operate where it matters most — when and where no one else can.

THANK YOU

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