Mission Engineering in Healthcare and What We Can Apply to the Military

Richard Threlkeld
PhD candidate and Chief Technology Officer
rtv69@mst.edu

Dr. Cihan Dagli
Professor Founder and Director Systems Engineering Graduate Program

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY
Rolla, Missouri, U.S.A.

Presentation Outline

- AI Enabled Capability for Meta Complex System Architectures
- Integrating AI architectures with Complex Systems Architecting
- Mission Engineering for Donor Kidney Transplant Systems of Systems in healthcare
- Mission Engineering in the military
- What can we apply to the military and examples

AI Enabled Capability for Meta Complex System Architectures

The Meta-Architecture provides the structure of relationships that integrates the complex system.

It structures the appropriate balance to relieve tensions between the autonomy of subsystems and the integration of the complex system as a whole,

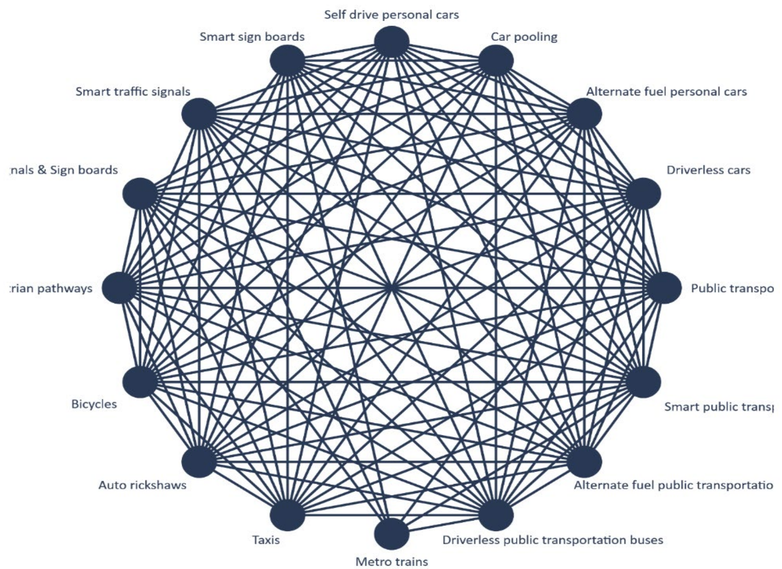
Purposeful design and self-organization, focus on maintaining stability or pursuing change .

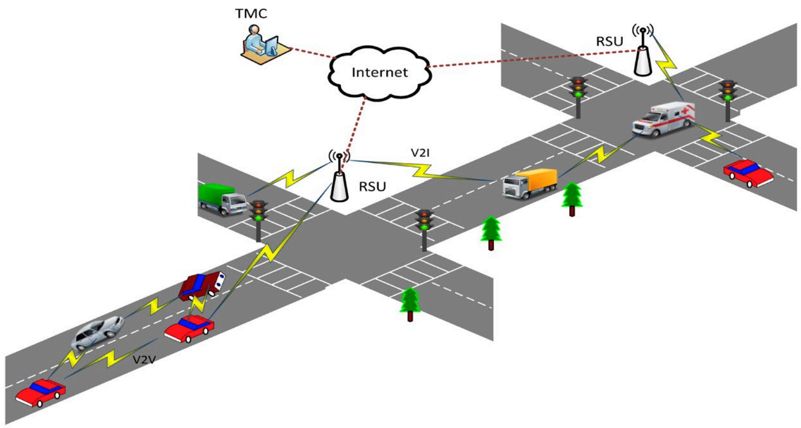
Emergence will produce those patterns/properties that are necessary to resolve structural tensions and maintain complex system viability.

Smart Engineering Systems Lab
Engineering Management and Systems Engineering Department

AI Enabled Capability for Meta Complex System Architectures

System	Vertex	Edge
Facebook	Person	Friendship
Brain	Neuron	Synapse
Air Traffic Network	Airports	Routes
Mission Focused System	System	System to system interfaces
World Wide Web	Websites	Hyperlinks





A complex system can be represented as a network where:

Elements ↔ vertices and Interactions ↔ edges

An edge between 2 vertices means they interact.

Integrating AI Architectures within Complex Systems Architecting

Organ Procurement Organization (OPO) System of Systems

Organ Procurement Organization (OPO)

- Not for profit organizations
- Recover organs
- Work with decedent's family to increase donation
- Assess donor potential
- Record donor characteristics
- Perform Match-run United Network for Organ Sharing (UNOS) UNet
- Present offers to transplant centers
- Perform histocompatibility
- Procure organs
- Deliver organs

Increase kidney utilization

Transplant Centers (TXCs)

Nephrology (outside of scope)

- Evaluate candidates
- Add candidate to waitlist

Transplant Surgeon (within scope)

- Assess organ offers (kidneys)
- Engage candidates in decision making (if potential)
- Add/remove candidates unfit for transplant
- Modify acceptance criteria
- Transplant organs (kidneys)

Post-transplant (outside of scope)

- Follow up with transplant recipient If Graft failure

Increase life-years gained

Waitlisted Candidates

- On dialysis
- Apply to get waitlisted
- Can be waitlisted in many TXCs (Benefit from donor-specific areas, TXC risk tolerance, average time on waitlist, etc.)
- Become potential transplant recipients (PTRs) if found compatible
- Evaluate Offer with Surgeon/Transplant Coordinator
- Blood work
  - If compatible, receive transplant
- If/when graft failure, get waitlisted
- Can/have transplanted many kidneys

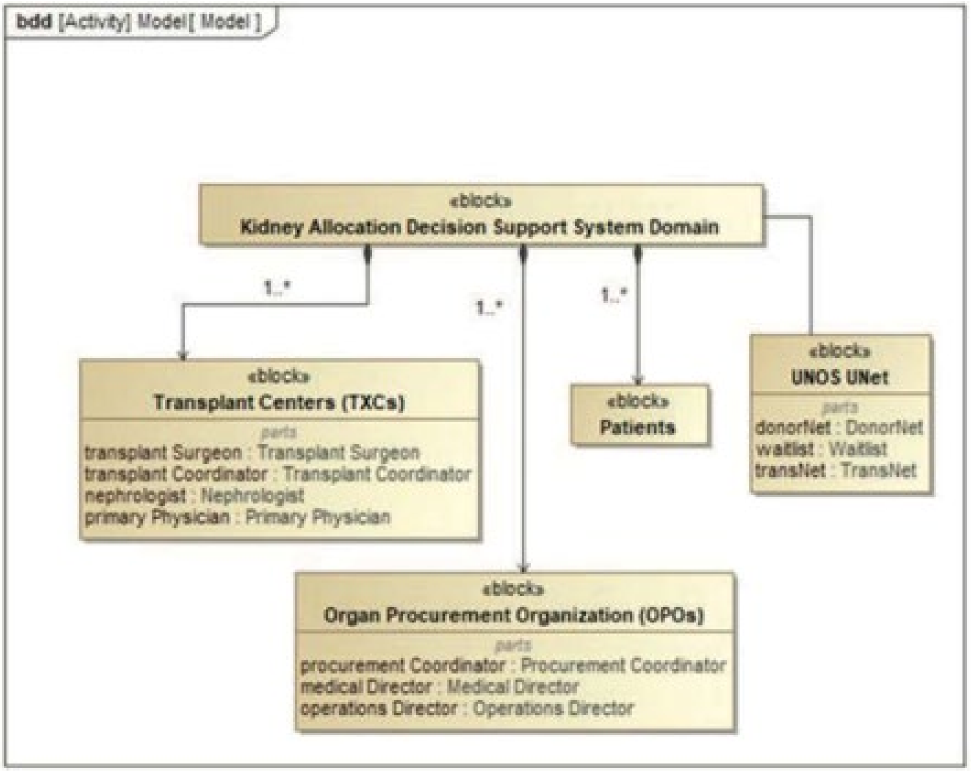
Increase Quality adjusted life years (QALYs)

Kidney Transplantation Domain Networks

Stakeholder Associations and System Boundaries

Stakeholders from five states

Roles within each block
- 57 OPOs
- 250 TXCs
- 11 Regions (UNOS)

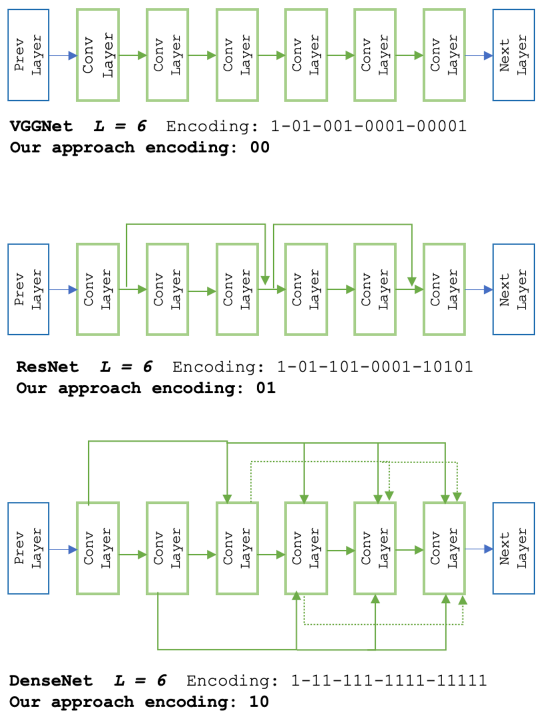


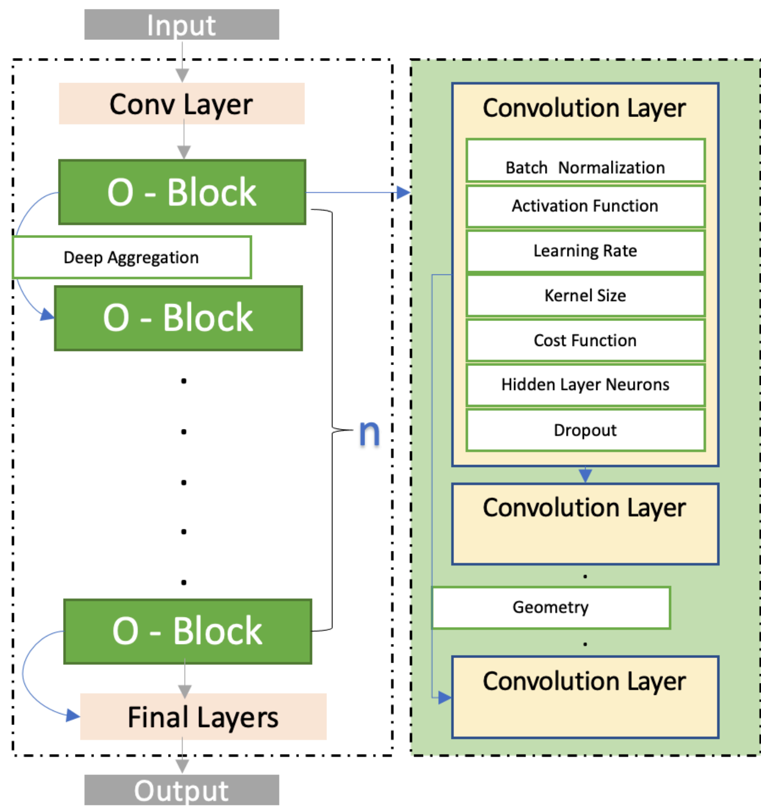
Integrating AI Architectures within Complex Systems Architecting

Deceased Donor Organ Assessment

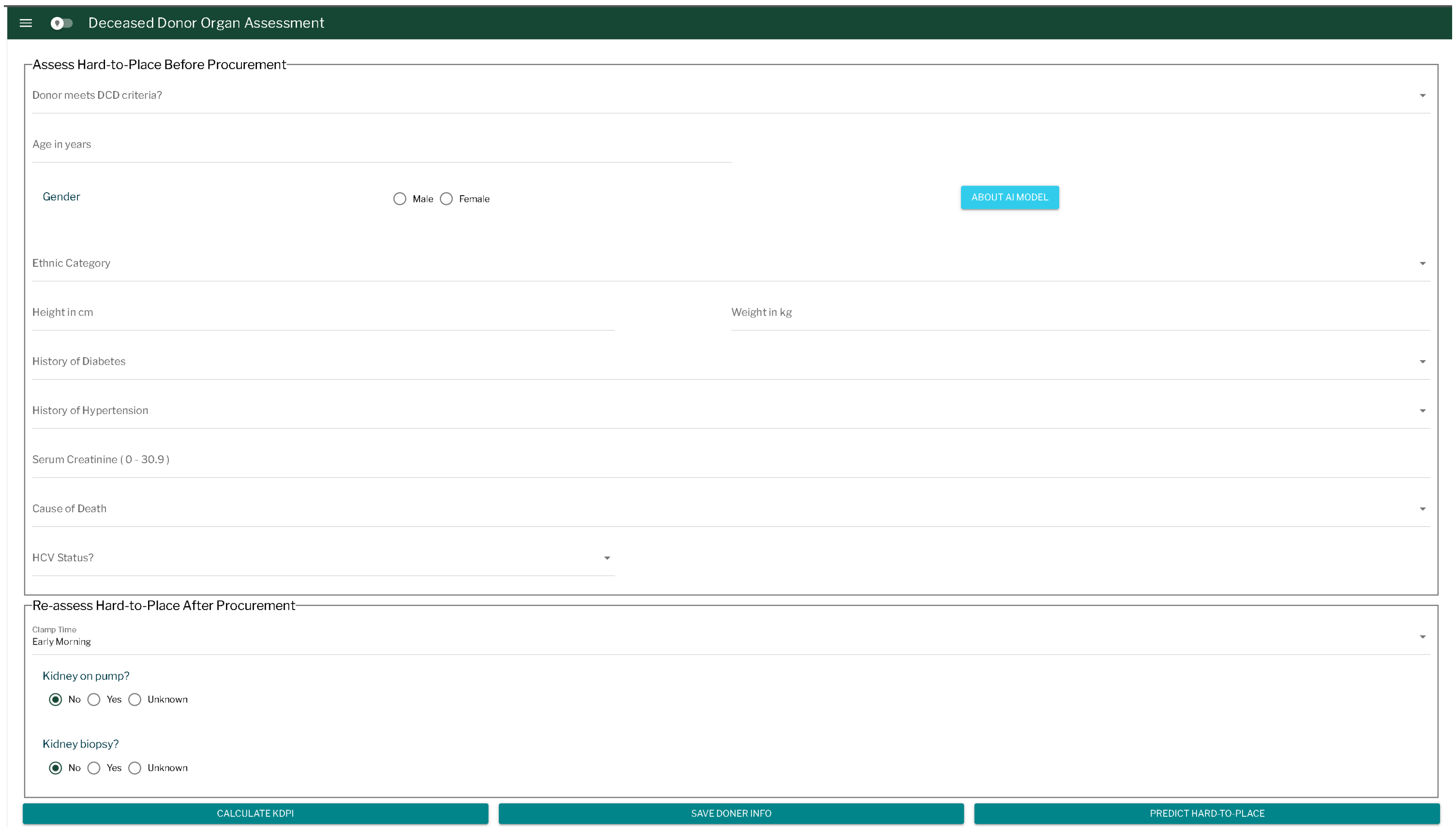
Deep Learning Optimization Approach

- Use of Genetic Algorithm to Tune Deep Learning Parameters



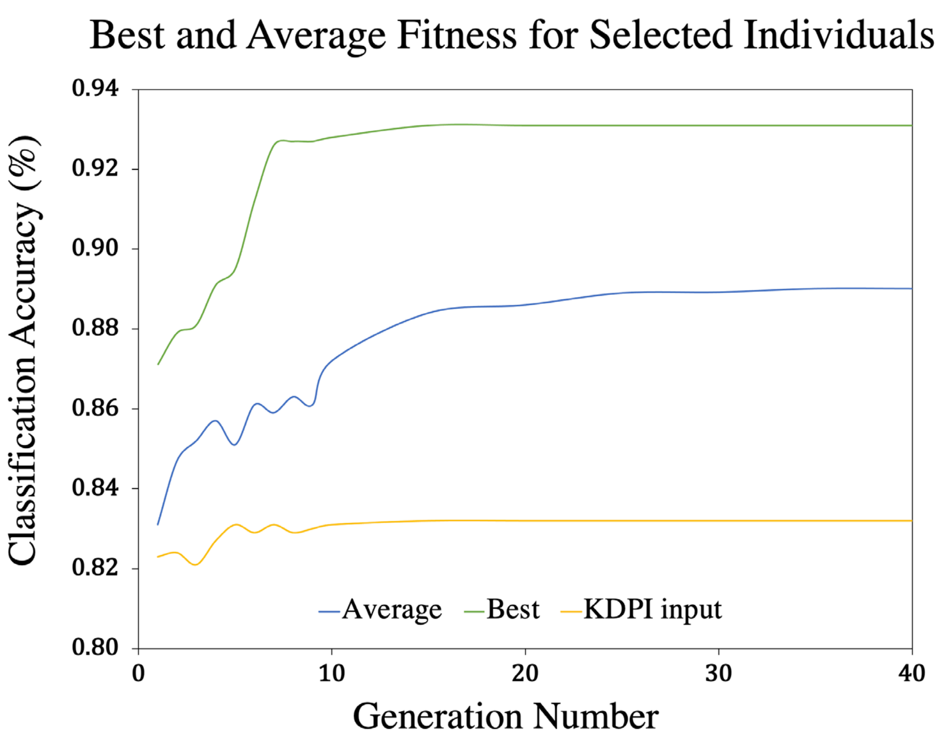


DDOA Application



https://ddoa.mst.hekademeia.org/#/kidney

DDOA Model Performance



n = 5546	Predicted: **0**	Predicted: **1**	
Actual: **0**	814	326	1140
Actual: **1**	56	4350	4406
	870	4676	

Class 0 **(discard)** Class 1 **(transplant)**

```
Accuracy Score: 0.9312333213
Classification Report:
          precision recall f1-score support
0           0.93     0.71    0.80     1140
1           0.93     0.98    0.95     4406
```

Meta Architecture for Donor Kidney Transplant Systems of Systems

- Mission Description
  - Successful allocation of each donor kidney for transplant
  - Mission duration ~34 hours for each kidney
  - OPO needs a Meta Architecture for each donor kidney
  - OPO operates 24 hours 365 days a year
  - Transplant surgeons have ~30 minutes to respond to an offer at any time of day
  - Donor kidney is degrading as time continues
  - Information about logistics, patient, donor kidney, transplant surgeon are changing by the minute with new information

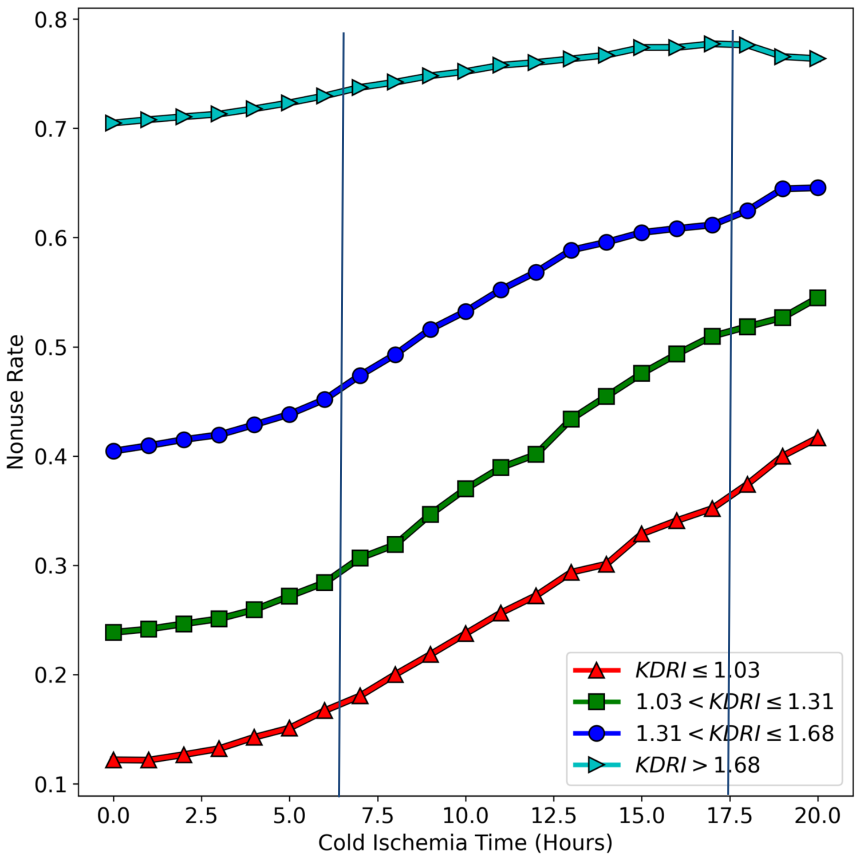
OPO Key Performance Parameters Methodology

Mission Performance

Discard Rate

Cold Ischemia Time

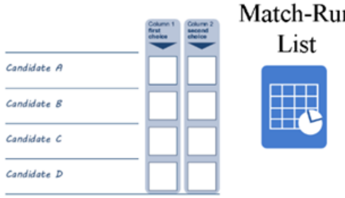
Kidneys degrade over time. How to address information changing dynamically and quickly which affects decision making. How can we make decision with real time data, instead of stale data.



Software Platform to Support Decision Makers

Organ Procurement and Transplantation Network (OPTN) Policies

Match-Run List



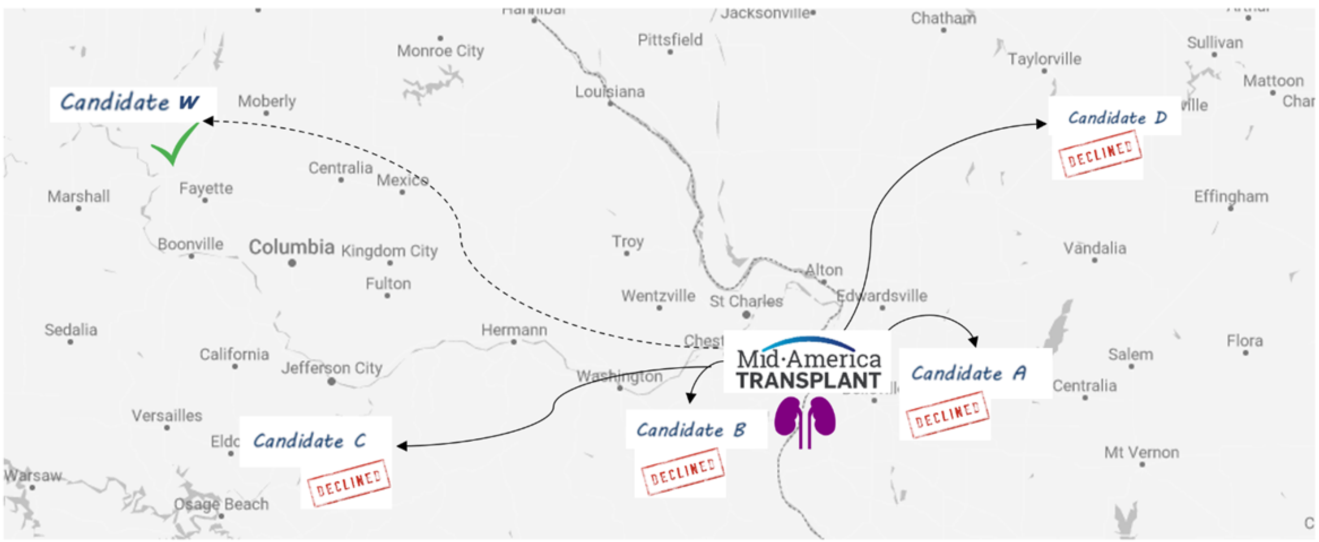
→ Sequence

- - - -► Out of Sequence

Evaluate policies over time in simulation before implementation in real life to see the affect on utility and equity. In Development

Supported by:

Mid-America TRANSPLANT



- Is the kidney considered high-risk for non-utilization or hard to place?
- Has it been declined by many transplant centers?
- What is the likelihood of it being accepted for transplant?

2022-2024. Mid-America Transplant. AI-Enabled Digital Support to Increase Placement of Hard to Place Deceased Donor Kidneys. PI: Cihan Dagli

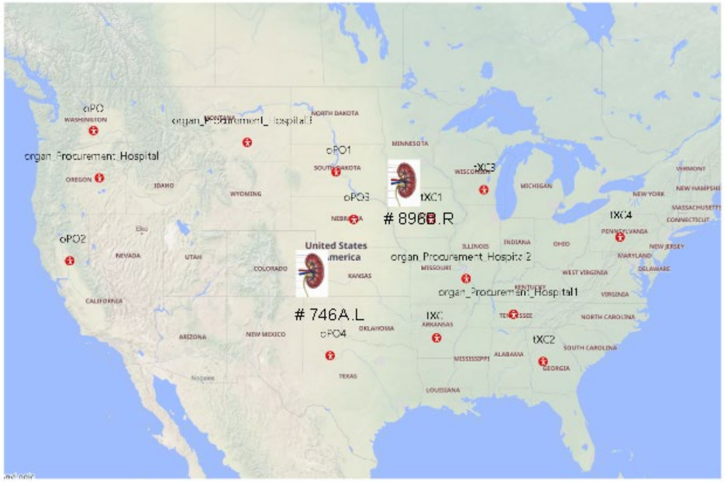
Threlkeld, R., Ashiku, L., Dagli, C. (2023). A Use Case for Developing Meta Architectures with Artificial Intelligence and Agent Based Simulation in the Kidney Transplant Complex System of Systems. *18th Annual System of Systems Engineering Conference (SoSe)*, Lille, France, pp. 1-6, doi: 10.1109/SoSE59841.2023.10178576.

Data Inputs

anylogic®

OUTPUTS

- Automated Kidney donor characteristics
- DDOA characteristics
- Logistical Information
- Policy Selection
- Transplant Center



- Hard to place kidney algorithm
- Most likely to accept transplant center algorithm

- Utility KPA
- Equity KPA

- Performance of Policies

- Tracked Metrics

- DDOA Algorithm
- Most likely to accept transplant center algorithm

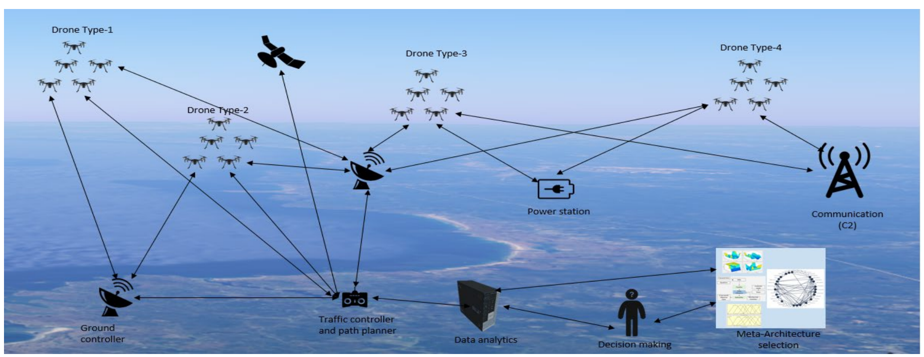
How can AI assist in military decision making

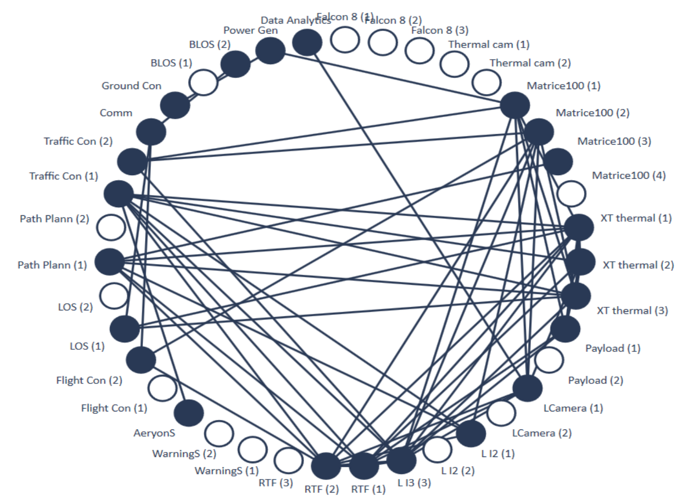
- Military missions are complex, occur in many domains, and information is changing constantly
- Whoever can get through the OODA loop faster has a significant advantage
- How can we help the commander/staff/warfighter with the fight?

AI enabled Meta architecting to advance the science and analysis of all domain systems of systems warfare

Combination of various systems and/or SoSs that may or may not be available at any given time during the fight create many SoS meta-architectures

Can be thousands of meta- architecture
Difficult to select best meta-architecture





Choosing the best systems in an All-Domain fight

AI enabled Meta architecting to advance the science and analysis of all domain systems of systems warfare

Objective Statement:

Missouri University of Science and Technology proposes to develop engineering methods and tools with relevant Army use cases and developing new artificial intelligence enabled optimization for both simplified and technical methods to analyze SoSs. The engineering methods and tools will also have the ability to analyze multiple version of SoS packages and recommend the most optimized SoS based open key performance attributes such as mission success, logistics (Supply classes), combat power, and time.

Desired Effects:

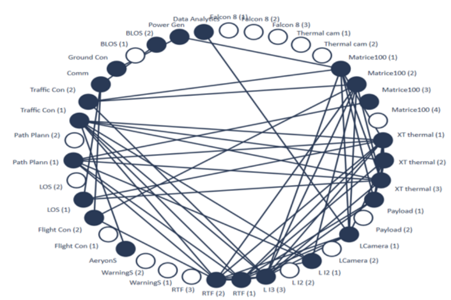
- Develop AI Meta architecting approach for all domain SoS analysis.
- Integrate multiple machine and deep neural network
- Real time analysis for autonomous and man-machine teams for SoS
- Reduction of operator burden

To help achieve

- Make informed decisions about multiple SoS
- Gain situational awareness In all domain SoS
- Faster decision making and military planning

Provide the ability to

Inputs characteristics from SoSs and individual key pacing items for a given mission.



Output optimal Meta Architecture based upon mission key performance attributes.

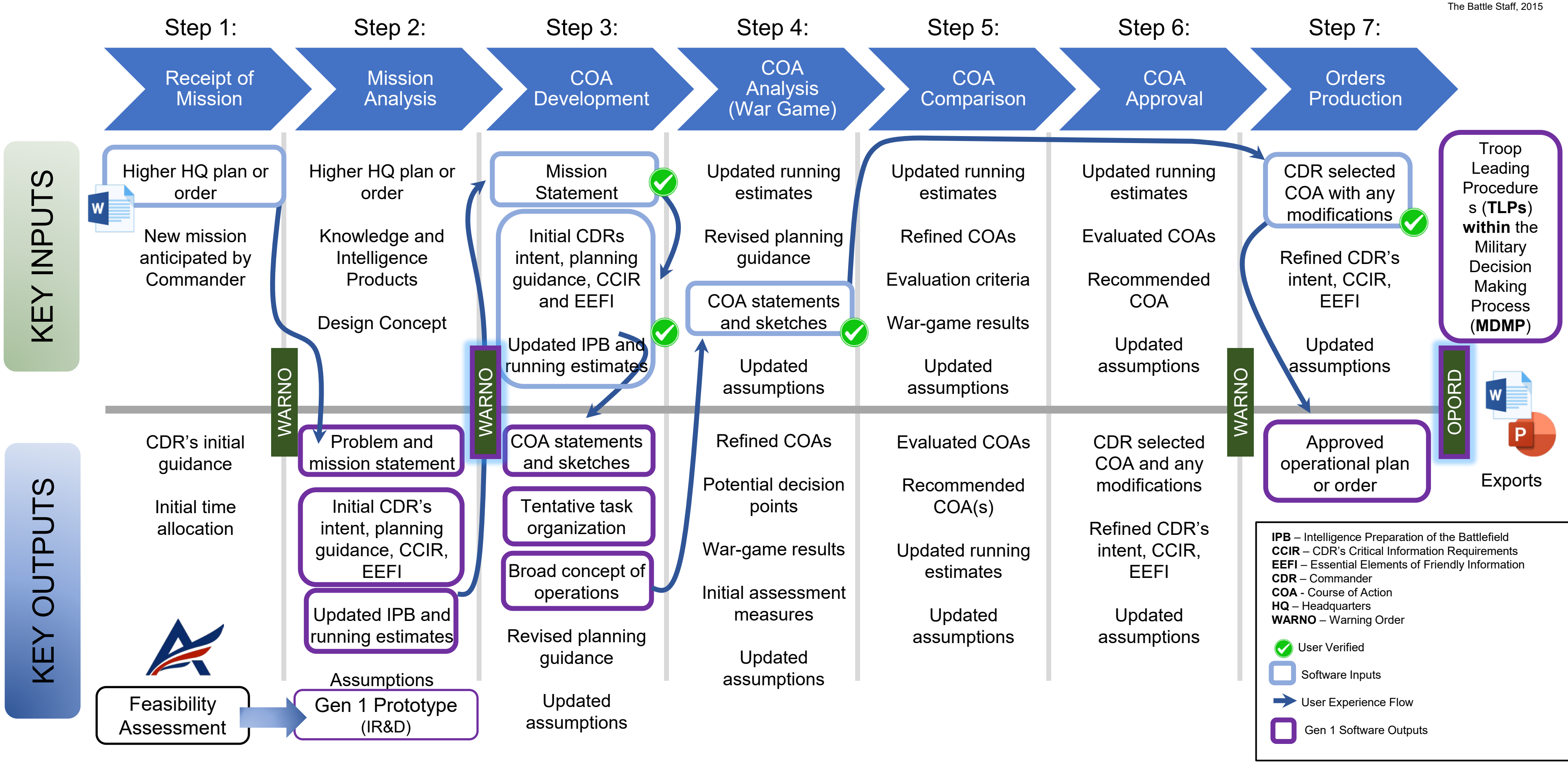
Combines 1 to many SoS for analysis.

AXIOM AI

Military Decision Making Process (MDMP)

Sources:
GTA 31-01-003
Detachment Mission Planning Guide, July 2012

BSS5 Smartbook, 5th Edition
The Battle Staff, 2015



NLP in GUI for MDMP Product Creation

AXIOM AI

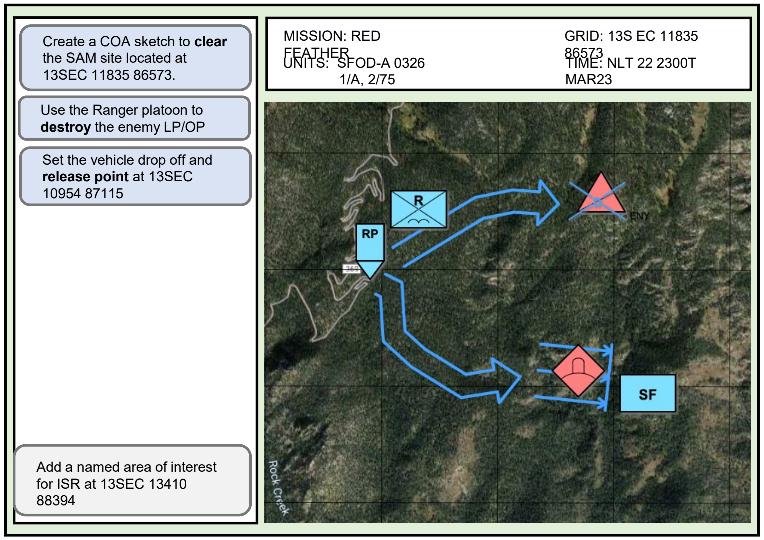
INPUTS

Higher HQ OPORD

Ingests military guidance to frame the operational design

Text to refine the operational design

OPERATIONAL DESIGN



Graphical representation of the operation using doctrinal military terms and graphics provides instant feedback to the user

FEEDBACK

OUTPUTS

CONOP

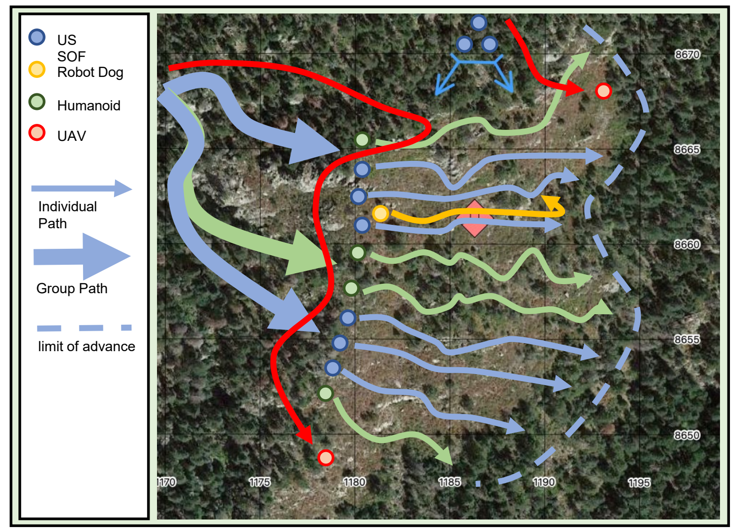
COA Analysis

- Fastest Route (95%)
- IED avoidance (100%)
- Stealth (80%)
- Weather Risk Factors (65%)
- Vehicle capabilities (50%)

INPUTS

1. Operational Design
2. GUI to Modify Execution Plan

SCHEME OF MANEUVER



OUTPUTS

CONOP

COA Analysis OPORD

ROS **Autonomous System Instructions**

Questions

R. Threlkeld, L. Ashiku, C. Dagli. "A Use Case for Developing Meta Architectures with Artificial Intelligence and Agent Based Simulation in the Kidney Transplant Complex Systems of Systems" IEEE SOSE 2023.

C. Dagli, R. Threlkeld, Ashiku, L. "Computational Intelligence Approach to SoS Architecting and Analysis" Systems Engineering Research Center. Systems Engineering in the Digital Age: Practitioner Perspectives (In print by Wiley).

R. Threlkeld, Ashiku, L., Dzieran R., C. Dagli, M. Schnitzler, C. Canfield, K. Lentine, and H. Randall. "AI-Enabled Digital Support to Increase Placement of Hard-to-Place Deceased Donor Kidneys" In AMERICAN JOURNAL OF TRANSPLANTATION, TBD. 111 RIVER ST, HOBOKEN 07030-5774, NJ USA: WILEY, 2023.

Ashiku, L., Threlkeld, R., Dagli, C., Schnitzler, M., Canfield, C., Lentine, K., and Randall H. "Donor Disposition AI Model to Predict Transplant for Recovered Deceased Donor Kidneys" In American Transplant Congress 2022.

R. Threlkeld, L. Ashiku and C. Dagli, "Complex System Methodology for Meta Architecture optimization of the Kidney Transplant System of Systems," 2022 17th Annual System of Systems Engineering Conference (SOSE), 2022, pp. 304-309, doi: 10.1109/SOSE55472.2022.9812668.

Threlkeld, R., Ashiku, L., Canfield, C., Shank, D. B., Schnitzler, M. A., Lentine, K. L., ... & Dagli, C. (2021). Reducing Kidney Discard With Artificial Intelligence Decision Support: the Need for a Transdisciplinary Systems Approach. *Current transplantation reports*, 1-9.

M. M. Karim and C. H. Dagli, "SoS Meta-Architecture Selection for Infrastructure Inspection System Using Aerial Drones," 2020 IEEE 15th International Conference of System of Systems Engineering (SoSE), Budapest, Hungary, 2020, pp. 23-28, doi: 10.1109/SoSE50414.2020.9130538.