Resilient Military Mobility: A Hypergraph-based Digital Twin Solution for Seamless and Efficient Movement across NATO's Europe

Military operations require sophisticated solutions for seamless and efficient movement across varied physical and digital landscapes. Challenges posed by diverse NATO member state regulations, unsuitable infrastructures, and the lack of a common digital solution call for innovation. This abstract presents a unique solution—integrating geospatial dashboards and secure mobile apps, transforming humans into real-time sensors—to enhance military mobility across Europe, focusing on road and rail infrastructure.

A Digital Twin for Resilient Military Mobility

Our solution leverages a hypergraph-based digital twin, reflecting the real-world military mobility network and its operations. Unlike a typical digital twin, ours abstracts key operational modules, functions, services, and processes important to the mobility challenges.

The digital twin's hypergraph-based representation uses nodes and hyperedges to depict objects, transformations, abstractions, and compositions. Here, objects embody the military mobility network elements, transformations signify the processes and changes applied to these objects, abstractions illustrate the interconnections between various modes of transport and potential routes, and compositions represent the aggregated elements derived from real-time data and feedback.

A Scenario Manager AI sets system rules for the integration of objects, transformations, abstractions, and compositions. This, in tandem with the hypergraph representation, enables the system to dynamically and locally adapt to changes through event-driven communication, bypassing the need for a complete system restructuring.

Key Performance Indicator (KPI) or resilience indicator metrics derived from real-time data serve as the formal guiding mechanism for the Scenario Manager. This guides the system to dynamically adjust the hypergraph by modifying hyperedges, enabling it to adapt the sequence of operations to changing conditions.

Secure mobile apps create a novel opportunity for real-time monitoring and calculations, using the mobility of humans-in-the-loop personnel as a participatory sensor system. This innovative approach, leveraging consumer devices as sensors, provides a cost-effective method to obtain extensive real-time data at scale, empowering real-time monitoring.

The emergent digital twin, embodying redundancy, modularity, robustness, and coverage, serves as a universal abstraction layer. It interprets, processes, and normalizes data from various domains, feeding it into an adaptive data mesh framework for informed decision-making and information exchange.

Integrating Technologies

Our digital twin leverages Booz Allen's cutting-edge technologies to form the hypergraph network; including the ATLAS data fusion analytic platform, the Secure Mobile App as a Sensor leveraging the XRAE suite of AI performance monitoring and analysis, and the LOGWERX Conceptual Solution, a secure app-based solution for event response route planning.

The Geospatial Dashboards integrate diverse geospatial datasets to provide comprehensive situational awareness, essential for effective military mobility operations. This tool's deep integration capabilities

facilitate access to detailed deployment data, capability catalogs, and strategic activities such as cross-border movement permissions and convoy support.

Our Secure Mobile App morphs users into data providers, collecting real-time information to monitor military movements and assess their carbon footprint. Resilient against cyber threats, this app ensures secure information exchange and synergizes smoothly with other systems.

Lastly, the LOGWERX Conceptual Solution simplifies route optimization and planning, offering a secure platform for vital information exchange. This solution's capabilities span regulatory monitoring, threat surveillance, and infrastructure resilience tracking, all contributing to the efficiency of military mobility operations.

Functional Degeneracy and the Digital Twin

The Scenario Manager, using a hypergraph model, sequences operations for efficient military movement planning. It allows local reconfigurations based on real-time data or KPIs, enhancing system adaptability and provides a level of functional degeneracy—the ability to reach the same goal via multiple paths, enhancing resilience.

Conclusion

Our proposed digital twin effectively integrates scalable, cutting-edge technologies, adaptive system design, and hypergraphs to generate a system that is resilient, highly dynamic, and interoperable. This architecture can ingest, abstract, and learn policy information common across domains, facilitating its exchange across environments, such as LOGFAS.

With potential applications in both military and civilian domains, this solution plays a significant role in enhancing military mobility across NATO's Area of Responsibility (AOR) in Europe. By enabling real-time traffic monitoring, situational awareness, and resilience to cyber and hybrid threats, the proposed system promotes efficient and secure transportation of forces and equipment, ultimately enhancing the operational anti-fragility of military missions.