Agentic AI for Adaptive and Resilient Middle-Mile Freight Operations

The U.S. freight transportation system depends heavily on the middle mile, which links warehouses, distribution centers, and regional hubs to support timely, reliable deliveries. Current middle-mile operations are managed through sequential planning: central planners set routing and load plans, and facilities execute them with minimal ability to influence upstream decisions. While local optimization and machine learning (ML) tools are increasingly applied for tasks like dock scheduling and routing adjustments, these remain siloed, reactive, and narrow in scope, offering only marginal efficiency gains at the network level. This proposal aims to transform middle-mile logistics by developing **Intelligent Middle-Mile Transportation Networks (iMTN), powered by a multi-tier, agentic AI framework** that enables real-time, adaptive, and coordinated decision-making. The system integrates optimization with ML, balancing feasibility, adaptability, and interpretability across three tiers:

- **Tier 1** – *Data Collection & Analytics*: Multi-agent systems continuously gather telematics, equipment, workforce, and environmental data, applying predictive analytics to anticipate disruptions such as equipment failures, demand spikes, or weather events.
- **Tier 2** – *Autonomous Decision Control*: Functional agents combine optimization (e.g., mixed-integer programming) and ML (e.g., reinforcement learning, neural networks, foundation models) to generate and refine transportation schedules, allocate resources, and negotiate across hubs. These agents enable lateral coordination across facilities, shifting decision-making from local fixes to network-wide optimization.
- **Tier 3** – *Oversight & Governance*: Human supervisors validate outputs, ensure transparency, and provide safeguards during high-risk events. This layer uses explainable AI and interactive dashboards to strengthen trust, accountability, and compliance.

By enabling proactive disruption response, scalable reasoning, and human-AI collaboration, iMTN addresses key limitations of today's fragmented logistics practices: poor facility utilization (averaging $\tilde{6}5\%$), on-time delivery rates still below pre-pandemic benchmarks, and reactive adjustments that can take 30-60 minutes to implement.

The proposed system is expected to raise on-time delivery rates to 97-98%, boost facility utilization toward 95%, and cut disruption response times to under five minutes. This capability directly supports U.S. DOT goals to modernize freight infrastructure, strengthen supply chain resilience, and embed data-driven decision-making into national logistics systems.

The research will be conducted in three phases over 3-4 years: (1) prototyping perception and hybrid optimization-ML agents, (2) extending to multi-hub testbeds with supervisory dashboards, and (3) demonstrating full-scale pilot operations. Emphasis will be on open, modular, and interoperable architectures, producing tools and benchmarks that can be adopted across industry and government.

Impact extends across the freight ecosystem: private carriers will gain efficiency and reliability, facility supervisors will receive actionable real-time decision support, and public agencies will benefit from more resilient and sustainable supply chains. By aligning with the U.S. DOT's National Freight Strategic Plan, the project advances national priorities in infrastructure modernization, supply chain resilience, and data-driven innovation.