ABSTRACT

Modular vehicles are vehicles with interchangeable substantial components also known as modules. Fleet modularity provides extra operational flexibility through on-field actions, in terms of vehicle assembly, disassembly, and reconfiguration (ADR). The ease of assembly and disassembly of modular vehicles enables them to achieve real-time fleet reconfiguration, which is proven as beneficial in promoting fleet adaptability and in saving ownership costs. The objective of military fleet operation is to satisfy uncertain demands on time while providing vehicle maintenance. To quantify the benefits and burdens from modularity in military operation, a decision support system is required to yield autonomously operation strategies for comparing the (near) optimal fleet performance for different vehicle architectures under diverse scenarios.

The problem is challenging because: 1) fleet operation strategies are numerous, especially when modularity is considered; 2) operation actions are time-delayed and time-varying; 3) vehicle damages and demands are highly uncertain; 4) available capacity for ADR actions and vehicle repair is constrained. Finally, to explore advanced tactics enabled by fleet modularity, the competition between human-like and adversarial forces is required, where each force is capable to autonomously perceive and analyze field information, learn enemy's behavior, forecast enemy's actions, and prepare an operation plan accordingly. Currently, methodologies developed specifically for fleet competition are only valid for single type of resources and simple operation rules, which are impossible to implement in modular fleet operation.

This dissertation focuses on a new general methodology to yield decisions in op-

erating a fleet of autonomous military vehicles/robots in both conventional and modular architectures. First, a stochastic state space model is created to represent the changes in fleet dynamics caused by operation actions. Then, a stochastic model predictive control is customized to manage the system dynamics, which is capable of real-time decision making. Including modularity increases the complexity of fleet operation problem, a novel intelligent agent based model is proposed to ensure the computational efficiency and also imitate the collaborative decisions making process of human-like commanders. Operation decisions are distributed to several agents with distinct responsibility. Agents are designed in a specific way to collaboratively make and adjust decisions through selectively sharing information, reasoning the causality between events, and learning the other's behavior, which are achieved by real-time optimization and artificial intelligence techniques.

To evaluate the impacts from fleet modularity, three operation problems are formulated: (i) simplified logistic mission scenario: operate a fleet to guarantee the readiness of vehicles at battlefields considering the stochasticity in inventory stocks and mission requirements; (ii) tactical mission scenario: deliver resources to battlefields with stochastic requirements of vehicle repairs and maintenance; (iii) attacker-defender game: satisfy the mission requirements with minimized losses caused by uncertain assaults from an enemy.

The model is also implemented for a civilian application, namely the real-time management of teams of reconfigurable manufacturing systems (RMSs). As the number of RMS configurations increases exponentially with the size of the line and demand changes frequently, two challenges emerge: how to efficiently select the optimal configuration given limited resources, and how to allocate resources among lines. According to the ideas in modular fleet operation, a new mathematical approach is presented for distributing the stochastic demands and exchanging machines or modules among lines (which are groups of machines) as a bidding process, and for adaptively configuring these lines and machines for the resulting shared demand under a limited inventory of configurable components.

The main original contributions of this dissertation are: (i) proposed a new stochastic MPC framework for managing the dynamics of operation/manufacturing systems considering the uncertainty; (ii) created a novel agent based model to simulate the human-like decision making process; (iii) formulated an attacker-defender game to highlight the tactical advantages brought by modularity; (iv) designed a negotiation algorithm among teams of vehicles/reconfigurable manufacturing machines for real-time task allocation and resource sharing.