Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

GENERATIVE AI AND SIMULATION-DRIVEN PREDICTIVE MODELING FRAMEWORK: ENHANCING RESILIENCE AND RISK MANAGEMENT UNDER DISRUPTIONS

Seung Ho Woo[1]

[1] Edwardson School of Industrial Eng., Purdue University, West Lafayette, IN, USA

ABSTRACT

Maintaining stability and resilience in complex systems by predicting and mitigating risks is essential in the modern era. This research investigates generative AI-enhanced predictive modeling methodologies to strengthen risk mitigation and supply chain resilience. In particular, generative AI is employed to enhance data augmentation with multimodal fusion, adaptive parameter tuning, disruption environment generation, and dynamic model updating. A novel generative AI-based predictive modeling framework is then developed, which combines diverse types of data with advanced learning algorithms to increase the accuracy of the prediction and simulate the impact of disruptions. The preliminary findings suggest that the proposed generative AI-integrated predictive models show advancement in risk and supply chain resilience management and reveal the potential of models for robust prediction.

1 INTRODUCTION

As today's real-world systems are becoming increasingly interconnected and complicated, mitigating potential risks via accurate prediction is essential to maintain resiliency of those systems. Risks and disruptions include natural disasters and human-made crises such as floods, power outages, and cyber security breaches. This work investigates the innovative potential of generative AI in predictive modeling via deep learning and simulation for integrated risk management in complex systems. Generative AI has the potential for data augmentation, adaptive parameter tuning, dynamic model updating, multimodal data fusion, and disruption environment generation. These capabilities could offer powerful tools to overcome challenging tasks. This research aims for developing an AI-based predictive modeling methodology that integrates multiple data sources with learning algorithms to predict and simulate risks and impacts in an intricate environment. By applying natural language processing, data fusion, reinforcement learning, and digital twin with generative AI, this work focuses on predicting the impacts of the risk in society and supply chain networks to enhance adaptivity and resiliency of the systems. This approach advances the field of risk and supply chain resilience management by integrating generative AI with predictive models to diagnose and suggest strategies for a dynamic society.

2 RESEARCH OBJECTIVES

2.1 Generative AI and Deep Learning for Risk Impact Extraction and Prediction

The first objective of this research is to develop a novel risk domain-specific language model by applying generative AI with a deep learning model to extract and predict the impacts of risks. The focus is to develop and refine risk assessment and impact prediction methodologies by processing and analyzing irregular data from news reports, social media, and other textual sources. A crisis domain-specific entity extraction language model has been developed, which leverages the synergy of BERT and GPT to overcome the limitations of existing natural language processing technologies in the risk management field. This model utilizes generative AI for domain-specific data augmentation and annotations to train and fine-tune the

language model under the BERT base model via transfer learning depicted in Figure 1. The model outperforms in impact extraction tasks compared to other language models. This study further highlights the risk domain-specific model to accurately extract the entities of power outage events in the U.S. to diagnose the power grid's resilience and predict the impact of power outages in society. This research explores generative AI technologies into predictive models for risks to demonstrate the potential to improve risk management strategies.

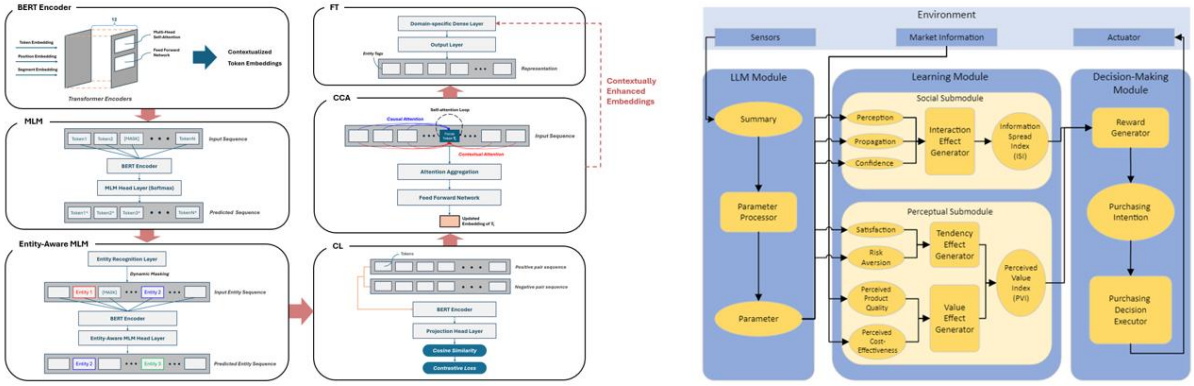

Figure 1: Architectures of language model and LLM-integrated decision-making model.

2.2 Generative AI and Multi-Agent Simulation to Enhance Supply Chain Resilience under Risk

The second objective of this research is to demonstrate generative AI, reinforcement learning (RL), and multi agent-based simulation to improve the supply chain resilience in communities under disruptive risk events. In particular, an LLM (Large Language Model)-integrated decision-making model is proposed to model interactions and propagation of information between agents to reflect risk scenarios. This framework integrates generative AI with a blend of environmental, intra and inter-agent information to analyze agents' behavior and help make more reasonable purchasing decisions for essential supplies based on reward models and updates, as shown in Figure 1. Besides interaction effects, our framework is distinguished in the aspect of learning parameters with the aid of generative AI and updated rules in the decision-making process. The Variational Autoencoder (VAE) generates disruption scenarios, and the agents in the system are modeled by RL algorithms to enable agents to learn optimal decision-making strategies dynamically for essential goods purchased in pre- and post-risk events. This work, by applying a reward system from the RL algorithm, generative AI deployment, and agent interactions, thereby optimizes key decision variables that closely mirror supply chains of essential supplies during risk scenarios and allows to make better decisions of agents.

2.3 Generative AI and Self-Learning Crisis-Responsive Multimodal Simulation

The third objective of this research is to propose an advanced agent-based simulation framework integrating generative AI, multimodal data fusion, and self-learning algorithms. The two main modules in the framework are risk-adaptive multimodal generative AI and self-learning digital twin. Risk-adaptive multimodal AI module reflects real-time supply chain dynamics under risks by fusing various data types, including textual reports, IoT sensors, social media, and satellite imagery. This module aims to apply generative AI to generate and diagnose risk scenarios. It constructs robust, crisis-responsive simulation environments to predict the potential impacts on the supply chain network under disruptions. The updates in real-time data achieve the adaptiveness of the simulation to refine the prediction. The self-learning digital twin module generates a virtual replica of the evolving supply chain networks to reflect real scenarios. It utilizes various data streams and adapts generative AI to develop dynamic, detailed risk scenarios. By the self-learning algorithm, the accuracy and efficiency of the digital twin are continuously improving over time to autonomously calibrate the model and strategies.