Maximizing FRC Autonomous Efficiency with Probabilistic Decision-Making Models

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ABSTRACT

This paper explores the application of probabilistic decision-making models to enhance the efficiency and reliability of autonomous operation in FIRST Robotics Competition (FRC) robots. Traditional deterministic autonomous programs often struggle with variability in sensor data, drivetrain inconsistencies, and unforeseen obstacles, leading to suboptimal performance. By integrating probabilistic models, robots can dynamically adjust their actions based on real-time conditions, optimizing movement strategies and increasing scoring efficiency. Drawing from research in autonomous vehicles and Bayesian networks, this study examines how probabilistic frameworks improve adaptability and decision-making in uncertain environments. Key findings demonstrate that probabilistic approaches enhance FRC autonomous strategies by enabling real-time adjustments, reducing error rates, and maximizing competitive performance. The results suggest that future FRC teams can benefit from incorporating probabilistic modeling techniques to develop more robust and flexible autonomous routines.

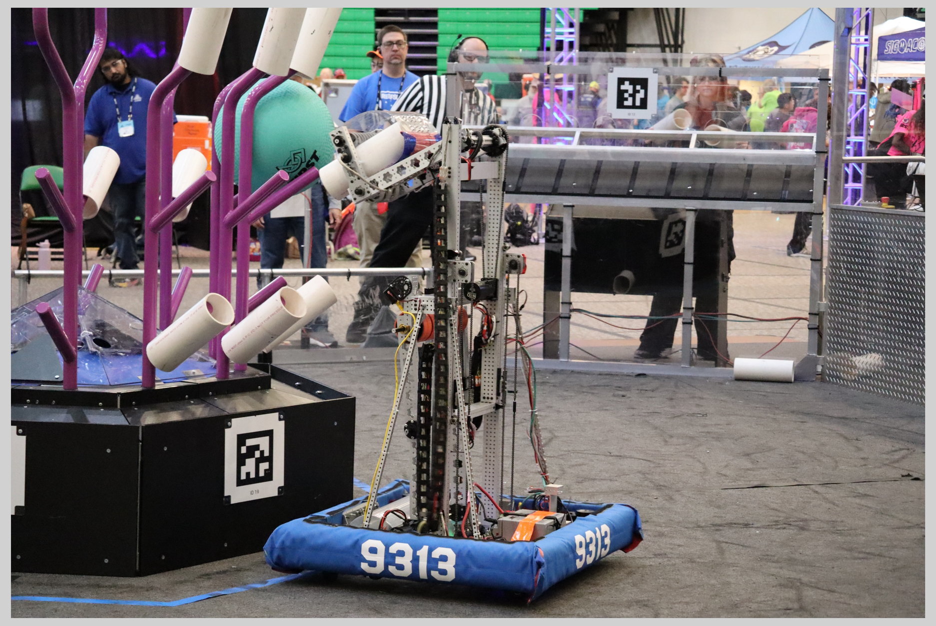
INTRODUCTION

Autonomous play in the FIRST Robotics Competition (FRC) is the most important factor in a team's success, with robots having to perform tasks independently with no human intervention within a limited 15-second time window. Traditional autonomous programming relies on deterministic models, where robots move along pre-programmed paths with little flexibility. These approaches fail to deal with real-world uncertainties such as sensor noise, drivetrain variation, and unexpected obstacles.

To address such issues, probabilistic decision models offer a more adaptive approach with the ability for robots to respond in real time in situations of uncertainty. Such models consider multiple likely outcomes and choose the most effective course based on probabilities, leading to greater efficiency and reliability.

This study looks at probabilistic models—those ubiquitous in autonomous vehicles, AI robotics, and medical decision-making—and how they can be applied to improve FRC autonomous approaches. By integrating Bayesian networks, stochastic models, and real-time adjustment of decisions, teams will be able to design robots that dynamically adapt to shifting contexts.

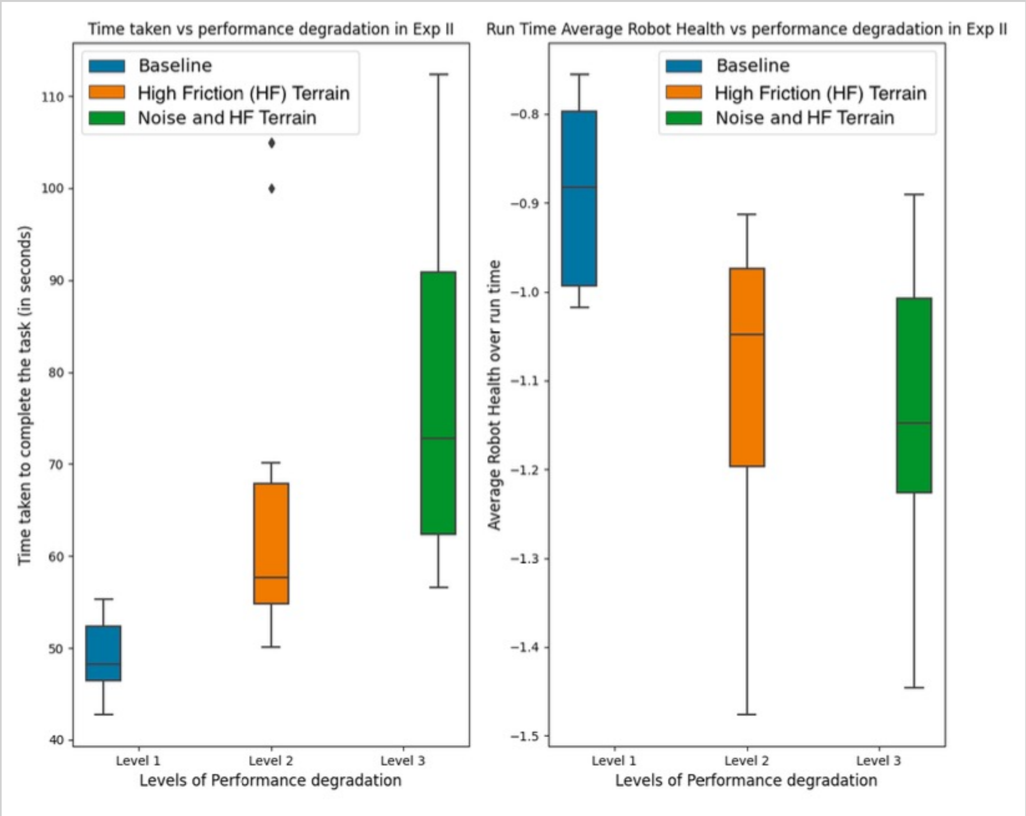
The study discusses the underlying principles of probabilistic decision-making, its applications in robotics, and how such methods can be applied to enhance FRC autonomous performance and other real-world autonomous systems.



FRC Team 9313's robot successfully scoring a game element during the autonomous period using a probabilistic decision-making model. This approach allows the robot to dynamically adjust its actions based on real-time conditions, improving efficiency and adaptability in unpredictable match environments.

IMPROVED REAL-TIME ADAPTABILITY

In FRC autonomous mode, robots navigate dynamic environments where sensor noise, drivetrain variation, and obstacles affect performance. Unlike deterministic models, probabilistic models use probability distributions to measure uncertainty and adjust actions in real time. This enables adaptive behavior, optimizing path planning and maintaining consistent performance.



Source: Ramesh et al. (2021), HRI '21 Companion: Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction

Boxplots for Tcomp (left) and average robot health (right) in Experiment II, with diamonds indicating outliers, adapted from Ramesh et al. (2021)

Ramesh et al. found a strong negative correlation ($\rho = -0.77$, $p < 0.001$) between average robot health and Tcomp values, highlighting the importance of real-time monitoring and adaptive control in preventing delays. Their model emphasizes tracking robot vitals to detect system degradation and adjust behavior, aligning with FRC autonomous strategies that use probabilistic models to handle sensor failures, drivetrain mismatches, and obstacles.

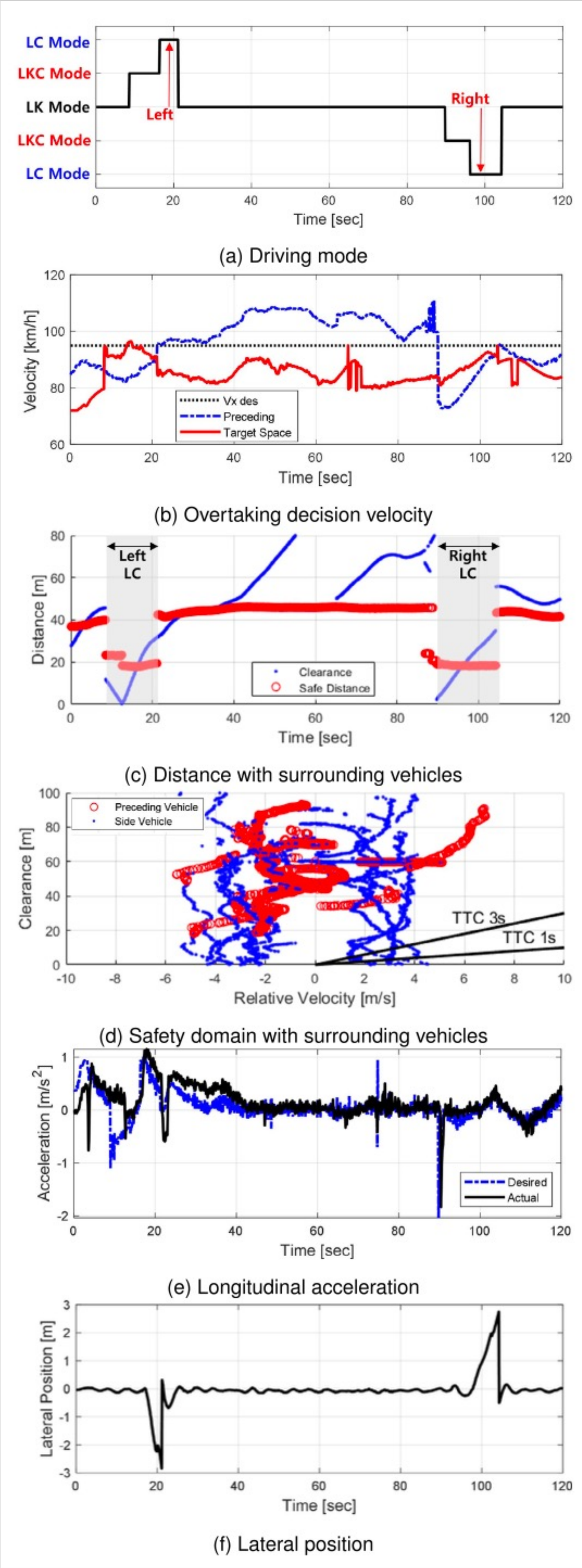
ENHANCED DECISION-MAKING IN DYNAMIC ENVIROMENTS

In dynamic environments, autonomous systems must make effective decisions despite uncertainty. Probabilistic decision-making models improve this by incorporating real-time updates with new information. Unlike deterministic models, which follow fixed paths, probabilistic models assess multiple outcomes and assign probabilities to each. This enables robots to navigate noisy or incomplete data. In FRC autonomous modes, probabilistic modeling helps robots predict obstacles, adjust flight trajectories, and find optimal paths for safety and efficiency.

"Bayesian networks were used to estimate the likelihood of collision with nearby targets" (Jeong 15255). This approach enabled autonomous vehicles to assess risks and make optimal decisions in uncertain traffic. Similarly, in FRC autonomous modes, static routes can cause collisions or inefficiencies. By using probabilistic models like Bayesian networks, FRC robots can adjust trajectories, predict collisions, and make better decisions in dynamic environments. These models allow autonomous systems to act intelligently, adapting to uncertainty rather than relying on fixed responses. Just as they help vehicles navigate traffic, they enable FRC robots to strategize and perform effectively in high-stakes situations.

PREDICTIVE MODELING FOR UNCERTAIN CONDITIONS

Surprise uncertainty in autonomous systems arises from sensor noise, surprise obstacles, or varying environments. Probabilistic decision-making models allow for predictive modeling for robots so that robots can forecast upcoming situations and adjust their plans afterward. Probabilistic models are distinguished from deterministic models, which respond based on established assumptions because probabilistic models treat an array of possible results and assign probabilities to an array of possibilities in the light of present evidence. In FRC autonomous modes, robots must navigate a dynamically changing environment in which the opposing robots, game pieces, and field elements form uncertain conditions. Predictive modeling enables robots to make well-informed decisions by extrapolating future states, predicting interactions, and dynamically adapting their actions. This facilitates more efficient path planning, better resource utilization, and reduced collision or strategic error risk.



Source: Chae and Yi (2020), IEEE Access

"Since most autonomous vehicles recognize the environment by the local sensor, there is a problem with the limitation of the cognitive range. Virtual targets have been devised to cope with this problem" (Chae and Yi 51375). Similarly, in FRC autonomous operation modes, robots must operate in situations where sensor visibility is limited, calling for predictive models to predict potential hazards, opponent movements, or optimal scoring positions. Using probabilistic decision models, FRC robots can model future game situations and adapt accordingly, increasing reliability and performance under uncertain situations.

APPLICATIONS

The use of probabilistic decision-making models in FRC autonomous routines demonstrates how adaptive algorithms can improve performance in dynamic, unpredictable environments. These models allow robots to make real-time decisions based on uncertainty, rather than following rigid, pre-programmed paths. While this research focuses on FRC, the principles of probabilistic modeling have far-reaching applications in robotics and engineering.

Robotics & Autonomous Vehicles

- **Self-Driving Cars** – Probabilistic models help autonomous vehicles navigate uncontrolled intersections, avoid collisions, and adapt to unpredictable driver behavior (e.g., Bayesian networks for real-time risk assessment).
- **Industrial Automation** – Robots in manufacturing use probabilistic models to optimize task execution, detect failures, and adapt to changing assembly conditions without human intervention.

Biomedical Engineering & Healthcare Robotics

- **Surgical Robotics** – Probabilistic models enhance robotic-assisted surgeries by accounting for variations in patient anatomy and adjusting tool movements in real time.
- **Prosthetics & Exoskeletons** – Adaptive control systems allow wearable robotics to predict user intent and adjust support dynamically, improving mobility for individuals with disabilities.

Image generated by Copilot, 2025.

CONCLUSION

Probabilistic decision-making models provide a significant advantage in FRC autonomous performance by allowing robots to adapt to real-time uncertainties rather than following rigid, pre-programmed paths. Unlike deterministic models, probabilistic approaches improve efficiency, reliability, and adaptability, making autonomous routines more dynamic and responsive. Research from autonomous vehicles, AI-driven robotics, and Bayesian decision-making demonstrates the broad applicability of these models beyond FRC, influencing fields such as self-driving technology, industrial automation, and biomedical engineering. As robotics and artificial intelligence continue to advance, integrating probabilistic decision-making will be essential for optimizing autonomous systems across various industries. For FRC teams, embracing these techniques can lead to more competitive, intelligent, and efficient robots, paving the way for innovation in both engineering and real-world automation.

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