RL for F1 Race Strategy Optimization

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F1 is more than Speed - Strategy Wins

Track Position

- Knowing where you are relative to ALL other cars
- Predicting Pit Windows

Tyre Management

- Balancing degradation vs. pace
- Adjusting strategy based on compound and wear

Pitstop Timing

- Overcuts → Staying out longer to gain advantage
- Undercuts → Pitting earlier to gain track position

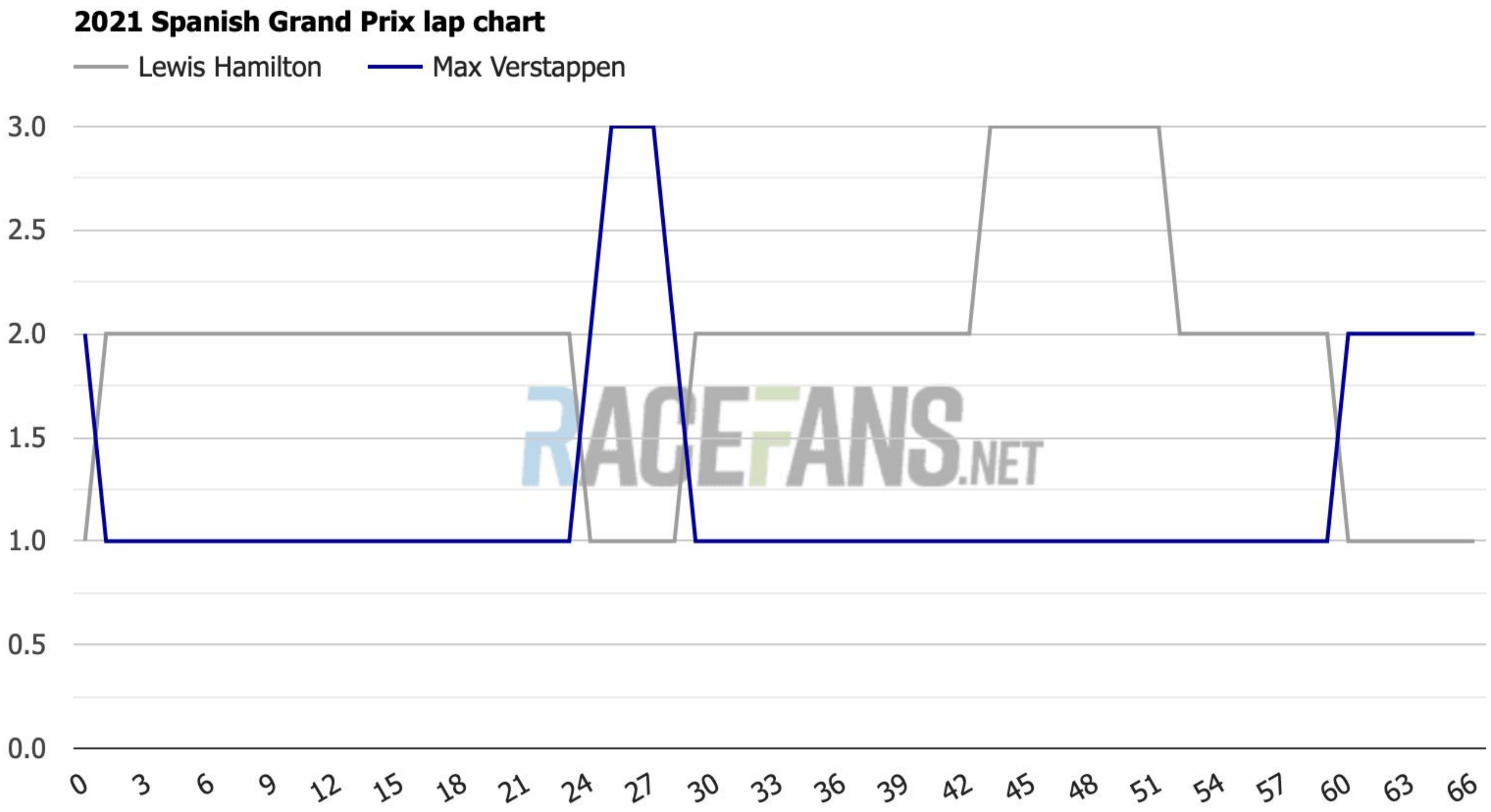
Monitoring your Rival

- Defensive driving → Responding to rival attacks
- Adapting strategy based on rival's tire wear

Complexity of a race engineer’s job

- Raw pace does not guarantee wins
- Race strategists and engineers are just as responsible as drivers
- They balance:
  - Tyre degradation vs. pace
  - Timing pit stops to avoid traffic
  - Predicting rival behavior

Goal: Create a model to optimize strategy


2021 Spanish Grand Prix lap chart
Lewis Hamilton
Max Verstappen
3.0
2.5
2.0
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3
6
9
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Model Goal

<u>Goal:</u> Create a model to optimize strategy

<u>Objective</u>

- Predicts best lap to pit
- Adapts to rival behavior
- Considers traffic and race conditions (i.e. rain)

Model Outline

Inputs:

- Current Lap
- All Laptimes of every driver up to that point
- Driver/Car whose race you want to optimize
- Their rival that you want to beat

Outputs

- Which lap(s) to pit

Modeling Strategy as an MDP

Race Strategy can be modeled as an MDP

- State space: (Track Position, Lap Times, Gap to Rival, Traffic)
- Action space: Pit or stay out, Tyre selection, Push/manage
- Rewards: Gain/Lose position, successful over/undercut, avoiding traffic
- Dynamic Transition Probabilities based on
  - Track (average lap speed, track length, # corners)
  - Pace difference between rival
  - Time gap between rival
  - Tyre wear delta

RL Algorithms

- Policy optimization
- Multi Agent Dynamics

Inputs and State Space

Input:

- Current Lap number
- All previous lap times of all drivers
- Tyre state: compound, age (number of laps)
- Gap to Rival
- Projected Traffic if pitted on current lap

Action Space

Actions

- Pitstop timing (which lap is best)
- Tyre compound choice (soft, medium, hard)
  - Soft: Fastest but does not last many laps
  - Hard: Slowest, lasts many laps
  - Medium: Balance of both speed and longevity
- Driving Strategy
  - Push: Higher pace, more degradation
  - Defend: Slower pace, conserve position
  - Manage: Maximize longevity of tyres

Overtaking Probability Model

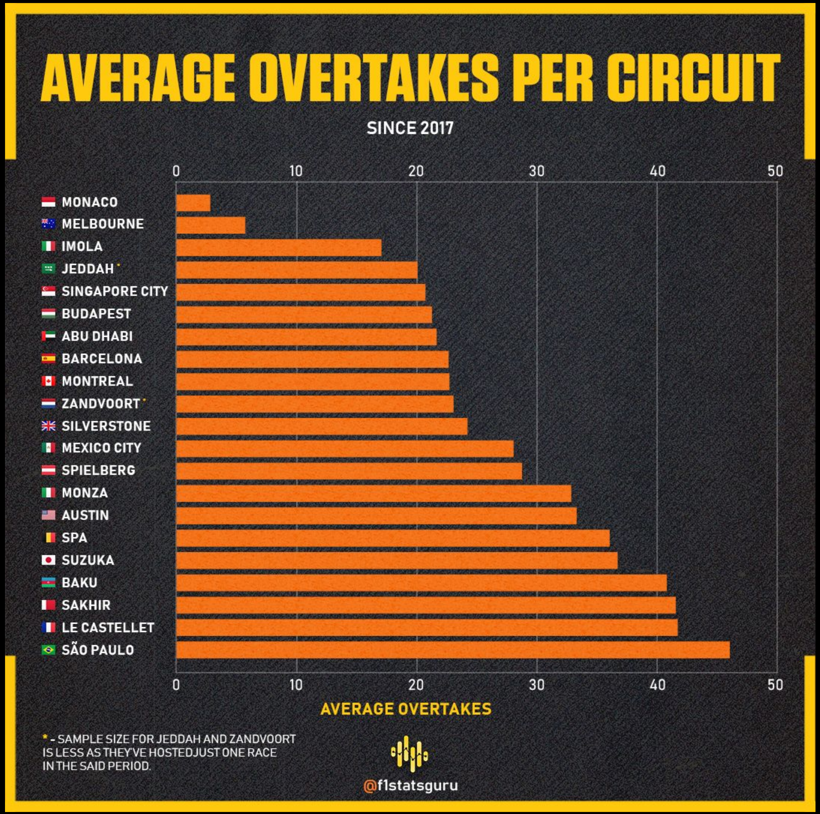
Probability of an overtake depends on:

- Pace difference between two cars
- Pace is correlated to tyre wear
- Gap between two cars

But you have to take into account which track you are at:

- Monaco is Near impossible to pass
- Sao Paulo is much easier to pass

This is where we introduce a scaling factor for each track applied to calculated probability

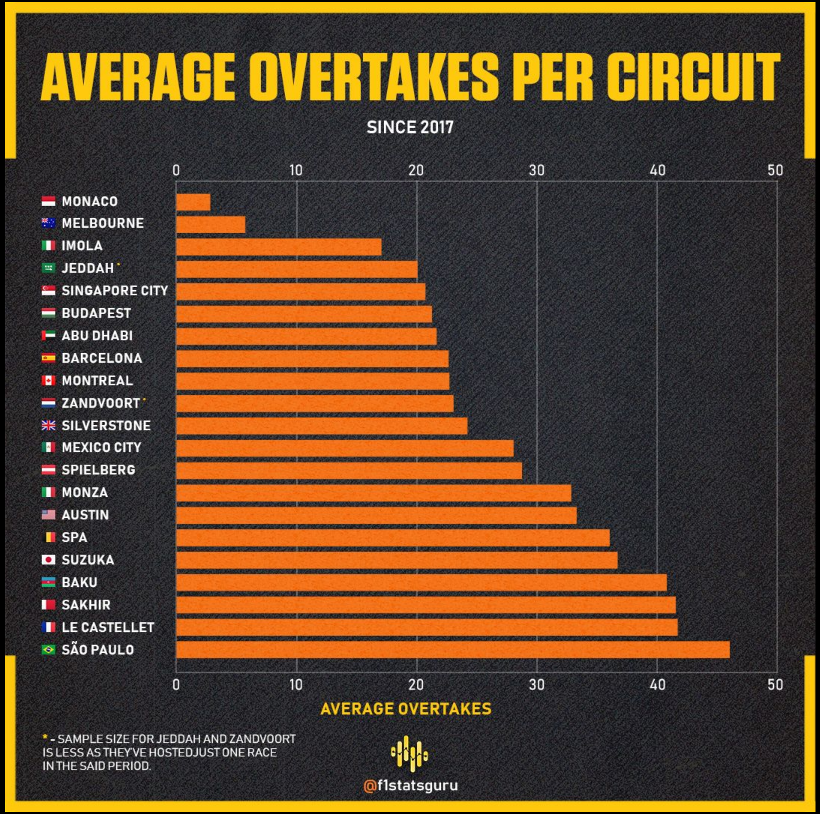


Overtaking Probability Model

Sigmoid based Probabilistic Model

$$P_{\text{overtake}} = \frac{1}{1 + e^{-(\Delta\text{pace} - \text{threshold} - \text{gap})/\text{scaling}}}$$

Threshold = minimum pace advantage for a certain overtake
Pace delta = difference in lap times on previous lap
Gap = difference between two drivers
Scaling factor = variable for each track



Modeling opponent strategy

Start Heuristically

- Fixed strategy and tyre management
- Learns from simplified model

Then introduce Multi Agent modeling

- The other agent updates its policy based on your actions and vice versa

Adaptive behavior

- Learns to prioritize and optimize final position
- Penalize for pitting in bad windows (release into traffic)

Data and Training

<u>Dataset</u> - Kaggle Full F1 Dataset

- Includes lap times of every driver from every race
- Has pitstop information
- Car status (i.e. crash/accident/retire)

Evaluate performance by simulating **Full** races

Success Criteria

- Finish ahead of rival
- Optimal tyre management
- Successful over/undercuts

Simplifications and Assumptions

- **Weight with fuel loss**
- **Use Data after 2014**
- No track evolution
- Safety cars are present
- Variable condition races
- Pit stops times can be modeled as gaussian distributions
- ERS ignored
- DRS provides overtake probability bonus
- Agent starts in a fixed position, grid slot

Summary

- **Take Past F1 Race data**
- Model lap times and races as MDPs
- Train an RL model to automate race strategy
- Validate by trying to replicate wins like Lewis Hamilton's in 2021

Q & A