iJRASET

International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: V Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.82773

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Lap Time Simulation Using Ghost Car

Ms. Pooja Tupe[1], Mr. Gandhar Hemant Sutar[2]
Dept. Of Information Technology University of Mumbai, Mumbai, India

Abstract: Racing pushes limits, so teams lean on number crunching and digital models just to keep up. Because every second counts, computers help build plans shaped around track conditions and unique scenarios. When setups need tuning, a sharp simulator shows exactly when tires should swap or how much fuel suits each run. Instead of guessing, engineers see gaps in speed through layered lap visuals made by custom software built only for race machines. Behind quick fixes lies steady tech mapping out where drivers lose ground.
Keywords: Lap Time Simulation Ghost Car Motorsports Formula 1 Vehicle Dynamics Track Modelling Racing Line Aerodynamics Gear Ratios Friction Coefficients Throttle Braking Augmented Reality Hybrid Vehicles Machine Learning Autonomous Racing Driver Performance Telemetry Optimal Trajectory Planning Energy Management.

I. INTRODUCTION

Right now, tools like smart software and internet-based systems matter a lot - many fields use them to strengthen how they're seen. Winning fast matters most in track races - you push to cross the line early for top marks. Outside elements shift results; reading numbers carefully helps crews stay ahead. Models help designers spot what could go wrong before points slip away or victory fades.

A. MotorSports

Race tracks around the world see car makers battling hard in events like Formula 1, IndyCar, MotoGP, and Le Mans. Outcomes often hinge on tiny gaps - sometimes just bits of seconds decide who wins. Victory comes from crafting machines built to master different kinds of courses, then pairing them with elite drivers aiming for titles. Sharp engineering meets smart coordination behind the scenes, along with raw talent behind the wheel. Together, these pieces create pressure-cooker settings where tech leaps forward, teamwork gets tested, limits shift.

B. Formula 1

Most people view Formula 1 as the top level of car racing, often described as the peak achievement in the field. Getting there means moving up from earlier stages such as Formula 2 or Formula 3, one step at a time. Today's cars mix traditional engines with electric systems, drawing strength both from fuel and stored electrical charge. A full year includes around 24 events, kicking off in Australia while wrapping up under lights in Abu Dhabi. Before any race weekend begins, teams spend several days checking their machines, sometimes on tracks located in places like Bahrain or near Barcelona. Some teams run two drivers at once under what F1 calls a constructor label. Come 2026, eleven outfits mean twenty-two cars lined up when engines fire. Money spent gets checked by a rule called Cost Cap so small crews aren't buried by big budgets. Points decide everything - one prize goes to the top crew, another lands with the strongest individual racer. Three full days make up each event; Friday brings two trial runs, Saturday adds a third plus time trials right behind it. Then comes Sunday - the long wait ends with wheels spinning fast down the straight. Friday brings just one practice session during a sprint weekend. After that comes sprint qualifying Saturday morning, setting grid positions for the short race later that day. Main event qualifying follows in the afternoon, locking in starting spots for Sunday's grand prix. Teams must stick to strict guidelines throughout. Officials wave different colored flags to send messages - green means drivers may continue at speed. When two yellows appear together, it warns of obstacles ahead requiring reduced pace. Other signals guide behavior under changing conditions

C. Lap Time Simulation

Simulation of lap time begins by studying details about a car. Different pieces come together - how the vehicle moves, the shape of the circuit, tires' traits, airflow effects, plus how drivers act. These inputs feed structured math models. Outcomes point toward optimal race strategy, fine-tuned settings, correct fuel load included.
Testing circuits before hitting the track saves hours later. A simulator shows what happens when settings shift, revealing hidden gains. Instead of guessing, teams adjust virtual dials to match real-world demands.

Even so, nothing replaces actual laps under pressure. These tools cut down trial runs, focusing effort where it matters most. Hidden flaws surface early, avoiding delays once wheels spin.

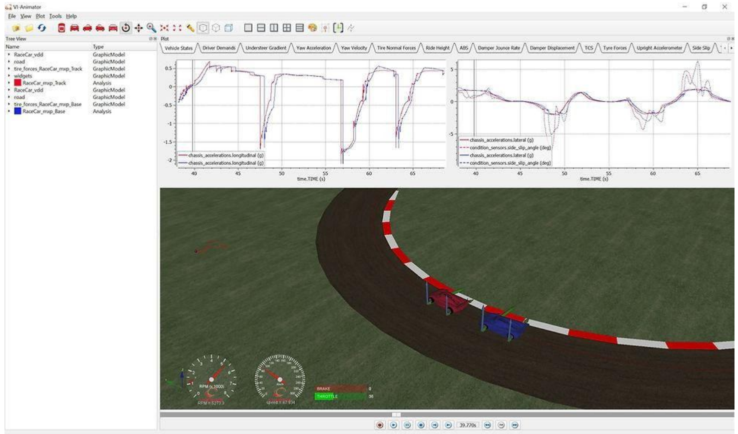

Figure 1: Lap Time Simulation from [30]

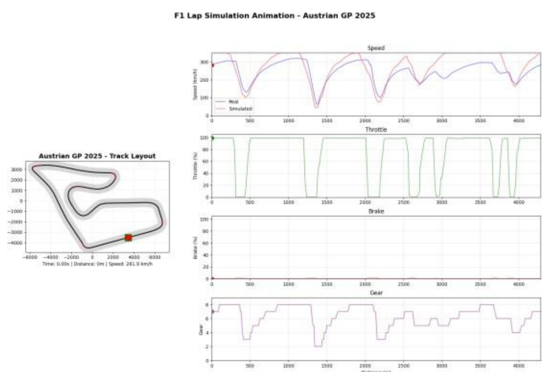

FIGURE 2:LAP TIME SIMULATION AT RED BULL RING, AUSTRIA [32]

The specified parameters are crucial for modeling vehicle dynamics and track performance during laps. Here's a comprehensive analysis of the impact of each parameter on the simulation:

1) Track Design and Racing Line

A virtual version of the track gives engineers a way to mirror real details - changes in height, bumps under tires, grip differences - down to the smallest point, much like how lasers capture data. Through turns, the fastest path follows a clear pattern: start broad on the approach, touch the tightest inside spot mid-corner, then open up again at the exit, trading space for momentum without losing stability or needing heavy slowing.

2) Vehicle Mass

Come 2022, cars had to weigh no less than 798 kilograms - fuel aside. By 2025, that floor climbed two kilos higher; bumping up to 800kg. The reason? Drivers themselves must now tip the scales at 82kg. That extra load pushed overall limits upward. Yet a shift looms ahead - downward, actually. In 2026, expect a drop to just 768kg. How? Slimmer frames help: think 1900mm wide, stretch of 3400mm between wheels. Tires will be narrower too. Even bulky batteries won't stop this cutback. Lighter build means quicker reactions when airflow tweaks are needed mid-race.

3) Aerodynamic Performance (Cd and Cl)

Cars today manage lift-to-drag numbers near 2.5 to 3, thanks largely to advanced underbody shapes that harness airflow beneath them. Top speeds beyond 350 km/h become possible because drag values drop lower, even if exact data stays locked away within team records. From 2026 onward, moving parts will shape how air flows - front and back wings shifting into a stretched-out position without relying on DRS.

This shift allows less resistance and grip whenever needed during straight-line runs. Up front, wing tips pull inward, slimming the overall width to better match demands for speed versus cornering force. Higher efficiency should follow, especially once engine output lines up smoothly with handling traits.

4) Gear Ratios

Some teams run eight-speed shift systems using fixed, approved gear steps - take Red Bull's setup, shifting from 2.95 down to 0.977 across its range, alongside a 4.9 rear axle rate. Tuned differently depending on the track, gaps between cogs typically fall between 0.8 and 0.88 when measuring engine speed shifts. Come 2026, even though those numbers lock after approval, engineers can swap one setting yearly to match updated motor traits or course demands.

5) Tire Friction

Pirelli's Formula One tyres reach a peak grip level near 1.7 when the track is dry, though regular slicks usually sit around 1.55 up to 1.6 - this supports lateral forces from 4 to 5 times gravity. When wet, that number drops sharply, landing just above 0.8. Beyond next year, major shifts aren't expected, yet thinner tyre profiles could shift how traction spreads across the contact patch.

6) Throttle System

Every time you press the gas pedal, signals adjust both motor response and energy capture at once. Built-in settings help manage grip while boosting how well the hybrid parts work together. Even if big changes stay under wraps through 2026, adding a sharper MGU-K improves how smoothly power gets handed out.

7) Braking System

Stopping fast isn't just about force - carbon discs handle extreme loads, bringing speeds down hard, up to five times gravity's pull. Hydraulic power drives the front brakes into action, yet the back relies on both fluid pressure and reclaiming energy during slowdowns. Come 2026, expect smarter electronics behind the rear wheels, boosting how much power gets saved while slowing. Speed drops sharply when these parts work together, each playing its role without delay.

Out here, these parts join forces to build a full-scale test world where how cars move matches real responses to road surfaces along with what drivers do. Tweak one setting at a time, results show clear balances and choices tied to boosting speed or control.

8) Ghost Car

Figure 3: Ghost Car [31]

On screen, a rival's previous lap appears ghosted over live footage. This view helps crews see exactly where their driver speeds up or slows down compared to others. Instead of guessing, they observe precise paths taken through turns. Braking spots become visible, frame by frame. Line choices show up clearly when layered atop real-time driving. During tight qualifying runs, these visuals sharpen understanding. Time differences reveal themselves in how corners are approached. Clarity improves because movements align side by side. Seeing it unfold together makes gaps obvious

II. LITERATURE REVIEW

Starting off, Kobayashi, I., and colleagues in 2022 looked into mixed-power systems for small race vehicles over a stretch of 400 meters. Rather than full circuits, they leaned on simulated runs at nearly constant speeds, using clocked times to reveal how engines and motors balance output. Instead of complex loop modeling, their path to fine-tuning came from simplified trials - motion held stable - to expose performance when things stay even. Insights emerged clearly only once variability dropped away.

Over near the kilometer-long circuit, Kobayashi's group built a shifting mechanism that watches many things at once before picking gears. Signals shift on their own while moving through parts of the machine, tuned by physical checks along the way. Unlike older versions stuck tracking just one path, this setup follows several paths together - making motion sharper and effort smoother. Instead of fixed rules, choices now come from live responses when weight, slope, or pace change. Adjustments snap into place fast, keeping push and pull of energy steady without delay.

Though short-term shifts mattered, accuracy in modeling took priority over guesswork. Veneri, M. (2019) [3] worked to cut lap times using math tweaks that handled fast-changing motion plus tire behavior through Pacejka rules. Instead of sticking to rigid starting points, each cycle adapted mid-process. Real-time changes shaped every run - assumptions shifted as conditions did.

Starting with actual driving data, Doyle along with team members built a lap time tool inside Simulink back in 2019 to study how much energy electric Formula Student cars really use. Performance across different stages of a race was judged using g-g-V plots that reveal grip and motion limits. Rather than relying on guesses, their approach turned physical conditions into clear predictions about what happens on track. Through careful breakdowns, vehicle drive behavior got tied straight to specific course traits like corners or straights. Beyond just velocity, shifts in energy during speeding up and slowing down were followed closely, showing how dynamic responses relate to measurable settings - making trade-offs in engineering choices easier to see.

Sometimes software helps predict lap times using basic car physics made just for student racing teams. This one treats the car like a single moving dot plus bike-like turning behavior when things stay stable. A clean screen lets users interact even if they have never written code before. Running step-by-step, it tests many track situations while adjusting settings automatically across countless variable changes.

Starting with digital curves shaped like pie pieces, Toyoshima, T., et al. (2019) [6] built a method to guess how fast cars might go on real roads. Instead of sharp corners, smooth bends linked straights to turns. While crafting versions of vehicles like the NSX and Civic Type R, they wove true street layouts into simulations right at the start. Because of this shift, teams could judge behavior long before building any test model you can touch.

From real-world test numbers, Broatch built a moving lap-time model in Simulink for student race vehicles back in 2019. Instead of leaning on abstract ideas, it relied heavily on what the sensors actually recorded. Results came out just a fraction - about one-tenth - off from true laps. Because of that small gap, raw field measurements proved strong enough to predict motion accurately, even without heavy theory backing them up.

Back then, around 2021, work by Massaro, M. together with Limebeer, D. took a close look at how fast routes can be simulated [8]. Not just static setups but also moving-based calculations were part of their review - covering machines balancing on two wheels just like those rolling on four. What they focused on was mapping out paths that save time, while pulling together nearly every known way it had been done before.

Curves tilted sideways caught their attention - Lovato, S., et al. (2021) [9] leaned into that detail when upgrading flat-track models. Instead of sticking to straight, even paths, they wove in gentle bends and slopes. Realism sharpened once banking angles entered the math. Performance numbers began mirroring actual race data more closely after that shift.

One study by Spanoudakis, P. along with peers in 2020 looked at how single-speed systems work in electric cars. Fixed ratios shape everything since there are no shifting gears to adjust. Depending on which number is picked, power needs shift dramatically. Certain values wasted more electricity while different ones stretched battery life farther. Finding smarter numbers became the mission after seeing such strong differences across tests.

A lap time tool for hybrid vehicles came together in 2025 through Noronha's work, built with Python to track how energy moves and power spreads. Unlike broad simulations, this one zeroes in on systems that divide power differently. Race scenarios shape its core - control strategies get tested under pressure using software tuned for instant responses. Rather than simplify what batteries do, it captures detailed ways they release energy. Because it mimics how torque mixes, accuracy improves, matching output to how gasoline engines and electric drives work together.

Midway through a race, Karanth, Y., et al. (2025) [12] rolled out an LSTM-driven system meant to predict Formula 1 lap times. Shifting conditions - track heat creeping up, tires losing bite, fuel load lightening - get folded into its calculations. While complex in design, it tweaks forecasts on the fly as variables shift. Each new moment brings updated estimates, adapting without pause.

Out of small tweaks came quick updates, each guess refining the route a bit more. Patel, P., along with team members in 2024, turned to feedforward neural nets to pin down best paths on tracks. Instead of complex setups, they leaned on lightweight math that runs fast. Their method built precise driving lines by design, not chance. Progress showed up quietly, born from stripping things back.

Starting with smart algorithms, Garlick and Bradley explored how self-driving vehicles can plan routes effectively. Instead of fixed paths, their work focused on predicting fast lap times by tapping into live data streams. As conditions changed, machine learning allowed continuous adjustments to navigation choices. Cited here under reference fourteen, the research highlights responsiveness in autonomous driving systems.

Out of raw data streams pulled from MoTec i2 Pro, patterns began to surface. Through algorithmic runs, Hojaji, F., et al. (2024) [15] spotted what really shifts outcomes midway through a race. Fast laps alone didn't tell it - hidden within were decisions, small but weighty. Trends from intense simulated circuits pointed toward timing, flow disruptions, pressure spots. Instead of guessing, models traced behavior grounded in actual performance cues. Surprisingly detailed patterns emerged when algorithms examined behavior, not merely pace. Real online actions formed the foundation, yet meaning stayed hidden until every piece got reviewed.

Close to the edge of what physics allows, Montani, M., et al. (2021) [16] tested a fresh way to steer race vehicles through live path shifts. Rather than sticking to fixed lanes, decisions unfold step by step. As conditions change, small updates refine handling on tight corners and high-speed straights alike. Balance between rapid motion and precision emerges under intense demands.

Deep learning takes over complete driving tasks in race cars, Wadekar, S. N., plus team explored that in 2021. A single neural network links steering with throttle instead of using separate systems. Rather than splitting controls like older approaches do, their design merges decisions into one flow. Raw sensor inputs feed the system straight - no hand-written rules involved. Even though built for circuits, it could work well in other fast-moving situations too. Results showed smoother handling than older methods when tested.

Picardi took a close look at machine learning using Reinforcement Learning, aiming to build AI suited for digital race games. Performance inside simulated tracks became the main interest rather than broad uses across fields. Based entirely on game-like setups, each method was tested deeply - only a few stood out through repeated trials. Even though reinforcement methods showed potential, their edge faded depending on the scenario.

When the weather turns bad, self-driving tech tends to stumble - Fursa and team in 2021 dug into that dip using virtual environments. Instead of real roads, they leaned on digital models to track how much performance slips when rain or fog hits.

Out of nowhere, Chen (2025) - listed as source twenty - dug into race simulations to see how people act when pushed in digital competitions. Instead of just clocking speed, attention drifted toward decisions made under stress.

Out there among solar cars on campus, Forysiak J. led a team peeking into how headsets shape understanding. Not with old-school meters or printouts - instead, live numbers floated in front of testers' eyes. While wheels spun and circuits hummed, learners saw shifts right where they mattered most. Choices behind the wheel linked straight to what flashed in their view moments later.

In 2023, Wu H. together with team members [22] built a system mixing reality layers so digital racers take part alongside live runners on physical tracks. Moving through real circuits, simulated athletes mirror genuine actions, merging screen-based action with grounded motion in shared arenas. As races unfold lap after lap, computerized matchups join forces with live timing, making blended interactions possible across different worlds of competition.

Back in 2021, Shi along with colleagues looked into ways of reducing motion sickness during virtual reality racing experiences - source number 23 points to their work.

That fall, Sawan along with colleagues studied how blended and cutting-edge visual tools shaped sports. Fan reactions shifted, athlete interactions changed - this happened as such systems spread steadily through venues. While clear patterns did not always emerge, signs pointed toward rising approval whenever technology played a bigger role. Moments felt different when virtual layers crossed into live sightlines, especially if they disrupted familiar rhythms without warning. Findings focused on what actually occurred instead of imagined outcomes.

From a different angle, Cossich, V. R. A. (2023) [25] looked into how artificial intelligence, virtual reality, along with augmented reality might be used to assess sports performance - focusing on fresh ways to show information. Though less common, these tools open doors for imaginative displays of athlete data.

Out there among the flashing screens and leaderboards, Markopoulos tossed a new idea into the pit lane back in 2019. Instead of relying only on checkered flags to thrill fans, some F1 crews started using game-like online spaces. Through playful clicks and choices, followers stayed tuned in - no matter how rough the real-world laps got. Victory wasn't the sole hook anymore; what mattered was clicking, playing, staying part of the moment.

Started by Markopoulos, E., along with others in 2019 [27], "F1 Legends" came up as a fresh way. Through it, Formula 1 squads reached fans more directly while spotting sponsorship chances. Not just fanfare - the project reshaped outreach using digital tools few had tried before.

Later on, Simon, J., and team in 2025 looked into where augmented reality apps might head next. Because of smarter algorithms, responses feel more natural these days. Fast internet speeds help too - things load without delays that used to frustrate users. What once seemed rare is shaping how software gets built across different fields.

Later on, Malinen's 2026 study [29] spotlighted how Formula 1 stretched into online spaces. Instead of just mimicking tracks, racing games began mirroring real-world events so closely they gained status as official athletic contests. Because of this shift, more viewers saw simulated races not as play but as true high-speed sport. Off camera, something once seen as pure fun slowly became structured like televised athletics.

III. COMPARATIVE ANALYSIS

Sr. No	Paper Title	Authors	Year	Domain	Key Contributions	Limitations
1	Investigation of Gear Ratios for Hybrid System in Small Race Car Using Lap Time Simulation	Kobayashi I. et al.	2022	Hybrid vehicle simulation	A lightweight torque synthesizer hybrid system was proposed, and quasi-steady lap time simulation was employed to optimize motor and final gear ratios for a 400m straight line.	A simplified vehicle model that excludes load transfer and nonlinear tire dynamics, with evaluation limited to straight-line scenarios.
2	A Basic Study on Hybrid Systems for Small Race Car to Improve Dynamic Performance Using Lap Time Simulation	Kobayashi I. et al.	2022	Hybrid vehicle dynamics	Expanded the hybrid system study to an 800m closed circuit; created a multi-input, multi-output servo model; determined the best gear ratios.	Same simplified model limitations; no differential mechanism taken into account..
3	Machine learning approach for modeling and analyzing driver performance in simulated racing	Hojaji F. et al.	2024	Sim racing / ML	Applied XGBoost, SVM, and Random Forest to telemetry data from 174 participants; determined key performance metrics including speed, lateral acceleration, steering reversal rate, lane deviation, and steering angle.	A limited number of low-skill drivers in the dataset; potential off-tracking laps may not have been completely excluded; only a single track was analyzed..
4	The Future of Augmented Reality Application Development Trends and Opportunities	Simon J. et al.	2025	Augmented Reality	Analyzed AR trends such as AI integration, cloud computing, and 5G; spotted opportunities in education, retail, healthcare, automotive, sports, and the metaverse.	Not specified
5	Drives of Our Time – The Mediatization of Formula One Series to Esports and the Surge of F1 Esports into Media Sports	Malinen V.	2026	Esports / motorsports	A qualitative study employing interviews and social media analysis explored sim racing's place within esports and motorsports, emphasizing disparities in resources and image between F1 and F1 Esports drivers.	Restricted to Europe and the Asia-Pacific region; no female participants were interviewed; only Instagram was analyzed for driver images.
6	Minimum-lap-time optimization and simulation	Massaro M., Limebeer D.J.N.	2021	Vehicle dynamics	A detailed review of minimum-lap-time approaches was conducted, including quasi-steady-state and transient models, optimal control, road modeling, and vehicle positioning, with examples from both cars and motorcycles..	Not specified
7	Worsening Perception: Real-time Degradation of Autonomous Vehicle Perception Performance for Simulation of Adverse Weather Conditions	Fursa I. et al.	2021	Autonomous racing	Created a lightweight system for weather enhancement, including droplets and low light conditions, to degrade perception in real time with less than 8ms latency; tested on both real and simulated tracks.	Discrepancy between the simulated map and the real-world environment; low-light performance remains inadequate.
8	Towards End-to-End Deep Learning for Autonomous Racing: On Data Collection and a Unified Architecture for Steering and Throttle Prediction	Wadekar S.N. et al.	2021	Autonomous racing	Set up data collection protocols for predicting steering; showed combined steering and throttle learning without using feedback or recurrent connections.	Throttle prediction needed individual training; optimal path learning was not achieved (only high-speed stability was maintained).

9	Mixed and Augmented Reality Applications in the Sport Industry	Sawan N. et al.	2020	AR/VR in sports	Examined MR/AR applications in sports and identified six factors: training, marketing, fan experience, engagement, alternative during the pandemic, and sports evaluation.	Not specified
10	Virtual Reality Sickness Mitigation Methods: A Comparative Study in a Racing Game	Shi R. et al.	2021	VR sickness	Compared FOV reduction, DOF blur, and rest frame (target reticule) in a VR racing game; found no significant difference in sickness reduction; both FOV and DOF caused information loss.	Only participants who are young adults; only subjective measurements; a single racing game scenario.
11	Mixed Reality Racing: Combining Real and Virtual Motorsport Racing	Wu H. et al.	2023	Mixed reality	Introduced real-time mixed reality racing allowing e-racers to compete against a real vehicle; an AR app for spectators; received positive user feedback.	A small sample size was used for driving experience (n=3); the virtual car was not visible in the real driver's view.
12	Technological Breakthroughs in Sport: Current Practice and Future Potential of Artificial Intelligence, Virtual Reality, Augmented Reality, and Modern Data Visualization in Performance Analysis	Cossich V.R.A. et al.	2023	Sports technology	A detailed examination of AI, VR, AR, and data visualization in sports performance analysis, along with a suggested integrated performance analysis model.	Not specified
13	Lap Time Simulation For A Formula Student Car	Albertsson T. et al.	2024	Lap time simulation	Created point-mass and bicycle quasi-steady-state LTS with a GUI; features multi-event simulation, parameter sweep, and sensitivity analysis.	The bicycle model's pitch implementation is incomplete; while the required lap time accuracy of ±5 seconds was achieved, the desired accuracy of ±3 seconds was not met.
14	Investigating Performance Metrics in Simulator Racing with Existing Dataset	Chen Z.	2025	Cognitive science / sim racing	Utilized the existing IMSRaceII dataset; created a data cleaning pipeline for data not controlled experimentally; determined predictive metrics (throttle, off-throttle, path distance).	Significant data loss occurred during the cleaning process; the resulting sample size was small; and the predictive validity of the brake metrics was low.
15	Exploring Augmented Reality HMD Telemetry Data Visualization for Strategy Optimization in Student Solar-Powered Car Racing	Forysiak J. et al.	2025	AR / solar racing	Compared web-based and AR HMD telemetry visualization; AR HMD notably assisted less experienced users in specific tasks (e.g., tire puncture detection).	A controlled laboratory setting; restricted to four event types; small sample size for each condition.
16	Efficient Gear Ratio Selection of a Single-Speed Drivetrain for Improved Electric Vehicle Energy Consumption	Spanoudakis P. et al.	2020	EV energy efficiency	An experimental and simulation study on a single-speed electric vehicle found that a lower gear ratio of 1:6 resulted in 2.6% less energy consumption compared to 1:8, indicating that an optimal gear ratio can decrease grid demand.	Only three gear ratios were tested; results are specific to the vehicle.
17	A comparison of Different Machine Learning Techniques to Develop the AI of a Virtual Racing Game	Picardi A.	2021	ML / game AI	Compared Reinforcement Learning, Imitation Learning (GAIL), and Curriculum Learning for a racing game; Curriculum Learning achieved the best lap time, the highest full-throttle time, and the fewest crashes.	AI could become unbeatable if reward limits are not properly set, due to computational power constraints.
18	Minimum-lap-time of race vehicles	Veneri M.	2019	Optimal control / lap time	PhD thesis focused on creating steady-state models for cars and motorcycles, generating g-g diagrams, and developing quasi-steady-state apex-finding and OCP methods; introduced free-trajectory QSS OCP.	Not specified
19	Curved-ribbon-based track	Lovato S. et	2021	Track	The extended flat-ribbon road model	Assumption of a small camber

	modelling for minimum lap-time optimisation	al.		modelling	was expanded to account for lateral camber variations and was applied to Darlington Raceway, where changes in lateral camber can shift the optimal trajectory by several meters.	angle; only one track type.
20	Hierarchical autonomous driver for racing cars using real-time trajectory planning	Montani M. et al.	2021	Autonomous racing	Created a real-time trajectory planner using sequential convex programming (LP) and LQR for path tracking; achieved planning times under 0.1 seconds; lap time similar to that of a professional driver.	A simplified point-mass vehicle model is used, without a tire model, and offline pre-training is required for new tracks.
21	Real-time optimal trajectory planning for autonomous vehicles and lap time simulation using machine learning	Garlick S., Bradley A.	2022	Autonomous racing / ML	A trained feedforward neural network was used on more than 6000 circuits to predict the racing line in 33ms, which is 9000 times faster than OCP, with a MAE of ±0.27m; this makes it suitable for real-time trajectory planning.	Network predicts the racing line only; it does not generate a speed trace and requires significant offline training.
22	Machine learning-based dynamic trajectory optimization and lap time estimation for autonomous racing vehicles	Patel P. et al.	2025	Autonomous racing / ML	Comparable to Garlick & Bradley; employed ANN to forecast the racing line with an inference time of 33ms; MAE ±0.27m, apex error ±0.11m.	Not specified
23	Development of a lap time simulation tool for hybrid vehicles	Noronha L.F.	2025	Hybrid vehicle simulation	Created a Python-based quasi-steady point-mass LTS for hybrid vehicles; utilized B-spline track data from GPS; optimized MGU-K deployment strategies for qualifying and race situations.	MGU-H effects were approximated; thermal and wear models were not included; the distance-based strategy requires conversion into lookup tables.
24	Predicting Lap Times of Formula 1 Races using ANN	Karanth Y. et al.	2025	deep learning	An LSTM model that includes tire degradation (logarithmic), fuel consumption, and track temperature was assessed across several races, yielding R^2 scores ranging from 0.06 to 0.20.	Low R^2 value; pit stop impacts were not included in the model; limited data on soft tires; track conditions changes were not taken into account.
25	Lap Time Simulation Tool for the Development of an Electric Formula Student Car	Doyle D. et al.	2019	EV Formula Student	Created a Simulink-based LTS featuring four in-hub motors; utilized g-g-V diagrams; performed sensitivity analysis using Latin Hypercube; defined gear ratio (11) and battery capacity (6.764 kWh).	No test vehicle was available for validation; DUT12 data was used for partial validation; point-mass assumptions were made.
26	Lap time simulation technology for performance design during production car development	Toyoshima T. et al.	2019	Production car development	Created a lap time simulation for production cars (NSX, Civic Type R); applied circular arc and full transition curve techniques; generated various performance metrics.	Not specified
27	Lap time simulation for a Formula Student car	Broatch K.	2019	lap time simulation	A transient Simulink LTS model was developed using empirical data from bench tests; it was compared to actual lap times with approximately 10% accuracy and included optimization for the speed profile.	Insufficient load transfer and clutch model; braking deceleration was underestimated; GPS inaccuracies.
28	A gamified approach towards identifying key opportunities and potential sponsors for the future of F1 racing in a declining car ownership environment	Markopoulos E. et al.	2019	F1 / gamification	Expanded the VR sponsorship model to include the “F1 Legends” game; introduced ideas for multiplayer and campaign modes; explored strategies for monetization and user engagement.	Not specified
29	Virtual and Augmented Reality gamification technology to reinvent F1 sponsorship models	Markopoulos E. et al.	2019	F1 / VR/AR	Proposed VR F1 game featuring virtual sponsorships, dynamic advertising, and data collection to target new fan groups and attract sponsors; includes SWOT and BCG analysis.	Not specified

Table 1: Comparative Analysis

IV. RESEARCH GAP

Some past research looks at things like quick and slow lap simulations, how race cars respond to driver inputs, visuals showing g-forces, ways to manage hybrid power during races, smart predictions for best routes on track, also mixed or digital overlays used in racing tech. Yet not one dives into blending ghost car setups - showing a perfect model drive next to actual driving right now - within existing sim platforms. Areas remain untouched: instant reactions from racers on real tracks using up-to-the-second competition numbers, building fastest laps via machine learning, mixing digital opponents into combined fuel strategies, even checking whether such practice tools bring results close to elite-level performers.

V. FUTURE DIRECTION

Imagine racing against a shadow version of your best lap. That idea works well in smaller Formula 1 classes, turning numbers into clear visuals for drivers and crew alike. Instead of just charts and graphs, they see how each turn compares - where brakes were hit earlier or later, when the steering started changing mid-corner, how fast through the middle, whether power came on smoother. Seeing those differences helps talk about adjustments without guesswork. Young racers get sharper feedback even with fewer track sessions and less hardware to gather info. Mistakes stand out faster. Setup ideas prove themselves quicker too. Confidence builds because progress shows up plainly - not assumed, but visible.

VI. CONCLUSION

Ghost vehicles in simulation runs pushed racing analytics far past old limits. Teams watch exact differences unfold visually, ditching guesswork for live feedback. Merging car behavior models with virtual circuits reveals how drivers respond when stress climbs. A split second shows tires losing grip. The moment after captures tiny shifts in brake timing lap to lap. Right there beside the real machine, a digital twin delivers immediate clarity - even perfect predictions feel sharper. Split assessments? They click fast, almost without thought, once numbers on screen match rhythm on track. Fewer laps mean less wear, fewer fuel burns, lower costs piling up behind every tweak. Rookies learn quicker by shadowing avatars that move just like seasoned drivers. Decisions gain pace when tested first in lifelike duels inside the simulation world. Later on, these online versions could help machines improve themselves. As time passes, how well they work is easier to see because computer copies move at the same pace as physical ones.

REFERENCES

[1] Kobayashi, Ikkei, Kazuki Ogawa, Daigo Uchino, Keigo Ikeda, Taro Kato, Ayato Endo, Takayoshi Narita, and Hideaki Kato. "Investigation of gear ratios for hybrid system in small race car using lap time simulation." IFAC-PapersOnLine 55, no. 27 (2022): 442-447.

[2] Kobayashi, Ikkei, Kazuki Ogawa, Daigo Uchino, Keigo Ikeda, Taro Kato, Ayato Endo, Mohamad Heerwan Bin Peeie, Takayoshi Narita, and Hideaki Kato. "A basic study on hybrid systems for small race car to improve dynamic performance using lap time simulation." In Actuators, vol. 11, no. 7, p. 173. MDPI, 2022.

[3] Veneri, Matteo. "Minimum-lap-time of race vehicles." (2019).

[4] Doyle, Darryl Alan, Geoffrey Cunningham, Gavin White, and Juliana Early. "Lap time simulation tool for the development of an electric formula student car." In WCX SAE World Congress Experience. SAE Technical Paper, 2019.

[5] Albertsson, Tim, Isak Nilsson, and Alexander Wigh. "Lap time simulation for a Formula Student car." (2024).

[6] Toyoshima, Takayuki, Toshiaki Matsuzawa, and Tomoya Ushimura. "Lap Time Simulation Technology for Performance Design during Production Car Development." Honda R&D Technical Review 29, no. 2: 124-133.

[7] Broatch, Kester. "LAP TIME SIMULATION OF A FORMULA STUDENT RACING CAR." (2019).

[8] Massaro, M., and D. J. N. Limebeer. "Minimum-lap-time optimisation and simulation." Vehicle System Dynamics 59, no. 7 (2021): 1069-1113.

[9] Lovato, S., M. Massaro, and D. J. N. Limebeer. "Curved-ribbon-based track modelling for minimum lap-time optimisation." Meccanica 56, no. 8 (2021): 2139-2152.

[10] Spanoudakis, Polychronis, Gerasimos Moschopoulos, Theodoros Stefanoulis, Nikolaos Sarantinoudis, Eftichios Papadokokolakis, Ioannis Ioannou, Savvas Piperidis, Lefteris Doitsidis, and Nikolaos C. Tsourveloudis. "Efficient gear ratio selection of a single-speed drivetrain for improved electric vehicle energy consumption." Sustainability 12, no. 21 (2020): 9254.

[11] Noronha, Luís Felipe Ávila D'Aquino. "Development of a lap time simulation tool for hybrid vehicles." (2025).

[12] Karanth, Yashas. (2025). Predicting Lap Times of Formula 1 Races using ANN. INTERANTIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT. 09. 1-9. 10.55041/IJSREM43286.

[13] Patel, Parth, Madhusudan Barot, and Krupal Shah. "MACHINE LEARNING-BASED DYNAMIC TRAJECTORY OPTIMIZATION AND LAP TIME ESTIMATION FOR AUTONOMOUS RACING VEHICLES."

[14] Garlick, Sam, and Andrew Bradley. "Real-time optimal trajectory planning for autonomous vehicles and lap time simulation using machine learning." Vehicle System Dynamics 60, no. 12 (2022): 4269-4289.

[15] Hojaji, Fazilat, Adam J. Toth, and Mark J. Campbell. "A machine learning approach for modeling and analyzing of driver performance in simulated racing." In Irish Conference on Artificial Intelligence and Cognitive Science, pp. 95-105. Cham: Springer Nature Switzerland, 2022.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

[16] Montani, Margherita, Leandro Ronchi, Renzo Capitani, and Claudio Annicchiarico. "A hierarchical autonomous driver for a racing car: Real-time planning and tracking of the trajectory." Energies 14, no. 19 (2021): 6008.
[17] Wadekar, Shakti N., Benjamin J. Schwartz, Shyam S. Kannan, Manuel Mar, Rohan Kumar Manna, Vishnu Chellapandi, Daniel J. Gonzalez, and Aly El Gamal. "Towards end-to-end deep learning for autonomous racing: On data collection and a unified architecture for steering and throttle prediction." arXiv preprint arXiv:2105.01799 (2021).
[18] Picardi, Alessandro. "A comparison of Different Machine Learning Techniques to Develop the AI of a Virtual Racing Game." PhD diss., Politecnico di Torino, 2021.
[19] Fursa, Ivan, Elias Fandi, Valentina Musat, Jacob Culley, Enric Gil, Izzeddin Teeti, Louise Bilous, Isaac Vander Sluis, Alexander Rast, and Andrew Bradley. "Worsening perception: Real-time degradation of autonomous vehicle perception performance for simulation of adverse weather conditions." SAE International Journal of Connected and Automated Vehicles 5, no. 12-05-01-0008 (2022): 87-100.
[20] Chen, Zongchan. "Investigating Performance Metrics in Simulator Racing with Existing Dataset." perspectives 25 (2025): 101105.
[21] Forysiak, Jakub, Piotr Krawiranda, Krzysztof Fudała, Zbigniew Chaniecki, Krzysztof Jóźwik, Krzysztof Grudzień, and Andrzej Romanowski. "Exploring Augmented Reality HMD Telemetry Data Visualization for Strategy Optimization in Student Solar-Powered Car Racing." Energies 18, no. 12 (2025): 3196.
[22] Wu, Hsuehhan, Kelvin Cheng, Madoka Inoue, and Soh Masuko. "Mixed Reality Racing: Combining Real and Virtual Motorsport Racing." In ACM SIGGRAPH 2023 Posters, pp. 1-2. 2023.
[23] Shi, Rongkai, Hai-Ning Liang, Yu Wu, Difeng Yu, and Wenge Xu. "Virtual reality sickness mitigation methods: A comparative study in a racing game." Proceedings of the ACM on Computer Graphics and Interactive Techniques 4, no. 1 (2021): 1-16.
[24] Sawan, Nedal, Ahmed Eltweri, Caterina De Lucia, Luigi Pio Leonardo Cavaliere, Alessio Faccia, and Narcisa Roxana Moşteanu. "Mixed and augmented reality applications in the sport industry." In Proceedings of the 2020 2nd International Conference on E-Business and E-commerce Engineering, pp. 55-59. 2020.
[25] Cossich, Victor RA, Dave Carlgren, Robert John Holash, and Larry Katz. "Technological breakthroughs in sport: Current practice and future potential of artificial intelligence, virtual reality, augmented reality, and modern data visualization in performance analysis." Applied Sciences 13, no. 23 (2023): 12965.
[26] Markopoulos, Evangelos, Panagiotis Markopoulos, Mika Liumila, Ya Chi Chang, Vasu Aggarwal, and Jumoke Ademola. "Virtual and augmented reality gamification technology on reinventing the F1 sponsorship model not purely focused on the team's and car's performance." In International Conference on Applied Human Factors and Ergonomics, pp. 364-376. Cham: Springer International Publishing, 2019..
[27] Markopoulos, Evangelos, Panagiotis Markopoulos, Mika Liumila, Younus Almufti, Chiara Romano, and Paulina Vanessa Benitez. "A gamified approach towards identifying key opportunities and potential sponsors for the future of F1 racing in a declining car ownership environment." In International Conference on Applied Human Factors and Ergonomics, pp. 179-191. Cham: Springer International Publishing, 2019.
[28] Simon, János, László Gogolák, and Zlatko Čović. "The Future of Augmented Reality Application Development Trends and Opportunities." Analecta Technica Szegedinensia 19, no. 1 (2025): 28-37.
[29] Malinen, Ville. "Drives of our time: the mediatization of Formula One series to esports and the surge of F1 esports into media sports." PhD diss., University of Jyväskylä, 2026.
[30] https://www.waveydynamics.com/post/lap-time-simulation
[31] https://www.thedrive.com/news/41447/f1-ghost-video-shows-verstappens-pole-came-down-to-one-corner
[32] https://python.plainenglish.io/creating-a-dynamic-track-animation-from-an-f1-lap-time-simulator-fb2ba7e93317