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CONCEPTUAL PROPOSAL FOR ENHANCING AUTONOMOUS TAXI SYSTEMS: A FOCUS ON TESLA'S CYBERCAB

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ABSTRACT

This work provides a comparative analysis of Tesla's autonomous taxi model (referred to as robotaxi or Cybercab) and proposes a new design focused on enhancing efficiency and accessibility. Previous studies have examined efficiency differences between internal combustion engine (ICE) vehicles and electric cars, as well as the specific requirements of city taxis compared to high-speed vehicles, concluding that a specialized design could yield more efficient electric taxis. Our proposed robotaxi concept aims to address several limitations in Tesla's design, including:

1. **Increased Passenger Capacity:** Expanding seating from 2 to 4 passengers.
2. **Enhanced Accessibility:** Featuring a taller cabin, larger doors, and compatibility for wheelchair users traveling alone.
3. **Simplified Mechanics:** Using two sliding doors instead of Tesla's three upward-opening doors.
4. **Improved Luggage Access**: Positioning luggage space within the passenger cabin for convenience.

These modifications are expected to increase fuel efficiency relative to Tesla's model and reduce environmental impact, as discussed herein.

Keywords: energy efficiency in taxis; electric vehicle design; low-rolling resistance tires; aerodynamic drag reduction; Tesla Cybercab; accessible autonomous taxis.

INTRODUCTION

Globally, there are approximately 6 million taxis, with this market continuing to grow (Report #1, 2022), resulting in increased environmental impacts. A New York taxi driver, working around the clock, averages 130,000 miles per year, which is nearly nine times the mileage of an average driver (Report #2, 2022; Report #3, 2008). As a result, replacing an internal combustion engine (ICE) taxi with an electric vehicle (EV) yields environmental benefits nine times greater than for a typical end-user vehicle. Despite this, government subsidies have largely followed a customer-centered (and car manufacturer-centered) approach, incentivizing EV purchases without regard to usage frequency. While this market-driven strategy has fostered a robust electric car market, with 14 million EVs sold globally in 2023, it has not prioritized the development of more efficient taxis. Our previous work (Juanicó, 2024) suggested that designing specifically for the needs of urban mobility could address this gap by leveraging the unique advantages of electric cars.

Many recent ideas for electric taxis focus on car-sharing solutions (Henser et al., 2022; Prencipe et al., 2022; Tesla, 2024). Tesla's newly launched "robotaxi," the Cybercab, is an autonomous vehicle designed as a sleek, two-passenger taxi with a spacious luggage area. This low-profile, highly aerodynamic design aims to maximize fuel efficiency but sacrifices seating capacity, accommodating only two passengers. Tesla argues that this configuration is suitable for 84% of taxi trips, which typically involve one or two passengers, positioning it as an ideal solution for an efficient "robotaxi."

However, this approach has several limitations. This work will analyze the weaknesses of Tesla's Cybercab design based on a detailed examination of urban energy loss in transportation. We will then propose an alternative robotaxi design that addresses these shortcomings while maintaining a high level of efficiency.

ANALYSIS OF TAXI EFFICIENCY

Currently, most taxis use vehicles originally designed for the general consumer market rather than for the specific demands of taxi service. An exception is the traditional English LTI LX4 black cab (Report #4, 2018), which maximizes passenger space with two double seats facing each other. This design was later enhanced in the Nissan NV200, which features two sliding doors and two foldable seats to accommodate wheelchairs. Both models use a front internal combustion (IC) engine with rear-wheel drive (RWD) to achieve a minimal turning radius, avoiding the drawbacks of front-wheel drive, though this setup requires a Cardan shaft. In contrast, electric motors' compact size and minimal vibrations enable direct rear axle mounting, which is why many single-motor electric vehicles (EVs) use RWD. Other EVs opt for an all-wheel-drive (AWD) setup to achieve a sportier feel, but for urban taxis, simplicity and maneuverability should be prioritized—making RWD an optimal choice for minimizing the turning radius and maximizing the mechanical simplicity.

Urban taxis have two unique operating conditions that could be leveraged to optimize electric taxi design:
1) Taxis travel at low speeds on city streets, typically under 40 km/h.
2) A taxi's maximum speed could be limited to 80 km/h without affecting travel time, given that suburban highway speeds do not exceed this limit. Most consumer vehicles are over-engineered for maximum speeds up to 200 km/h, which is unnecessary for urban taxi applications.

The low-speed operation makes it possible to avoid designing around aerodynamic drag, which typically pushes sports car designs to be as low as possible. This low-profile design, however, limits passenger accessibility—a critical feature for taxis, especially for passengers with limited mobility. Given that aerodynamic losses are insignificant below 40 km/h, a taller vehicle structure could improve accessibility without compromising efficiency. This accessibility is especially vital in autonomous taxis, as passengers with reduced mobility need to board independently, without assistance from a driver. Tesla's Cybercab, for instance, would require an additional person to assist a wheelchair user, making it less practical for unassisted use. In traditional taxis, a driver can assist a lone passenger in a wheelchair with boarding and stowing the wheelchair. However, this assistance is not available in an autonomous taxi. For a wheelchair user to ride in an autonomous taxi, they would need to be accompanied by someone capable of transferring them from the wheelchair into the Cybercab's low seat, then folding the wheelchair and placing it in the rear luggage compartment. This process is physically demanding, especially considering the weight of the individual and the wheelchair, which can be substantial for motorized models. Moreover, this lengthy and complex boarding process must be completed on the street, potentially obstructing traffic and exposing both passengers and helpers to adverse weather conditions.

The second condition presents a significant opportunity to reduce energy loss from rolling resistance by using low-resistance tires and other minor modifications. Rolling resistance, often overlooked in ICE vehicle design, is crucial for EV efficiency. To understand why, let us consider the basic mechanics of energy loss in ICE cars.

The average efficiency of ICE vehicles is about one-third—only a third of the gasoline's energy is converted to propulsion, while the remainder is lost as heat. The effective energy is used to counterbalance various losses: aerodynamic drag, idle engine operation when stopped, and frictional forces from rolling resistance and braking. While aerodynamic drag is minimal at low urban speeds, brake friction and engine idle losses lead to higher fuel consumption in city driving than on highways. For instance, a Toyota Corolla averages 10 liters per 100 km in urban driving compared to 6 liters per 100 km on highways at 45 mph. Since rolling resistance is consistent across speeds and equal to aerodynamic drag at 45 mph (3 l/100km each), it contributes to only about 30% of urban energy consumption. Consequently, rolling resistance has typically been deprioritized for ICE efficiency improvements; studies show that low-resistance tires could reduce gasoline consumption by just 1.5-4.5% overall (Report #7).

Electric vehicles, however, avoid brake and idle losses through regenerative braking and lack of idle states. This difference enables EVs to consume less than half the energy on urban trips compared to highways. For instance, the small electric Renault Twingo consumes only 6.5 kWh/100 km in urban driving but 17 kWh/100 km at 120 km/h.

Our analysis highlights that EVs are better suited for urban taxi applications due to their efficiency in city driving. Next, we examine the underappreciated relationship between rolling resistance and maximum speed, leveraging this connection to enhance electric taxi efficiency.

Rolling resistance is often underemphasized by car designers, who regard it as a “necessary evil” for essential vehicle control, such as braking and turning. To ensure stability, rolling resistance is usually optimized for the most challenging conditions. Given that kinetic energy—and, thus, required rolling resistance—increases with the square of speed (relevant for both straight-line braking and turning on curves), designers base calculations on the car’s top speed, often around 200 km/h for modern vehicles.

This over-preparation results in rolling resistance values much higher than needed for typical urban and suburban driving. For instance, at 200 km/h, rolling resistance must be six times greater than required for local driving (up to 80 km/h) and 25 times more than necessary for city speeds (up to 40 km/h). In urban environments, this excess resistance causes significant energy losses that are avoidable in electric taxis.

To address this, we propose reducing average rolling resistance by about 50% for urban-use electric taxis, a change that could halve energy consumption in city driving. However, reducing rolling resistance can also affect the car's braking capacity, so a balanced approach is necessary.

A key proposal is to adjust rolling resistance differently for the front and rear axles, reflecting their specific functions. The front axle handles most braking force due to weight transfer during deceleration, and is also responsible for steering. Rear-wheel-drive (RWD) vehicles, commonly used for non-sport, utility-focused applications like taxis, rely on the rear axle primarily for acceleration. With these roles in mind, we recommend a differential approach: a modest 25% rolling resistance reduction on the front axle and a more substantial 75% reduction on the rear axle. This combination would reduce average rolling resistance by half while only slightly compromising braking capacity (around 25%).

The following modern features could effectively compensate for this reduction in rolling resistance:
1. **Enhanced Braking Systems:** Equipping all wheels with disc brakes and ABS would improve braking performance and offset the slightly lower stopping power from reduced rolling resistance.

2. **Emergency Brake Assistance:** Autonomous taxis could include emergency brake assistance to ensure quick and safe stops when necessary.

3. **Autonomous “Defensive” Driving:** An autonomous defensive driving system would anticipate traffic conditions, minimizing the need for sudden braking and potentially preventing many accidents typically caused by driver error. Additionally, an AI-driven system can adapt driving strategies to road conditions, such as wet or icy surfaces.

4. **Adaptive Tire Pressure Control**: The AI system could also manage tire pressure dynamically, adjusting it to match road conditions and further fine-tuning rolling resistance.
By integrating these features, this tailored approach to rolling resistance could significantly enhance the efficiency of electric taxis, specifically for urban environments, without sacrificing safety or performance.

CONCEPTUAL DESING OF A DIFFERENT ROBOTAXI

Our proposed robotaxi design addresses four main limitations observed in Tesla’s Cybercab: accessibility, passenger capacity, fuel efficiency, and environmental impact. Here’s a breakdown of each issue and how our design aims to improve upon them:

1. **Accessibility**. The low seating position in the Cybercab complicates the boarding process, particularly for passengers with reduced mobility. Moreover, a solo wheelchair user cannot board without assistance, as the Cybercab requires a helper to transfer the user, fold the wheelchair, and stow it in the luggage compartment. This process is time-consuming, takes place outdoors, and can obstruct traffic. In contrast, our design, inspired by the London taxi (Nissan NV200), features two sliding doors and foldable seats for easy wheelchair access. By using the space typically reserved for a driver, we expand the passenger cabin, allowing a wheelchair to be positioned facing forward during travel or near the exit for easier egress. Additionally, our design includes AI-powered automatic doors and a deployable platform to facilitate entry for wheelchair users.

2. **Passenger Capacity**. Tesla's Cybercab seats only two passengers, based on data suggesting that 84% of taxi trips involve one or two riders. While this configuration meets the majority of use cases, it leaves some passengers underserved, such as a parent traveling with two children who may need to send one child alone in a separate Cybercab. Our four-passenger design resolves this issue, offering flexibility for larger parties without requiring multiple vehicles, which enhances service quality and safety, especially for vulnerable passengers.

3. **Fuel Efficiency.** Tesla claims the Cybercab will achieve high fuel efficiency, largely due to its aerodynamic body and lightweight cabin design. However, as discussed earlier, aerodynamic advantages are less relevant at urban speeds and the Cybercab's oversized luggage space adds unnecessary weight. Our design doubles the cabin space by integrating luggage storage within the passenger cabin, yet maintains high fuel efficiency by using low-resistance tires. If both models achieve similar energy consumption, our four-passenger configuration would be 100% more efficient than Tesla's for the 16% of trips that would otherwise require two Cybercabs.

4. **Environmental Impact**. By providing additional passenger capacity in a single vehicle, our design reduces the need for an expanded fleet, which could otherwise lead to increased environmental burdens. Tesla's approach would require an estimated 16% more Cybercabs to meet demand, resulting in higher production, operational, and maintenance costs. Furthermore, scenarios requiring immediate access to a second Cybercab (such as for family trips) could necessitate an even larger fleet. Our design's increased capacity mitigates this need, minimizing both direct and indirect environmental impacts.

CONCLUSIONS

This work demonstrates the potential to enhance the efficiency and functionality of electric taxis through a design tailored specifically for urban needs, particularly by optimizing rolling resistance and improving accessibility. Unlike standard ICE vehicles, electric vehicles (EVs) benefit significantly from modifications to rolling resistance, making this a key factor in achieving energy efficiency in city environments. Our analysis has shown that a specialized approach for EV taxis—focusing on the unique conditions of urban driving—can deliver substantial energy savings.

The Cybercab design by Tesla achieves efficiency through aerodynamics and a compact, two-passenger layout. However, we have proposed an alternative autonomous taxi design that better meets the specific needs of urban taxi service. Our design improves upon the Cybercab by offering:

- **Increased Capacity:** accommodating up to four passengers, our design addresses the needs of larger groups without requiring multiple vehicles, enhancing convenience and safety for families or groups.
- **Enhanced Accessibility:** featuring a taller cabin, larger sliding doors, and wheelchair-friendly features, our design allows unassisted access for passengers with reduced mobility.
- **Efficient Design Choices:** by incorporating low-resistance tires and optimized rolling resistance, our design maintains high fuel efficiency despite the additional cabin space and increased passenger capacity.
- **Lower Environmental Impact:** with increased passenger capacity, our design reduces the need for a larger fleet, thereby minimizing production and operational demands. This result in a reduced environmental footprint compared to the Cybercab's smaller, two-passenger model.

In summary, this proposal provides a practical and efficient alternative to the current Cybercab model, offering improved accessibility, capacity, and sustainability, making it better suited for urban taxi services.

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