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Autonomous Mobility-On-Demand – A Solution for Sustainable Urban Personal Mobility

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According to the United Nations, the world population living in urban areas will double by 2050, with most of the urbanization occurring in the developing regions of Asia and Africa. Meanwhile, private car ownership continues to skyrocket, causing traffic congestion and pollution in the increasingly dense urban environment with limited available land for road expansion and parking spaces. All of this points towards the reality that private automobiles, which have served all of our personal mobility needs in the past century, are an unsustainable solution for the future of personal urban mobility.

One of the most promising approaches to solving the personal urban mobility problem is through one-way car sharing with light electric vehicles, also known as mobility-on-demand (MOD) systems. Car sharing has the potential to increase vehicle utilization rates, which are currently below 10% for private automobiles, and to promote sustainable urban land use, since fewer cars require less parking space. In the past few years, MOD services have begun operation in dozens of cities throughout North America and Europe, with notable examples including CAR2GO and Autolib' Paris.

The GM EN-V vehicle

Where Automonous Cars Rule

However, because some destinations in a city are more popular than others, customer trips to popular destinations will deplete cars from certain areas of the city, causing imbalance in the system. This imbalance strongly affects the availability of vehicles throughout the city and negatively impacts the convenience that was promised by this type of system. Proposed solutions to this problem include offering price incentives to customers, encouraging ride sharing/splitting, or hiring a team of drivers to rebalance the vehicles. However, incentivizing ride sharing adds inconvenience for customers and hiring rebalancing drivers increases costs for the service operator. This leads to increased prices for customers and less spending on maintenance and customer service, which are crucial for customer satisfaction. Indeed, a quick glance at the reviews for CAR2GO on Yelp reveals many of these underlying problems.

Very recently, a transformational technology is emerging where on-demand mobility is provided by driverless cars. The technology of robotic vehicles has progressed rapidly since the DARPA Grand Challenge in 2005, and robotic vehicles designed specifically for personal mobility are already being produced and marketed (for example, the Google car, Induct NAVIA, and General Motors' EN-V vehicle). Robotic vehicles hold great promise for MOD systems because they can rebalance themselves, thus eliminating the problem of system imbalance at its core. In addition, autonomous vehicles can relieve commuters from the burdens of driving, enable system-wide coordination, and potentially increase safety. Finally, through system-level coordination, autonomous vehicles can use existing road infrastructure more efficiently by following other autonomous vehicles more closely and help alleviate congestion by routing vehicles away from heavily congested areas. All of these benefits can translate into long-term environmental sustainability and potential cost savings for customers without sacrificing the convenience of personal mobility.

Reduced Environmental Costs

The environmental benefits of autonomous MOD systems result from the fact that car sharing yields high utilization rates and that vehicles are restricted to operate in a limited urban setting. An autonomous MOD system in a city will consist of mostly a single type of vehicle, which can be mass produced and maintained cheaply and efficiently by leveraging economies of scale. The high utilization rates of these vehicles will result in a shorter vehicle life span, allowing new technologies to be quickly deployed and integrated into the system. Sustainable recycling practices can be implemented to minimize the impact of manufacturing new vehicles. Purely electric vehicles are very suitable for autonomous MOD systems because vehicles are restricted to operate within the boundaries of a city. They will be able to charge their batteries when not serving customers, their speeds will be limited by what is practical in urban driving (around 20 mph), and charging constraints can be taken into account through system coordination to guarantee that vehicles have enough charge to carry passengers to their destinations. The relatively slow speeds of the vehicles, along with additional safety due to autonomous driving, means that the vehicles can be lighter, further enhancing their energy efficiency and sustainability.

For example, the MIT CityCar, the original vehicle proposed for MOD systems, weighs only 450 kg (40% the mass of a mid-sized sedan). If we made all urban trips in light electric vehicles such as the CityCar rather than privately owned gasoline-powered sedans, we would cut our energy expenditure by almost 50%, after taking into account additional trips made for system rebalancing. Depending on the energy infrastructure of the city, the CO2 emissions can potentially be reduced to zero. Furthermore, the batteries in the electric vehicles provide a large bank of energy storage and can sell electricity back into the power grid to mitigate peak demand, which is beneficial to renewable but intermittent energy sources such as solar and wind.

How Does it Work?

The practical benefits of autonomous MOD systems can lead to their widespread implementation in the next 5 to 10 years. Currently in the busiest cities in the US, traffic congestion adds an additional 60 hours per commuter per year in travel time for commuters. If commuters didn't have to be burdened with driving, this wasted time on the road can be turned into productive work, which can be converted into an average cost saving of over $800 per person per year! Perhaps most importantly, when operated correctly, an autonomous MOD system can in fact increase convenience compared to privately owned vehicles. Customers will be able to call a vehicle from their smartphones just prior to leaving their home, and by the time they step outside, the vehicle will be waiting for them. Customers can be productive while inside the vehicle and upon arrival at their destinations, would not need to worry about finding parking.

Through intelligent coordination techniques, autonomous MOD systems has the potential to drastically reduce the number of vehicles we need. A recent study conducted jointly between Stanford and the Singapore-MIT Alliance for Research and Technology (SMART) found that if we replaced all forms of transportation in Singapore with a single autonomous MOD system, we would need only need 300,000 vehicles, or one third the current number of cars in Singapore. Finally, robotic vehicles also hold the promise to increase safety by eliminating human factors, which contribute to 95% of current traffic accidents.

The Way Forward

Despite all the advantages of autonomous MOD systems, there are two key challenges that must be addressed before their widespread implementation. Firstly, even though autonomous driving technology has progressed a long way in the past decade, there is virtually an infinite number of possible traffic scenarios and weather conditions that an autonomous vehicle might find itself in. The robustness of the algorithms controlling autonomous vehicles have not been validated in these scenarios and therefore the absolute safety of the vehicles cannot be guaranteed. The problem arises particularly when autonomous vehicles interact with pedestrians and other human-driven vehicles. To tackle this problem, we must learn more about how humans interact with autonomous vehicles through small scale deployment and extensive testing.

Secondly, system-wide coordination of autonomous vehicles is essential to realizing the full financial benefits and convenience of autonomous MOD systems. One key criticism of autonomous MOD systems is that they may in fact increase traffic congestion due to the additional (empty) vehicles that are on the road en route to their next pickup. While it is true that more vehicles will be on the road for the same number of passenger trips, preliminary studies of simulations on road networks conducted at Stanford have shown that empty vehicles redistributing themselves throughout the city will typically travel along less-congested roads, and are unlikely to contribute to the maximum congestion in the city. However, this is highly dependent on how intelligently vehicles are routed throughout the city.

Research into autonomous MOD systems are still in its infancy, and while they hold great promise to provide sustainable urban personal mobility in the near future, several technological advancements are needed to fully realize their potential. The success of such a system is inherently tied to the commuter's willingness to adopt this technology because, ultimately, the MOD model represents a paradigm shift away from private ownership towards collective sharing and public ownership of our transportation infrastructure for a more sustainable future.

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