We present and analyze a queuing-theoretical model for autonomous mobility-on-demand (MOD) systems where robotic, self-driving vehicles transport customers within an urban environment and rebalance themselves to ensure acceptable quality of service throughout the entire network. We cast an autonomous MOD system within a closed Jackson network model with passenger loss. It is shown that an optimal rebalancing algorithm minimizing the number of (autonomously) rebalancing vehicles and keeping vehicles availabilities balanced throughout the network can be found by solving a linear program. The theoretical insights are used to design a robust, real-time rebalancing algorithm, which is applied to a case study of New York City. The case study shows that the current taxi demand in Manhattan can be met with about 8,000 robotic vehicles (roughly 60% of the size of the current taxi fleet). Finally, we extend our queuing-theoretical setup to include congestion effects and we study the impact of autonomously rebalancing vehicles on overall congestion. Collectively, this work provides a rigorous approach to the problem of system-wide coordination of autonomously driving vehicles, and one of the first characterizations of the sustainability benefits of robotic transportation networks.