The Sustainability of Zipline's Autonomous Aerial Logistics

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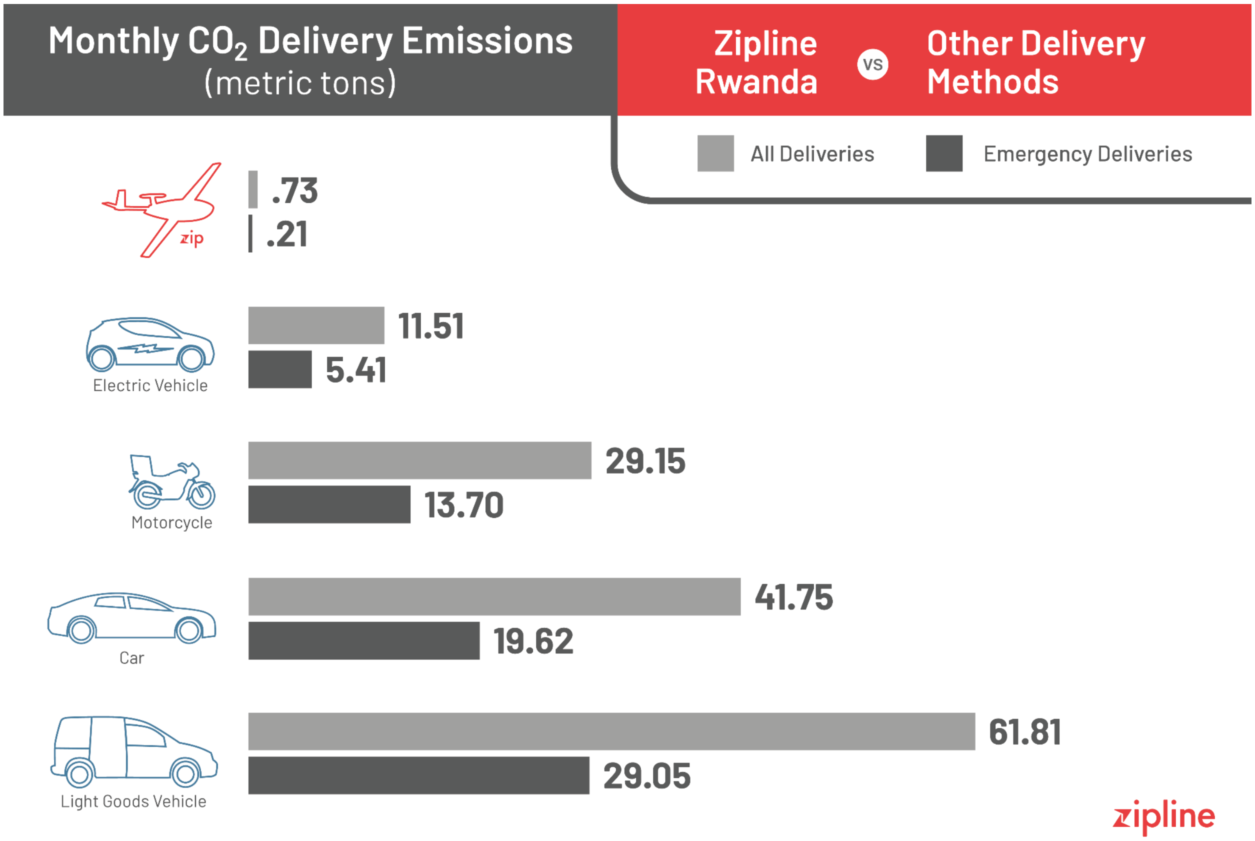
Zipline recently completed the world's first sustainability analysis of a real-world, scaled UAS logistics system's deliveries based on actual customer and order data, finding a **98% reduction in delivery emissions** compared to using cars.



By using Zipline's autonomous aircraft to provide essential medical products to rural hospitals and clinics, these on-demand deliveries experienced a:

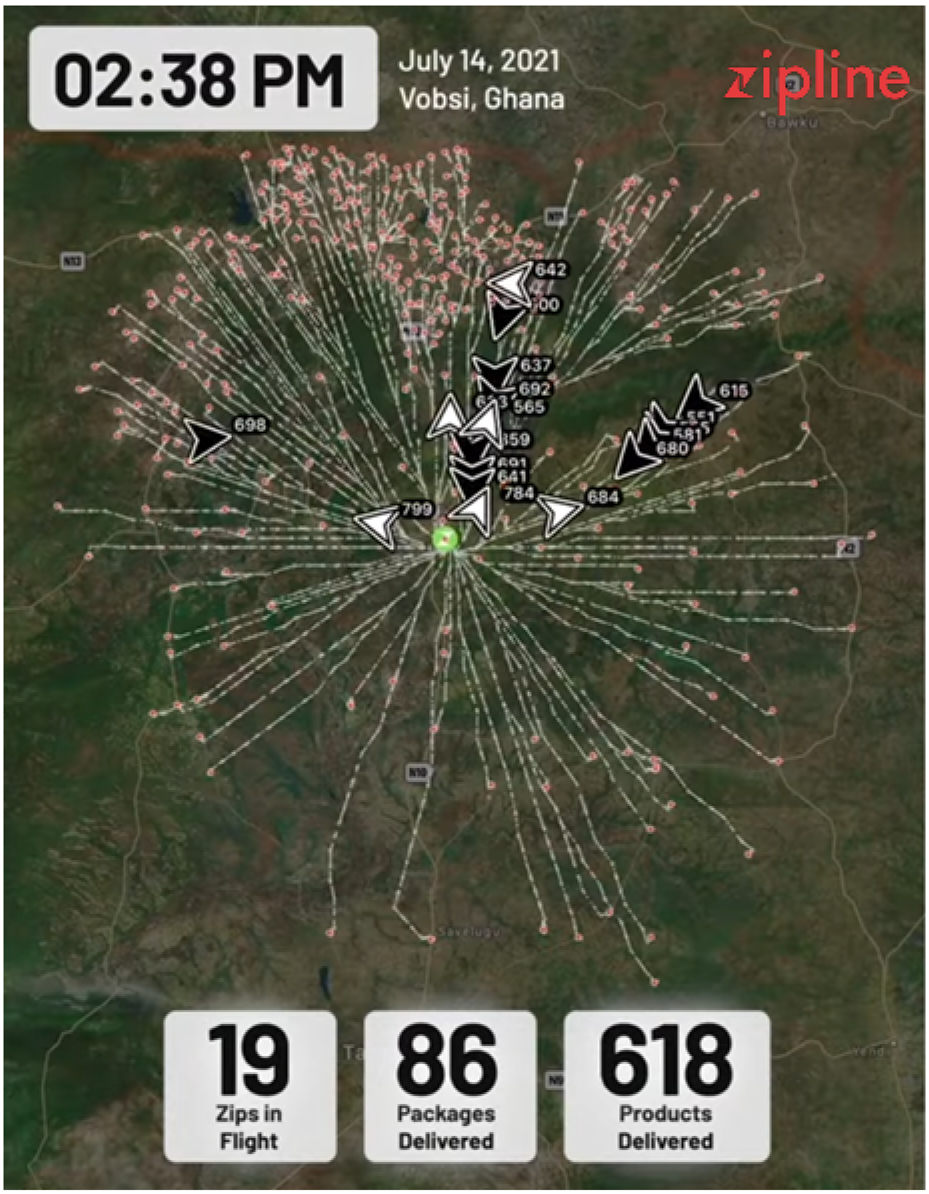
- **99% reduction** in delivery carbon emissions compared to using vans
- **98% reduction** in delivery carbon emissions compared to using cars
- **94% reduction** in delivery carbon emissions compared to using ***electric*** vehicles

Let's dive deeper into this graph, our methodology, and the sustainability of autonomous aerial logistics generally.

How Zipline Works

Zipline provides on-demand delivery of blood, vaccines, and other essential medical products using 50 lb, electric, fixed-wing autonomous aircraft ("Zips"). We deliver to hospitals, medical facilities, and patients within 80 km of one of our centralized medical warehouses and distribution centers.

When a doctor or hospital places an order, our medical warehouse prepares the order and places it into the bay of one of our Zips. The Zip is launched by catapult into the air and autonomously flies itself to the delivery site. Once above the delivery site, the Zip opens its bay doors to drop the package before turning around and heading back to the distribution center.



A typical day at our distribution center in Vobsi, Ghana.
White arrows indicate outgoing Zips; black arrows indicate returning Zips.

As of October 2021, we deliver over 200 different medical products, including medicine, blood, and vaccines, to over 2,000 medical facilities, serving 25 million people. We've completed over 200,000 deliveries of over 4 million products and doses, flying over 15 million autonomous BVLOS miles.

Over time, Zipline has become an integral part of the medical supply chain:

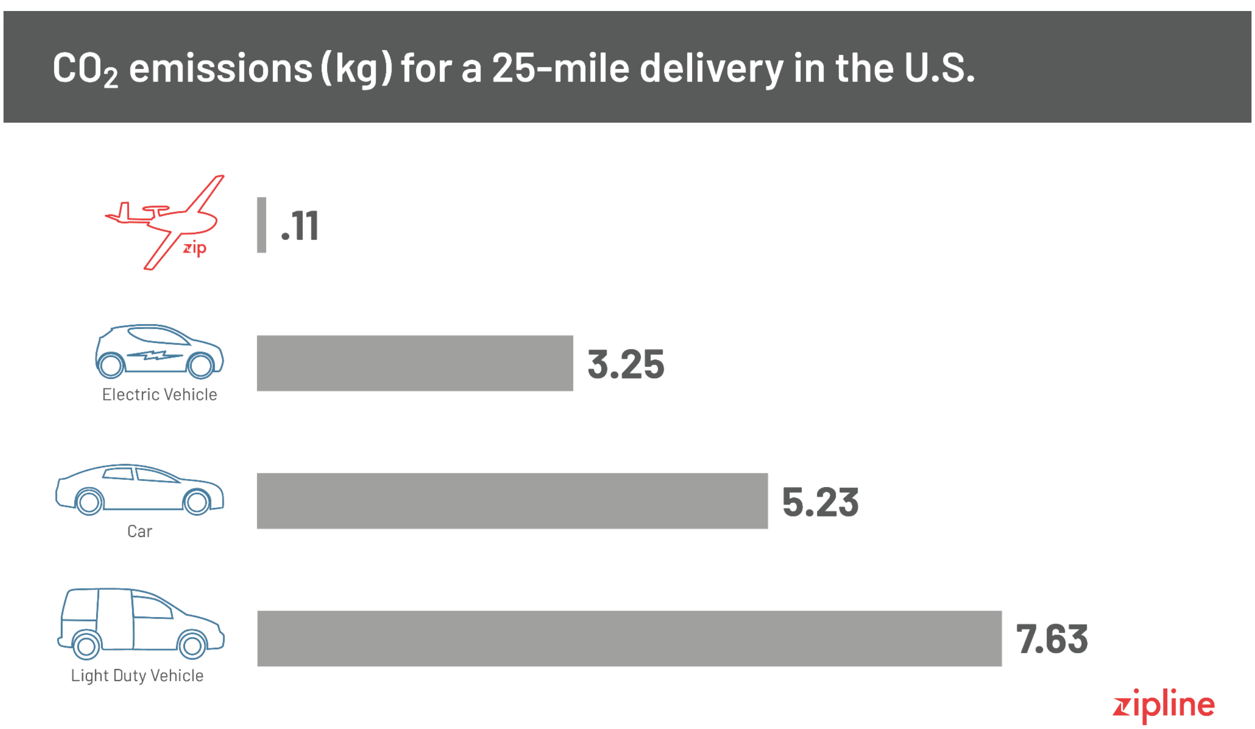
- 75% of the blood used in Rwanda outside of Kigali is now delivered through Zipline.
- Platelets' short shelf life make it difficult to keep in stock in rural hospitals. But because Rwanda hospitals now have access to platelets on demand, rural doctors are now trained to perform such transfusions themselves, instead of referring patients to distant specialists.
- We have reduced wastage rates by 98% while eliminating stockouts. Today, many of the rural hospitals we serve no longer stock blood at all, knowing that they can "just Zipline it".

Such scaled integration with the overall medical supply chain is what allowed us to conduct what we believe to be the first-ever sustainability analysis of a real-world UAS logistics system's deliveries, based on real customer and order data.

Sustainability of Zipline Logistics

The simplest way to analyze the sustainability of Zipline logistics is by examining the carbon impact of a straight-line trip. More precisely:

> *What are the carbon emissions associated with a 25-mile Zipline delivery, compared to a ground vehicle? Assume that both travel in a straight line, encountering no traffic.*



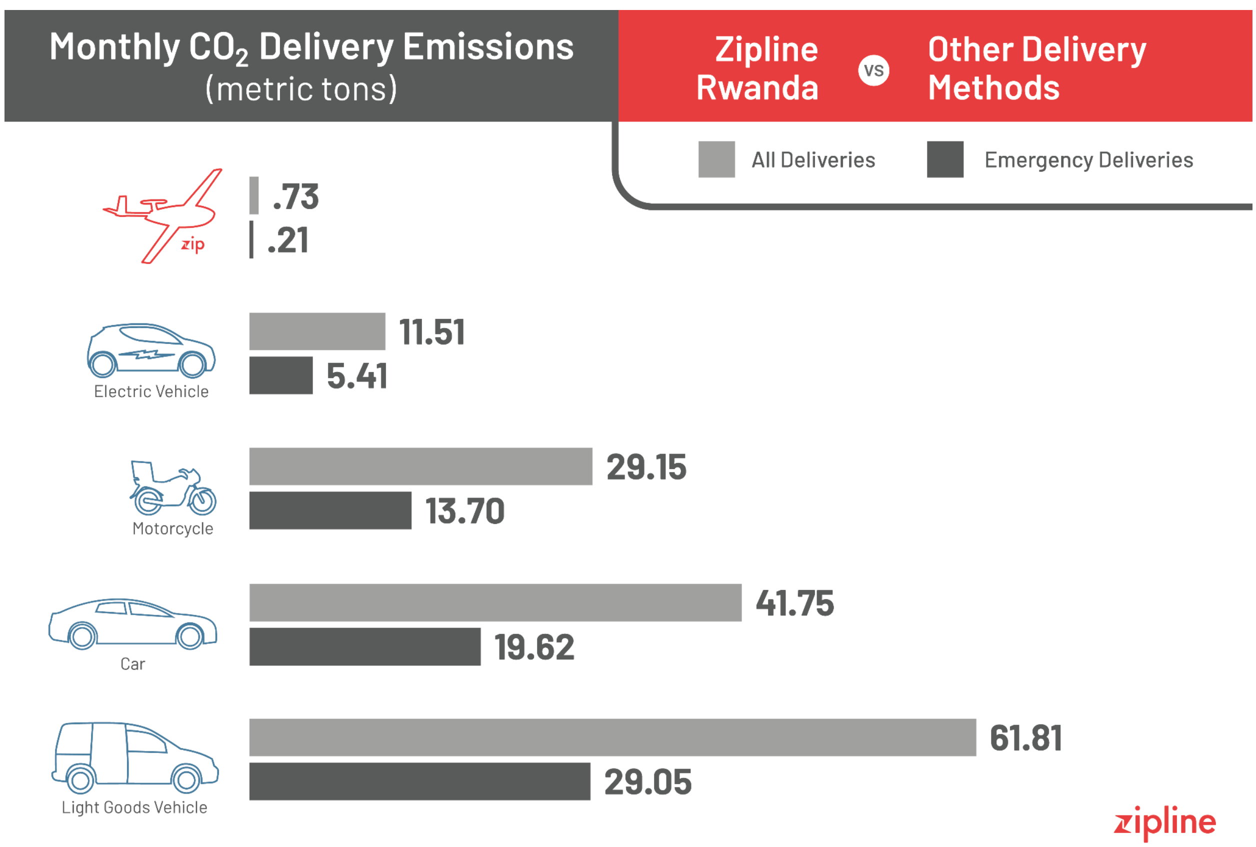
Sources: International Council on Clean Transportation; EV Database; EPA

This alone, however, does not necessarily translate to a more sustainable logistics system. In particular, the medical supply chain is one of the most difficult supply chains to decarbonize:

- Unpredictable yet urgent demand requires one-off, uncoordinated deliveries that are constrained by ground infrastructure and congestion.
- Waste is common, as hospitals must over-order to avoid the possibility of a stockout.
- Decentralized distribution is all but required for ground-based on-demand delivery, but it inhibits economies of scale, creates unnecessary duplication, weakens inventory management, and makes it more difficult to implement sustainable practices.

We therefore conducted a more robust analysis, using actual customer and order data from Zipline Rwanda, with the express goal of identifying the sustainability difference between our aerial Zipline network and an equivalent ground-based logistics network. More precisely:

> *What are Zipline's actual monthly delivery emissions in Rwanda, compared to what they would have been if we completed those deliveries using ground vehicles instead? Methodology, assumptions, and sources detailed in Appendix 1.*



Based on flight and order data for all products delivered by Zipline Rwanda in September 2021 (n=10,887).
Sources: [2020 UK Government Greenhouse Gas Conversion Factors](); [EV Database](); [Our World in Data]().

In short, by using Zips to conduct those deliveries, those deliveries experienced a:

- **99% reduction** in delivery carbon emissions compared to using vans
- **98% reduction** in delivery carbon emissions compared to using cars
- **94% reduction** in delivery carbon emissions compared to using ***electric*** vehicles

We attribute this near-total elimination of delivery carbon emissions to three factors:

- **Electrification.** Electrifying ground-based deliveries is hard and often requires the costly replacement of thousands of vans and cars. Instead, by adopting an electric aerial medical supply chain, all of those deliveries can instantly be electrified.
- **More efficient routing.** Zipline's autonomous aircraft can fly in a near-direct path to their delivery site, substantially reducing the distance required for the delivery. Not only does this make deliveries faster and more reliable, but it also substantially reduces carbon emissions.
- **Minimal energy use**. Zipline requires orders of magnitude less energy than electric cars. Even if Zipline had used all-electric vehicles to carry out its deliveries, it would have increased carbon emissions by 30x, while placing a significantly greater strain on the electrical grid.

We recognize that this is not the end of the story. Indeed, we describe two alternate approaches in Appendices 2 and 3, and we'd love to partner with sustainability experts to conduct the first lifecycle assessment of our autonomous aerial logistics system overall, not just our deliveries.

But we do believe that this is the beginning of an exciting story. Transportation is one of the most difficult sectors to decarbonize, and logistics even more so. By introducing a mode that reduces delivery emissions by 98%, Zipline and the UAS industry can play a key role in decarbonizing our logistics system and making our supply chain more sustainable, resilient, and equitable.

98%

reduction in delivery CO_2 emissions by using Zipline instead of cars

Appendix 1: Methodology

Our data source is flight, order, and product data (n=10,887) for all September 2021 deliveries by Zipline Rwanda.

To calculate Zipline's deliveries' carbon emissions, we multiplied the energy consumption of our Zips (kWh/km) by the round-trip air distance[1] traveled for all of our delivery flights (km), added the energy required for each launch and recovery (kWh), and multiplied that by the carbon intensity of Rwanda's electrical grid (gCO_2/kWh).

To derive a ground-based logistics comparison, we introduced the following assumptions:[2]

1. We would ignore any impact of traffic and congestion for ground vehicles.
2. We solely focused on tailpipe emissions, ignoring "well-to-tank" emissions, for gas-powered vehicles.
    a. For electric vehicles (and Zipline), however, we accounted for the carbon intensity of the electrical grid.
3. We assumed ground vehicles would "batch" their deliveries: that is, multiple products within an order could all be delivered by a single ground vehicle even if multiple Zips were used.
4. We would ignore the impact of non-CO_2 emissions, as well as non-exhaust particulate emissions from road transport, including wear of tires and road surfaces.
5. We assumed that all ground vehicles used had emissions levels as clean as the reference figures in the 2020 UK Government Greenhouse Gas Conversion Factors paper.
6. We assumed that facility emissions were identical, even though the transition from ground-based deliveries to Zipline has reduced the number of distribution centers required.
7. We assumed that hospitals did not care about time to delivery.
8. We assumed that ground vehicles were always available for delivery and did not "loiter".
9. We assumed that ground deliveries never failed and would never require additional deliveries.

For ground-based vehicles, we first identified the smaller set of ground-based deliveries required to fulfill all orders, per assumption 2 above. For each delivery, we used OSRM and the FOSSGIS routing API to calculate the shortest round-trip ground route (km) between the distribution center and the delivery site. We then multiplied that round-trip distance by each vehicle's average carbon emissions (gCO_2/km) per assumption 6. For electric vehicles, we instead multiplied that round-trip ground distance (km) by the average electric vehicle's energy consumption (kWh/km), and then by the carbon intensity of Rwanda's electrical grid (gCO_2/kWh).

[1] Air distance is distinct from ground distance in that it is not defined by reference to the ground or lat/long. Rather, it is tracked by onboard sensors and defined by reference to movement through the air, which factors in wind, ascent/descent to altitude, and the Earth's curvature.
[2] We do not rely on these assumptions in calculating Zipline's deliveries' carbon emissions, which are derived from actual flights and air distance traveled.

Appendix 2: Day-batching alternate approach

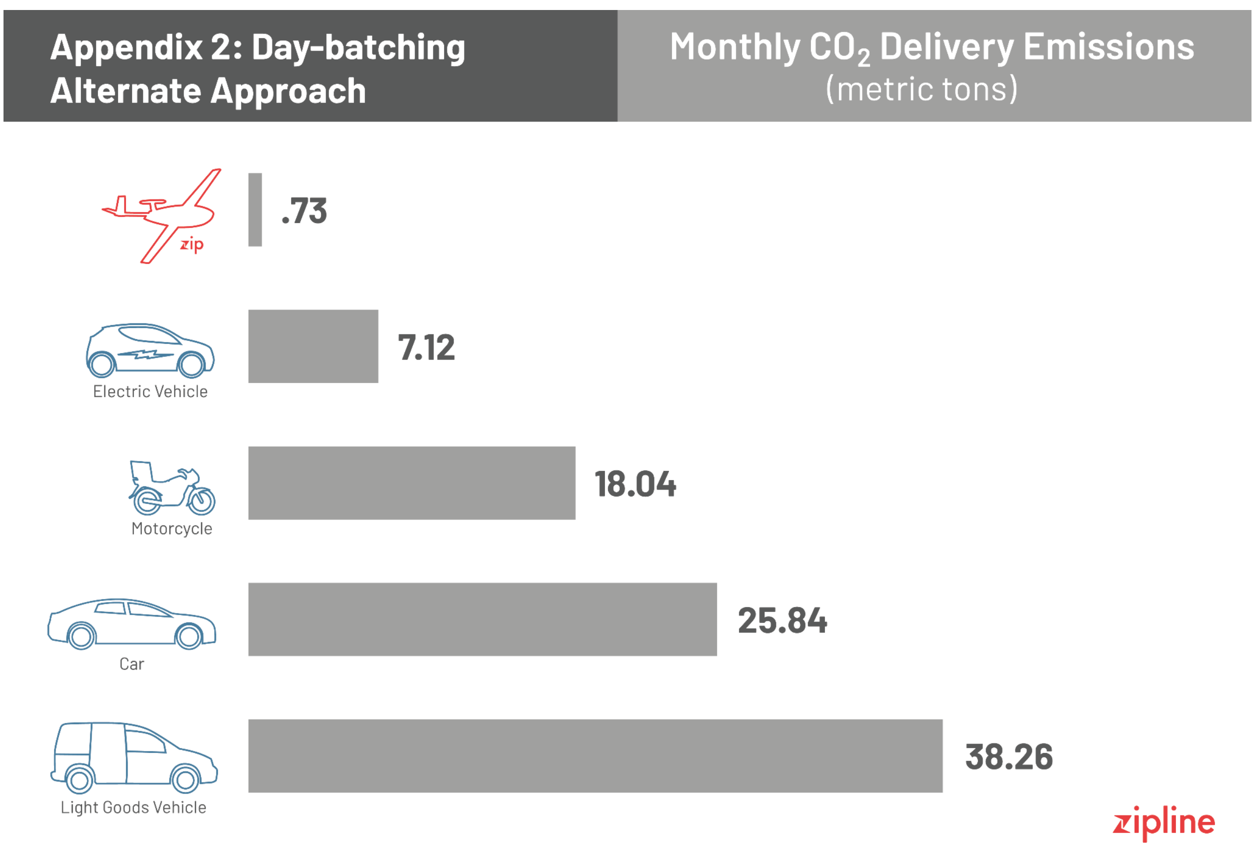
One might alternatively model on-demand ground vehicle logistics by batching deliveries by day, instead of by order. That is to say, if a hospital places an order in the morning and then again in the evening, such orders might be batched together into a single ground vehicle delivery instead of two separate deliveries.

We believe this to be an unrealistic model:

- Hospitals can already order as many products as they wish in a single order. Additional orders from a hospital in one day are typically emergency orders, which wouldn't be suitable for being held for batching into a larger delivery.
- Deliveries would be significantly delayed as hospitals would not be getting products on-demand, but instead only once daily.

Nevertheless, we explored what the carbon emissions would look like under such unrealistic assumptions, more precisely stated as follows:

> *Compare Zipline's actual monthly delivery emissions, to what carbon emissions would be if we sent only one ground vehicle a day to each facility that contained all of their orders for that day. No vehicle would be sent to facilities that did not place an order. Other assumptions remain the same (including no traffic).*



Appendix 3: Traveling salesman alternate approach

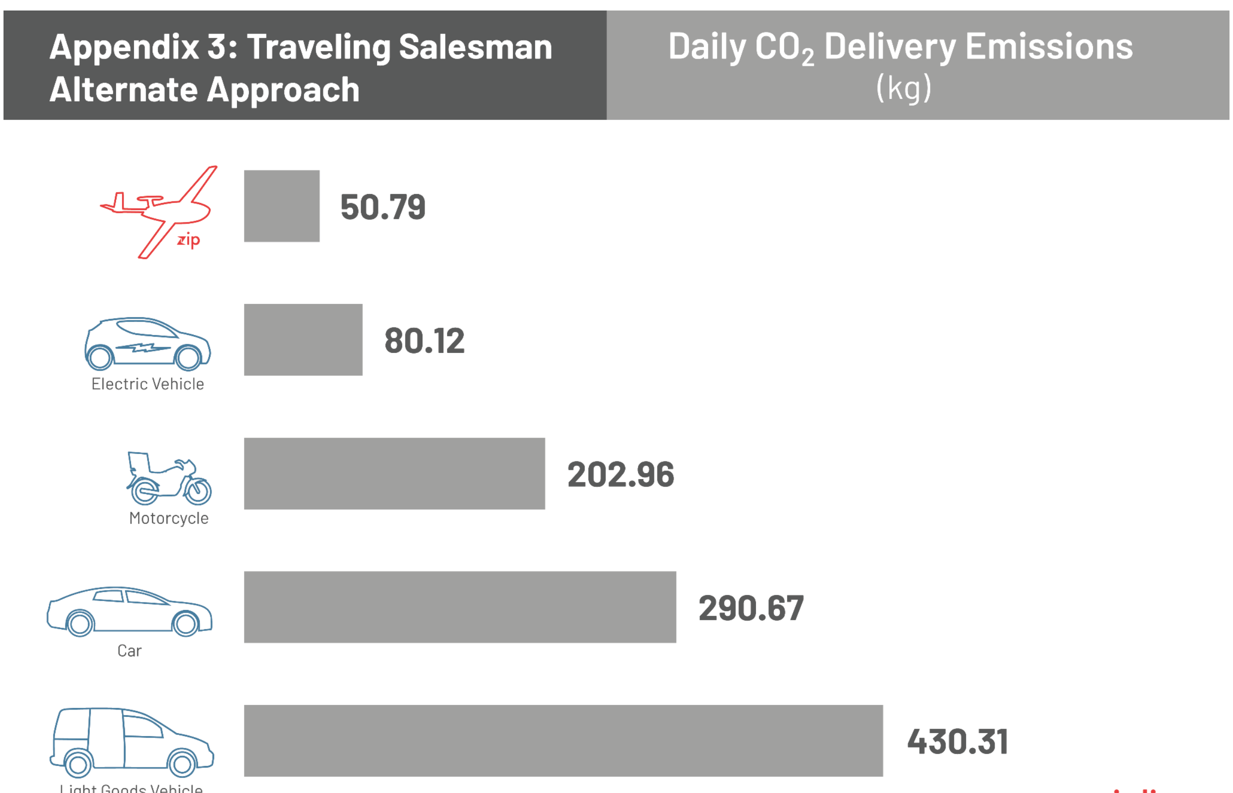
One might also alternatively model on-demand ground vehicle logistics through a "traveling salesman" sequencing approach. That is to say, assuming we know in advance which delivery sites will place an order, we could have a single vehicle from each distribution center visit every single delivery site for that day, following a pre-planned, maximally carbon-efficient route.

We believe this to be an even more unrealistic model:

- We do not know our orders in advance and cannot pre-plan carbon-efficient routes.
- This would take upwards of 30 hours for some deliveries: well outside what hospitals need, and no longer "on-demand".
- It would be extremely unreliable; any issue with a delivery vehicle would impact all subsequent deliveries for that day.
- This would be completely unworkable for emergency orders.

Nevertheless, we explored what the carbon emissions would look like under such extreme assumptions, more precisely stated as follows:

> *Compare Zipline's actual daily delivery emissions, to what carbon emissions would be if each of our distribution centers sent only one ground vehicle a day to sequentially visit every facility placing an order that day. All deliveries, including emergency deliveries, are known in advance, allowing the ground vehicle to take a pre-planned "traveling salesman"-optimized route (per the FOSSGIS API) that maximizes carbon efficiency. Other assumptions remain the same (including no traffic).*



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