IMPACT OF FREIGHT CONSOLIDATION ON LOGISTICS COST AND EMISSIONS

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Abstract

The transportation sector is one of the two principal contributors to greenhouse gas emissions (GHG) and its contributions are expected to double by 2050. Growing consumer demand for home deliveries with high service levels at low costs is quickly becoming the standard. As a result, retailers are transforming their supply chains to meet these requirements through innovation in transportation. However fast delivery is a double-edged sword – it is expensive for companies to sustain and generates greenhouse gases from fuel combustion, which is harmful to the planet. Previous studies have shown that customers may be willing to wait for their deliveries if the environmental impact of fast delivery is presented to them. Specifically, customers are willing to wait for up to 4 days for their shipments if greener means of transportation are used for delivery. The increase in delivery lead time will present opportunities to make operational changes centered on consolidating shipments and increasing density in last mile routes, which will help reduce unit cost and emissions. This is the core focus of this project. Our research considers the impact of freight consolidation on Carbon Dioxide equivalent emissions and logistics costs for omnichannel home delivery. We analyze data from a large retailer in Mexico, derive insights on current operational metrics, apply heuristic methods to minimize trips and validate our hypothesis by means of experiments run on specific scenarios. We find that increased delivery lead times can lead to better route utilization, fewer trips to deliver customer shipments and therefore cost saving opportunities and lower emissions.

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1. Introduction

Greenhouse gas (GHG) emissions and their effect on global climate is a popular area of scholarly research. EPA (The Environmental Protection Agency, 2019) of the United States has categorized greenhouse gases into 4 main segments - Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and Fluorinated gases. Of these, CO_2 is the highest emitted gas (approx. 80%) of all GHG emissions based on 2016 data from the EPA. Over the last few decades, the concentration of CO_2 has continued to increase as a result of rapid urbanization, population growth, environmental pollution, and deforestation, thereby bringing with it rising global temperatures and climate change. Research done by the Intergovernmental Panel on Climate Change (IPCC, 2014) indicates that global temperatures are expected to rise by up to 4 degrees Celsius by the start of the next century compared to average levels from 1980 - 1999, which could lead to problems like melting glaciers and sea levels rising by 0.26-0.59 m annually.

This research considers the impact of freight consolidation on Carbon Dioxide (CO_2) emissions and logistics costs for omnichannel home delivery. We study the delivery data provided to us by a large omnichannel retailer and make managerial recommendations on their delivery operations given additional available delivery lead times. Our analysis focuses on building shipment consolidation in their existing fleet and reducing the number of trips needed to deliver customer shipments.

We are working with Coppel, the largest omnichannel retailer in Mexico, with 1,300+ retail stores, 19 regional distribution centers (DCs), 1,200 last mile delivery vehicles and approximately 6 million deliveries annually (Coppel, 2018). They have showroom type stores where customers browse and place orders for home delivery. All products are shipped from a network of regional

DCs, direct to the customer's home (no intermediate hubs). Approximately 80+% of the volume is delivered within 1-2 days (Trevino, 2019). Initial analysis shows that a majority of Coppel's last-mile vehicles are underutilized today, where the average utilization of a vehicle is under 40%. Low utilization has led to sub-optimal routes with low package density, a higher number of trips to meet customer demand, and therefore high CO_2 emissions and cost.

A previously completed study at MIT focused on the customers of Coppel titled "Would You Be Willing to Wait?: Consumer Preference for Green Last Mile Home Delivery" *Fu and Saito* (Fu & Saito, 2018) showed that Coppel's customers were willing to wait longer for their home deliveries if doing so reduced fuel consumption, CO_2 emissions or had other environmental benefits, i.e., "green" delivery services. Specifically, the study concluded that Coppel's average Mexican consumer was willing to wait up to 4 days to receive their shipments using a green delivery service. Our research quantifies the cost and emission benefits from modifying current operational parameters if Coppel had an additional few days to complete deliveries. Intuitively, increasing delivery lead time should improve last mile consolidation and reduce delivery costs. Additionally, shipment consolidation should improve vehicle utilization and reduce trip frequency. That, in turn, will reduce fuel consumption, which directly impacts Coppel's carbon footprint. Our research will identify the direct benefits from the customer's willingness to wait, which can be used as a baseline to develop Coppel's last mile strategy.

One of the effects we will look at is improving the utilization of last mile routes with higher package density. We will also study the impact on inventory positioning in the logistics network and quantify savings from modifying warehouse transfer policies as a consequence of having a few additional days to complete customer deliveries.

This capstone project will provide the following managerial recommendations:

- Changes to the operating construct to improve shipment consolidation on a route.
- Given the additional delivery lead time, the impact of modifying the delivery frequency and delivery zones.
- The impact of increasing the time duration of a route toincreasing the number of shipments delivered on a route.

The results of this study can be extended to other markets, like the US / China consumer markets, where demand for green transportation initiatives can be used asa strategic advantage by e-commerce companies. Overall understanding and quantification of the impact of green initiatives on consumer behavior and therefore transportation strategy can be a key differentiator for companies.

The remainder of this document is organized as follows: Section 2 presents Literature that we have reviewed, Section 3 focuses on the current operating model and constraints, Section 4 details the Methodology including data cleaning, mathematical model and data analysis and sections 5 and 6 present the results and conclusions from our work.

2. Literature Review

We look at research work that has been done to study greenhouse gas emission trends and the impact of human activities on emissions. In addition, we explore consolidation impacts on last mile delivery and the impact of improved shipment consolidation on inventory positioning. The insights from these research papers will help us build our optimization models and derive insights for the company.

2.1 Impact of Human activities on greenhouse gases emission

Human activities, specifically the use of fossil fuels, are a major source of CO_2 emissions. In order to control and potentially reverse global warming, a few treaties have been signed since 1992 like the United Nations Framework Convention on Climate Change, the 1997 Kyoto Protocol and the 2016 Paris agreement. These treaties required governments to control CO_2 emission based upon the agreed-upon quota. Global emissions increased from 4.033 to 4.97metric tons per capita between 2000 and 2014 (World Bank, 2019). Upon diving deeper, we found that a few developed countries have had some success in controlling emissions, while the rest of the world has shown mixed results.

In the commercial sector, consumers are developing awareness, with increasing demand for information on CO_2 emissions in the supply chains of their products. Many companies now have CO_2 emissions data as part of the corporate social responsibilities section in their annual reports. Other than governmental efforts, there could be business benefits for the private sector to focus on building a sustainable supply chain. MIT Prof. Yossi Sheffi's 2018 book, (Sheffi, 2018) suggests three basic rationales for corporations to engage in sustainability efforts: cutting costs, reducing risk and achieving growth.

2.2 Impact of Land Transportation on emission

Road transportation, especially trucking, is one of the major emission factors among other human activities (Intergovernmental Panel on Climate Change, 2007). In Europe, trucking will account for 20% of the European Union's total emissions in the next 20 years (European Commission, 2011). In the United States, trucking is the only major emission source that continues to grow and accounts for 30% of the country's greenhouse gas emissions (Environmental Protection Agency, 2011). This trend is a major driving force us to analyze retailers like Coppel's road transportation operations for improvements and efficiencies.

2.3 Quantifying Emissions

One of the key questions answered in this project is the impact of consolidation on the environment, as measured by greenhouse gas emissions. Given that Coppel has accurate, historical vehicle data. We know there are multi inventories to convert activities into emissions. We will apply the "IPCC 2006 Guidelines for National Greenhouse Gas Inventories" (IPCC, 2006), which is the same as past and other MIT project sponsor by Coppel for consistency.

2.4 Urban Last Mile Route Time

Total route time is calculated as the sum of route prep time, stem drive time, in-zone drive time and time per delivery (Danganzo, 2010). Route prep time is defined as the total time taken to get a route ready for departure from the distribution center (DC). This includes time taken to stage shipments at the outbound dock, complete the handoff between the DC and delivery driver and depart the driver on his/her route. Stem time refers to the time taken to drive from the distribution center to the general delivery zone, typically the first stop on the route. In-zone drive time refers to the inter-stop drive time between all the stops on a route and finally, the time per delivery is the total time spent completing deliveries to customer's homes.

3. Operating Model and Constraints

This session presents the existing operating model and constraints that we gathered during a field trip to the company's distribution centers in March. Our sponsor company has a network of distribution centers (DCs) in Mexico. They have 6 borders DCs, which are in close proximity to important ports, mainly used for goods imported into Mexico and 20 regional DCs, which fulfill orders to a network of stores as well as directly to customers for e-commerce orders. The mix of products sold by Coppel can be classified into hard-lines, i.e., furniture and soft-lines, i.e., apparel. They run fulfillment operations 6 days a week (Monday to Saturday), starting with store fulfillment in the morning for 3 hours followed by home deliveries later in the day for 5 hours (Trevino, 2019). Coppel runs its own fleet of vehicles for all deliveries to stores as well as furniture deliveries to customers. Apparel and e-commerce deliveries to customers are outsourced to a third-party transportation provider like FedEx. Figure 1 represents Coppel's distribution network in Mexico.

Figure 1. Retail Company's Distribution Network, 2017 (Coppel, 2018)

Based on interviews with the management team, we learned that customers place orders for home-delivery in stores or online. About 5% of the total volume is ordered online, while the remaining are placed in stores. An internal system called "Apartado" immediately checks availability of inventory in the closest DC and assigns the order to a predefined route based on the destination address.

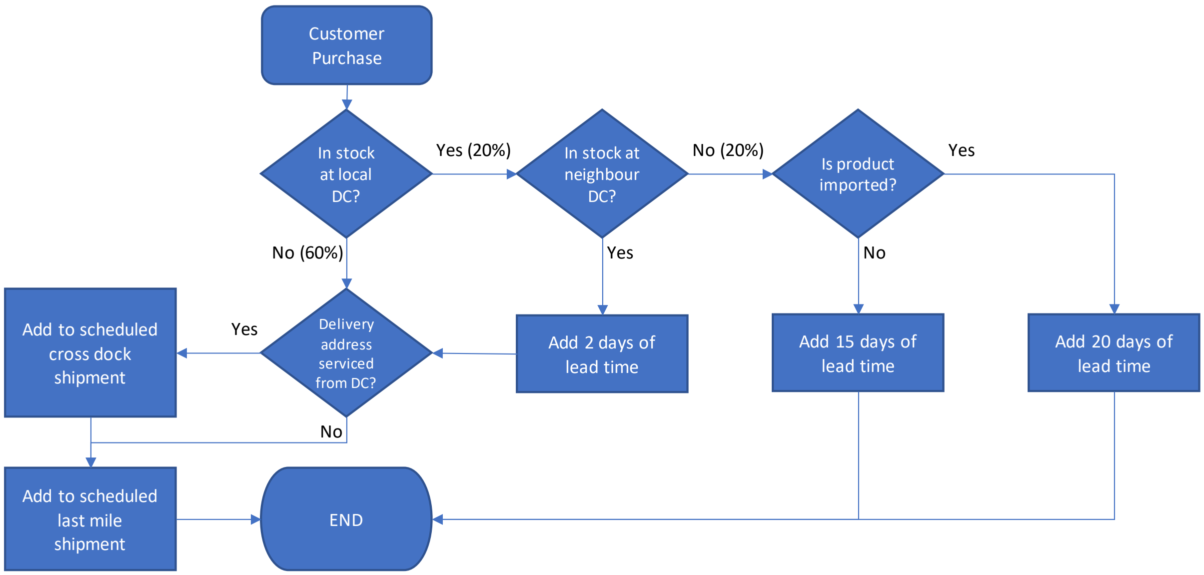

Figure 2. Current Fulfillment Decision Tree

Fig 2 shows the retail company's system checks for inventory availability in 1 or 2 other DCs if it isn't available in the closest one. When the inventory is available at the regional DC, it would be fulfilled and assigned to a vehicle for delivery. Each vehicle covers 50-70 kilometers per day on a route, however, this can vary based on the delivery market. Most vehicles have a driver plus an assistant to complete deliveries. The main constraints for delivery routes are total route time (currently 5 hours) and vehicle capacity, which means there is an upper bound when calculating vehicle utilization.

4. Methodology

This section covers the details of the methodology adopted to arrive at results. We received delivery data from 2018 across all distribution centers in CSV files. This data required extensive cleaning to be performed on it before we could use it for analysis. We first calculate the baseline metrics to understand the current state. As part of baseline calculations, we identify existing constraints in the delivery operation and suggest some operational improvements. Finally, we study the impact of building consolidation as a result of longer delivery lead times. Details can be found in the sections below.

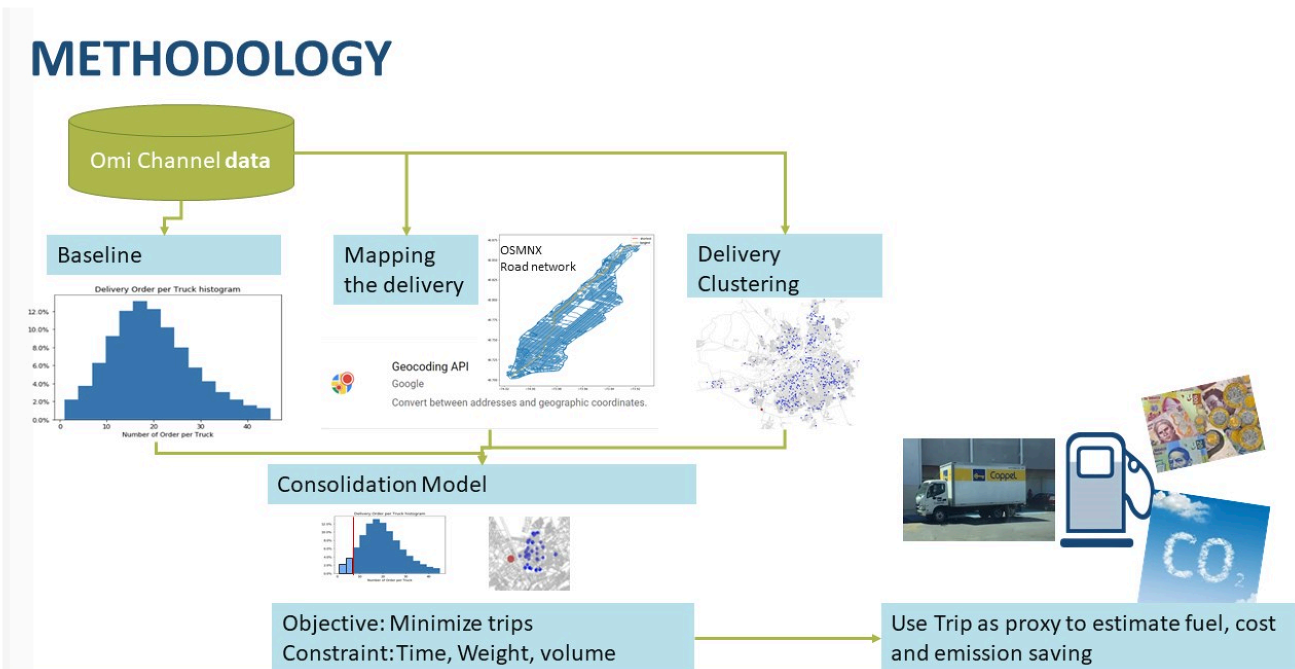

Figure 3. Methodology Diagram

4.1 Mathematical Model

Our goal is to calculate the impact of shipment consolidation on logistics cost is given an increase in delivery lead times. The longer lead times give us the opportunity to modify certain operating parameters to improve shipment consolidation in trucks and reduce emissions by running fewer trips to deliver customer shipments. Transportation cost can be modeled as a function of total time, as shown in equation 1. Due to the quality of the data provided, we will use sample data and run heuristics to arrive at practical results and compare those to the theoretical results. The objective function for our project is defined as below

Set:

I set of Regional DC's $I = \{1 \dots n\}$

J set of all customers $J = \{1 \dots m\}$

K set of all vehicles $k = \{1 \dots s\}$

Parameters:

R_k: Number of trips. Proxy for fuel consumption.

T_k: The maximum time available for a vehicle, spend on TSP route. (3 hours)

$K_{tsp(i)}$: TSP network factor, depends on the city's road network where DC(i) is located

A: Area of the delivery zone served.

$S_{tsp(i)}$: Average speed a vehicle travels within the delivery zone where DC(i) located.

$T_{d(i)}$: Average time required to unload and deliver goods to customer's homes from DC(i)

W_j: Gross weight of each customer's shipment

QW_k: Gross weight capacity of each truck

V_j: Volume of each customer's shipment

QV_k: Volume capacity of each truck

Decision Variables:

X_{ijk}: Equals 1 if customer j is served by vehicle k at DC i, 0 otherwise
n: Number of customers. Variable in this analysis

Objective function:

Minimize $\sum_{k \in K} R_k \sum_{i \epsilon I} \sum_{j \in J} x_{ijk}$

Subject to

$$\sum_{k \epsilon K} \sum_{i \epsilon I} x_{ijk} = 1 \qquad \forall\, j \in J \qquad (1)$$

$$\frac{K_{tsp(i)}}{S_{tsp(i)}} * \sqrt{An} + T_{d(i)} * n \leq T_k \qquad \forall\, k \in K \qquad (2)$$

$$\sum_{j \epsilon J} W_j \sum_{i \epsilon I, j \in J} x_{ijk} \leq QW_k \qquad \forall\, k \in K \qquad (3)$$

$$\sum_{j \epsilon J} V_j \sum_{i \epsilon I, j \in J} x_{ijk} \leq QV_k \qquad \forall\, k \in K \qquad (4)$$

$$n \geq 0, \quad X_{ijk} \in \{0,1\} \qquad \forall\, i \in I, \forall\, j \in J, \forall\, k \in K \qquad (5)$$

The objective function contains one term. It includes the number of total trips made within the system multiplied by the total distance that users will travel and the CO_2 emission reduction factor per mode of transportation.

(1) This constraint ensures each customer is visited once and only once.

(2) This constraint ensures the truck operating the last mile delivery operating within the time available for the 'traveling salesman' route within the delivery zone.

(3) This constraint ensures all customer orders within weight allowance of the delivery truck

(4) This constraint ensures all customer order within the volume capacity of the delivery truck.

(5) n number of customer orders per truck; x_{ijk} is a binary variable if the customer order j is served by a specific truck k via a specific DC i.

Our objective is to increase the number of shipments on a route through consolidation, which will result in fewer trips overall and higher delivery density. Increasing the average number of shipments on a route will, therefore, result in lower costs and lower emissions for the company. In our methodology, we explore different scenarios by adjusting the variables $T_{d(i)}$ and n for different values.

Increasing $T_{d(i)}$ from the current 3 hours will result in greater overall time on the route for delivery and improve consolidation opportunities on the route. Additionally, adjusting the zone configurations for last mile delivery can result in improved consolidations, which are explored a little later. Finally, we will explore running a clustering algorithm on the delivery data to develop clusters and use that to make recommendations on modifying the delivery frequency and adjusting delivery zones.

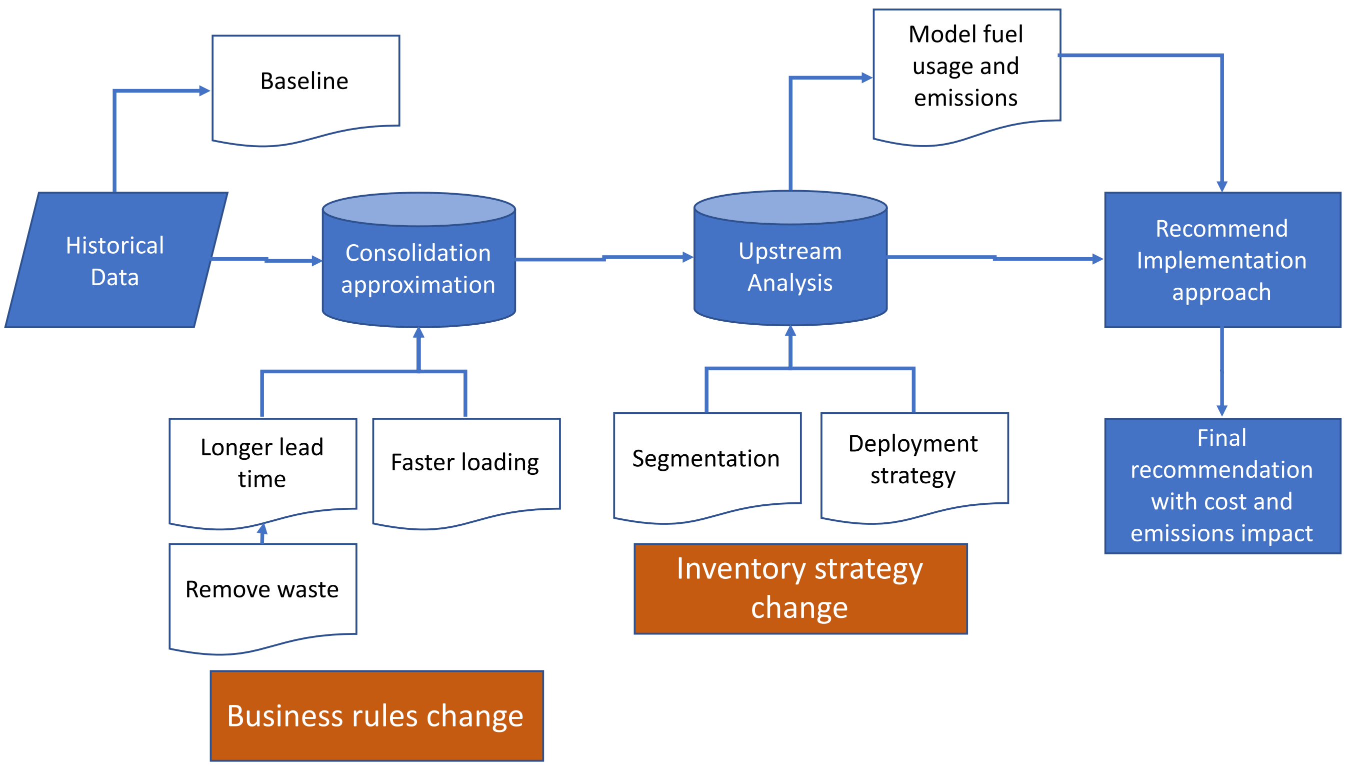

Figure 4 Methodology Flow Chart

4.2 Case Study: Baseline Calculations

In this section, we present key insights and metrics calculated from the data provided.

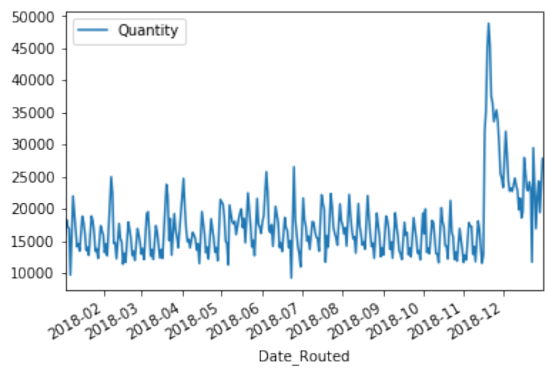

Figure 5. Quantity shipped per day

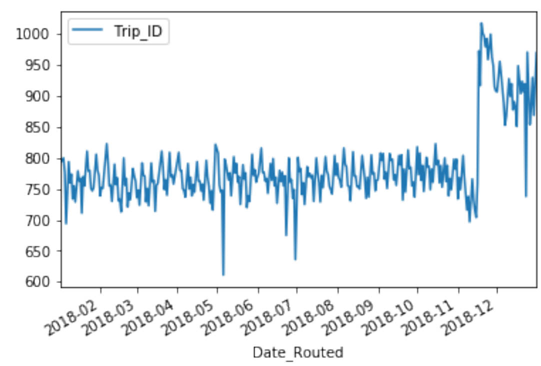

Figure 6. Trucks routed per day

Coppel has weekly and yearly seasonal patterns in their delivery data, but it is relatively stable from January to October, as shown in Fig 5 and 6. Volume spikes significantly between November and December during the weeks leading up to Christmas and then tapers back down in January. Stable volume for most of the year is favorable to implement consolidation by experimenting with lead times. We are using data from January to October in our analysis.

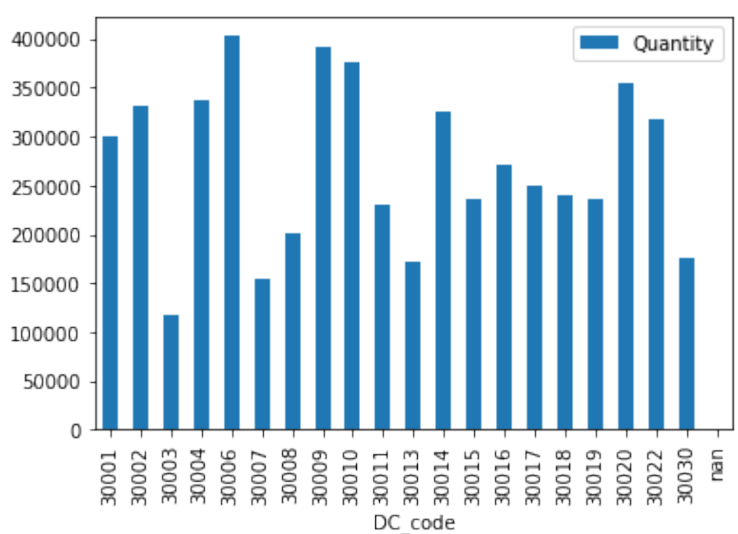

Figure 7. Annual volume shipped by each DC

Volume data shows that each DC at least shipped 120,000 units in 2018, with the biggest DC shipping around 400,000 units.

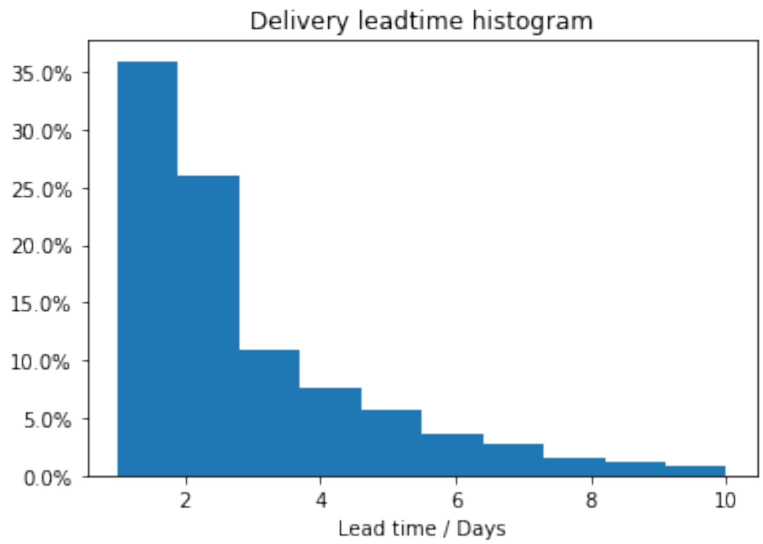

Figure 8. Delivery Lead time histogram

Analyzing the data for lead times, we found that about 60% of home deliveries were delivered within 2 days. Another 20% were delivered between 3 and 4 days, which could represent the scenario where inventory wasn't available in the primary DC and had to be shipped from a secondary DC. The remaining 20% that is delivered in greater than 4 days likely represents cargo shipped from another DC in the network or backorders from suppliers, either locally or overseas. This is represented in Figure 9.

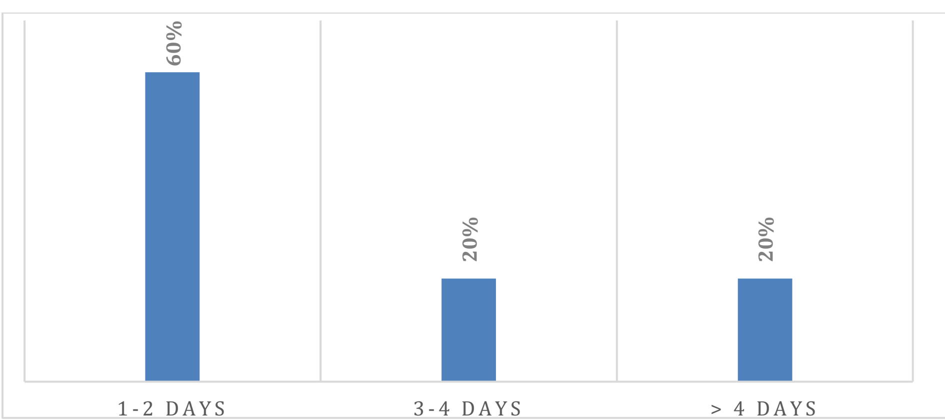

Figure 9. Home Delivery Lead Times

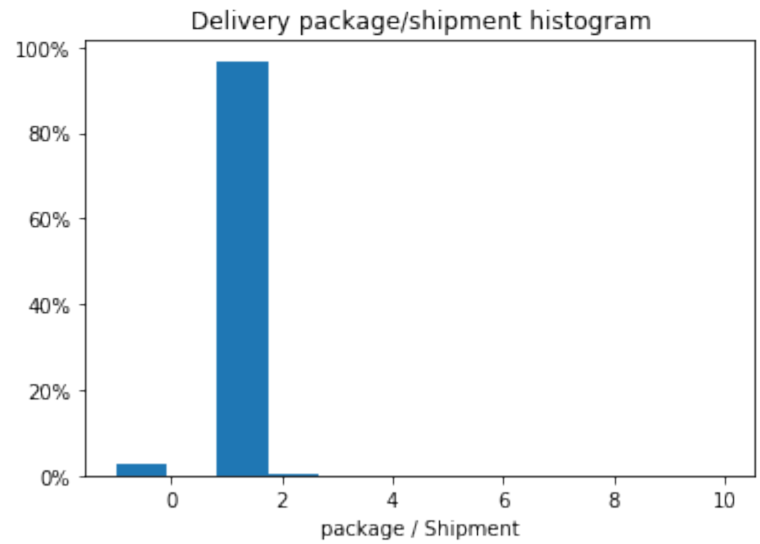

Figure 10. Units per Order

If we look deeper into the shipment profile, Figure 10 shows that most (~95%) shipments have only 1 package. There are very few (<2%) shipments that have multiple cartons/packages. The negative values (3%) represent shipment returns back to Coppel, which is out of scope for this project.

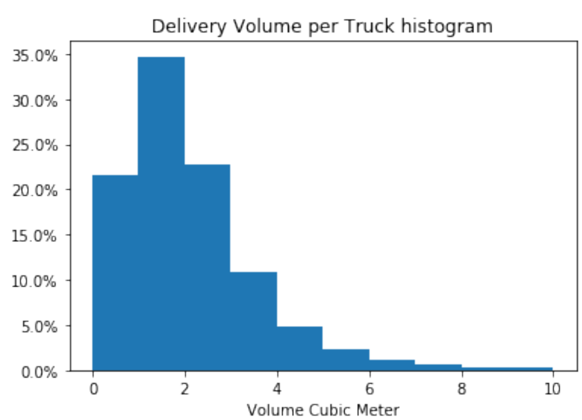

Figure 11. Volume shipped per truck

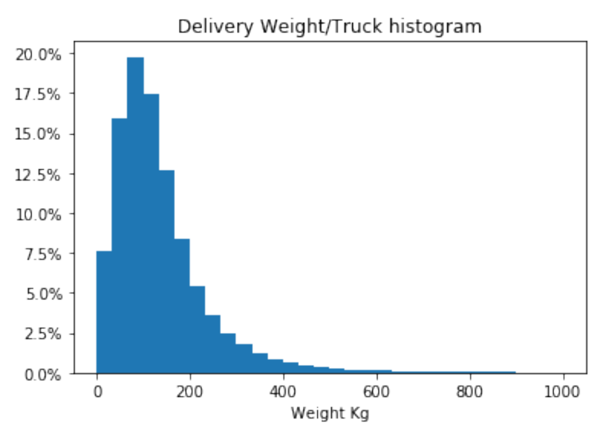

Figure 12. Tonnage shipped per truck

Upon analyzing truck utilization, we found that 75% of total home delivery trips had less than 3 cubic meters of cargo and 80% of trips had less than 200 Kg. As Coppel is currently using the Hyundai H100 or equivalent vehicles for delivery, each vehicle can roughly hold 1.26 tons and

10 cubic meters (Coppel 2018) of cargo. This means 75% of time Coppel's customer delivery routes have less than 40% utilization, which aligns with the observations from our site visit in March 2019.

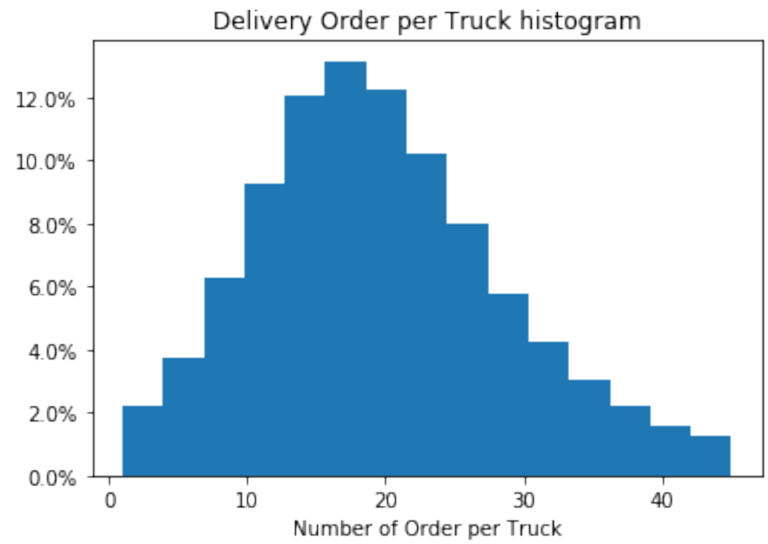

Figure 13. Orders per truck histogram

However, when we look into the number of orders per truck, we observe that about 60% of the time, trucks are delivering on average 15 - 20 orders a day. This suggests that Coppel's fleet is better utilized in terms of time compared to volume and weight.

4.3 Fuel Usage and Emissions

Coppel provided detailed data on their daily fuel usage and mileage drove for their fleet for 2018. After analyzing the fuel data provided, we conclude that out of 23.80 million liters of fuel used annually, 6.67 million liters are used on home delivery operations. This is equivalent to 17.99 million Kg of CO_2 equivalent emissions (IPCC, 2006).

4.4 Delivery Zone Analysis

We look at delivery zones for six distribution centers to compare high, medium and low order/truck density zones (i.e. High >=18 orders, Medium between 7 and 17 order, Low <= 6 orders) to identify inefficient zone which present consolidation opportunities. We also used the delivery zone information to make recommendations on the delivery frequency and identify zones which could benefit from longer route times. Figure 13 below shows the high, medium and low-density zones for Monterrey. The small colored dots represent the addresses visited by trucks and the big red dot represents the location of the DC.

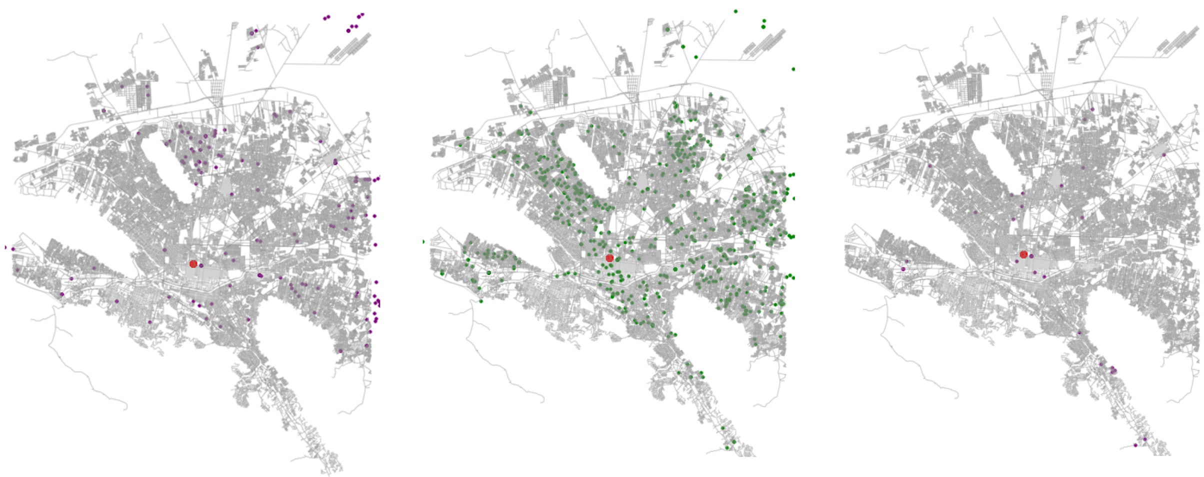

Figure 14. High, Medium and Low-Density Zones for Monterrey

Figure 15 shows the same for the DC in Tecamac a suburb of Mexico City)

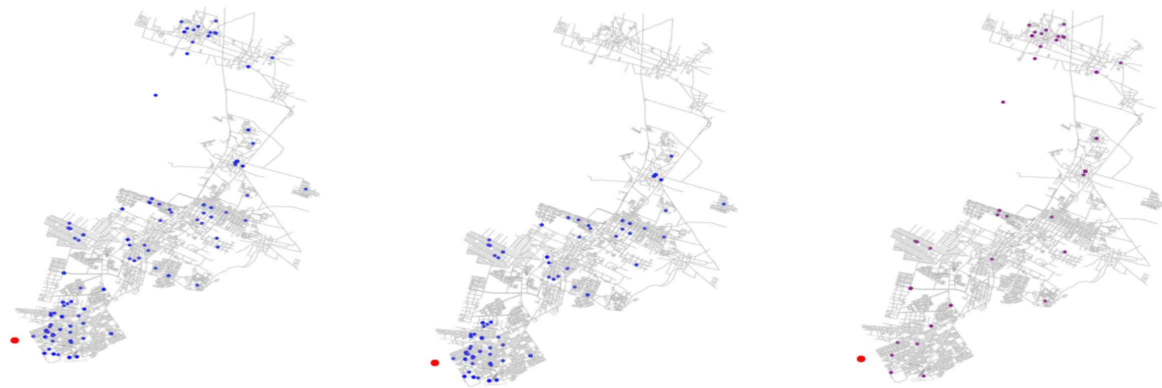

Figure 15. High, Medium and Low-Density Zones for Tecamac

Next, we apply a clustering algorithm on delivery addresses to calculate larger delivery zones, which encompass the above-mentioned smaller zones. Using K-Means clustering on the delivery data, we identified different clusters which represent the larger delivery zones. K-Means requires geo-coordinates to be passed into the algorithm for distance calculation, so we first ran the delivery addresses through a Google Maps API to get the latitude and longitude of every address. The Google Maps API geocodes at the speed of about 2 addresses per second, so we decided to limit the geocoding to six distribution centers in the interest of time – Culiacan, Leon, Hermosillo, Laguna, Monterrey and Tecamac (Mexico City). We ran one week’s worth of delivery data from these distribution centers through the geocoding API and got the geo-coordinates for each delivery address. Finally, we ran the K-Means clustering algorithm on these addresses and used Euclidean distance to cluster points together. The results can be found in Section 5.

4.5 Upstream Inter-DC Transportation Analysis

We look at the upstream impact of shipment consolidation as well, i.e., the potential impact oninter-DC inventory transfers. Today, there are two types ofinter-DC moves - Inventory

Replenishment (pull) and Inventory Allocations (push) (Trevino, 2019). The supplier's goods are delivered to a nearby DC. These goods are allocated to a DC based on the planner's instructions and then immediately distributed. Each DC will end up having its own cycle and safety stock. When a DC is running out of stock for a certain product, a replenishment order is placed and shipments are moved between warehouses for replenishment. These inter-DC moves are done on a daily basis. We find that the coefficient of variance (CV) of inter-DC shipments is somewhere between 0.3 to 1.45 for the top 9 DC, which represents 80% of inventory transfers. The fuel used in 2017 inter-DC inventory transfers is 14.8 Million Liters or about $24.7 million.

4.6 Assumptions and Data Cleaning Methodology

There were several quality issues with the data provided. There were inconsistent lead times, some as long as three years. We performed cleaning on this data to proceed with our analysis.

Sunday is a non-working day for Coppel operations. Yet, there were a few records in 2018 for Sunday delivery. We excluded these records from our analysis for the sake of accuracy.

Coppel continuously adds new SKUs into their sales channel and thus when we analyzed truck utilization, we used the 4-digit SKU family instead of the 6-digit SKU number to calculate the volume and weight of the truck. We believe this is a safe assumption on Coppel's vehicle utilization for 2019 and onward, as long as Coppel does not materially modify the product line on their home delivery service.

We received one year's worth of home delivery data from Coppel which was analyzed to study the impact of consolidation. The data included deliveries from each of Coppel's 20 DCs for 2018, SKU master, fuel consumption data and vehicle specifications. This data required significant cleaning before analysis could be performed on it. We performed the following steps to clean the data:

- Converted several columns to string and cut the decimals. Also converted dates to dates from strings
- Calculated lead times as the date route - date of sale and converted lead times to a number of days
- Included lead times from 1-10 days. There is a long tail for lead times, which we didn't visualize.
- Ran summary statistics on units/order. Limited the range from -1 (pickup) to 10
- Plotted graph of daily volume seasonality and number of trucks per day
- Concatenated SKU data for all products and dropped SKU greater than 5 cubic meters or had negative volume
- Dropped duplicate records, grouped products by family and populated volume and weight of each SKU family with mean + 1.64*sigma. Based on empirical distribution analysis this covers more than 90% of the SKUs in each family. Details can be found in table A1 in the appendix.

5. Analysis and Results

Our recommendations and analysis are captured in this section. Our analysis showed that Coppel's last mile routes are under-utilized and there are a lot of opportunities to improve route density and reduce trips to deliver packages. In this section, we present three managerial recommendations for Coppel to consider, with each recommendation aiming to improve shipment density on routes. The three-pronged recommendation focuses on 1) eliminating current inefficient practices like sub-optimal load splitting; 2) reducing delivery frequency given longer lead times, modifying delivery zones and 3) increasing the total route time. We explore the expected impact of each recommendation in detail in this section.

5.1 Utilization Insights

After analyzing the data provided, we found that Coppel's 2018 home delivery operation has low utilization in term of volume and weight, and we can safely conclude these are not constraints in their current operation. However, they could become constraints if we modify some operational parameters.

On the other hand, the number of orders per truck needed a deeper analysis. Using the time constraint (2) under Methodology in Section 4.

$$\frac{K_{tsp(i)}}{S_{tsp(i)}} * \sqrt{An} + T_{d(i)} * n \leq T_k \qquad \forall k \in K$$

Under the condition that Time is s constraint, there is only one parameter: A – the area of the delivery zone and variable n – the number of orders in the truck.

For atheoretical infinite small zone where A = 0 in the equation, we will have the theoretical maximum number of n allowed given the time constraint. N_{max}, which can be calculated as T_k divided by $T_{d(i)}$, is limited to 30 today. The time at the customer stop (unload + delivery) was consistently observed to be 6 minutes. The actual number of n for each zone is different but is in the range of 15-25 today. Therefore, we can safely assume that any trucks with fewer than 10 deliveries on a route are underutilized.

5.2 Recommendations

Based on Fu and Saito's 2018 paper, the customer is willing to wait up to 4 days if a more environmentally friendly delivery option is presented. The baseline data also shows 40% of shipments have lead time greater than 2 days. These two factors present an opportunity to change the current operating model to enable consolidations, through a three-step recommendation detailed below. The impact of recommendation is also calculated in this analysis:

- Level 1 consolidation: Remove the current operational inefficiency, without consolidation.
- Level 2 consolidation: Utilize the longer lead time in order to enable less frequent and therefore higher density routes.
- Level 3 consolidation: Increase the time available for home deliveries per truck.

5.3 Recommendation Details

Level 1: Remove the current operational inefficiency:

Currently, ~ 6% of truck moves are not bound by any constraint (volume, weight or time) and yet they depart with fewer than 6 orders in the truck. The baseline analysis shows that the delivery orders assigned to these lower utilized routes can be absorbed by other trucks serving nearby regions. We recommend a new procedure of not sending trucks with less than 6 orders and re-route these orders to other routes.

Level 2: Utilize the longer delivery lead times to enable less frequent and therefore higher density routes.

Currently, the total available route time is a binding constraint for roughly 60% of shipments, yet volume and weight capacity are not constrained. This presents an opportunity to deliver less frequently and consolidate shipments for two days into one route. In this case, the truck may not have time to deliver all shipments due to the time constraint, so we recommend that the delivery zone area be reduced in order to control the number of orders routed every two days.

Further, we found that if every zone is visited only 3 times a week, there is an approximately 13% reduction in the number of trucks required to deliver the same number of shipments. If every zone is only visited 2 times a week, this reduction will rise to approximately 19%. These are theoretical calculations based on Daganzo's equation mentioned in section 4. Section 5.4 has details on the practical findings.

Table 1. Estimated trip saving from reduced delivery frequency.

City Area (Km2)	No. of Zones	No. of Trucks	Days visited / week	Capacity / Truck	Total Capacity	Reduction in no. of trips
325	8	8	6	16	768	0%
325	14	7	3	18	756	13%
325	19.5	6.5	2	20	780	19%

Parameters used in the above analysis are, time per end customer delivery form the truck 0.1 hours, circuitry factor for Mexico 1.46, and the average speed of the truck in urban delivery is 25km/h.

Level 3: Increase the time available for home delivery per truck.

The limiting factor for last mile delivery operations is the total route time available. By increasing the total route time, Coppel can increase the number of orders on a route until one of the three constraints are hit. Per our analysis, if Coppel improves the efficiency of their current operation by 30 mins, they could reduce the number of trips by 12.5%. If the efficiency is improved by 60 minutes, the reduction in trips rises to 26.3%.

Table 2. Savings from increased route time

	Baseline	Adding 30 mins to route	Adding 60 mins to route
Total Area (KM^2)	325	325	325
Frequency of visiting a zone	6	6	6
Orders per trip	14	16	19
No. of trips required	6.50	5.69	4.79
% savings in trips		12.5%	26.3%

5.4 Results to Validate Hypothesis

Level 1:

Results show that 6% of trucks are running routes with 6 orders or less. With a longer lead time or with better route assignment, where these low-density routes are either shipped less frequently or merged with other routes, weekly demand can be delivered in 6% fewer trips. Figure 16 shows the distribution of orders per truck.

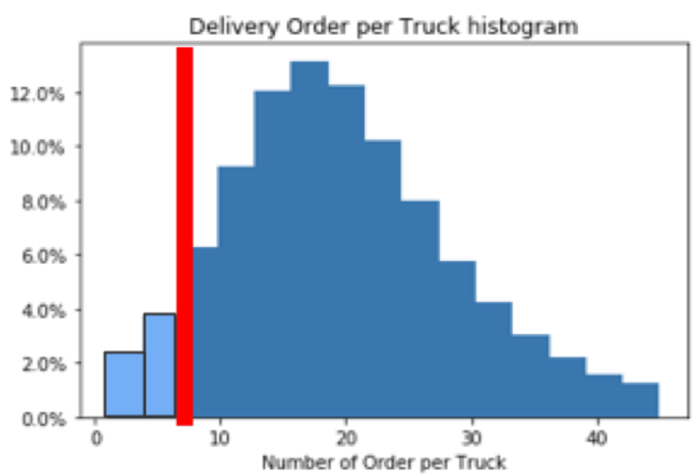

Figure 16. Representation of route utilization

Level 2:

We analyze 8 different cities having low-density but daily trips. To build consolidation, we suggest less frequent deliveries to these locations. Coppel is already doing this in some regions and should implement this policy across its network. Given the additional lead time, i.e., customer's willingness to wait, Coppel can implement recommendations 1 and 2, reduce the total number of trips, which will result in cost savings. Table 3 below shows the savings from Level 2 consolidation on selected locations.

Table 3. Savings from the reduced delivery frequency

DC location	The city served by the trucks	Trips	Truck /day	Orders	Order / day	Order per truck	Recommended Frequency	Trucks	Order per truck	% of trips saved
LAGUNA	Lerdo	12	2.00	137	22.83	11.42	3	3	15.22	25%
TECAMAC	Acolman	12	2.00	123	20.50	10.25	3	2.5	16.40	38%
TECAMAC	Ebano	6	1.00	82	13.67	13.67	4	1	20.50	33%
LEON	Dolores Hidalgo	14	2.33	145	24.17	10.36	3	3	16.11	36%
LEON	Silao	12	2.00	103	17.17	8.58	3	2	17.17	50%
HERMOSILLO	Aguaparieta	11	1.83	94	15.67	8.55	3	2	15.67	45%
HERMOSILLO	Miguelalem	11	1.83	42	7.00	3.82	3	1	14.00	73%
CULICAN	El, Rosario	9	1.50	124	20.67	13.78	3	2	20.67	33%

Level 3:

The high-density zones present the biggest opportunity for reduction of trips and therefore savings by extending the current constraint on routes – time. By adding one hour to the total route time, which will be spent in-zone making deliveries, each truck will be able to deliver more orders and could also cover a larger area, thereby improving the overall route and vehicle utilization. In our analysis, we looked at deliveries to 4 different Cities – Culiacan, Monterrey, Matamoros, and Ecatepec (Mexico City). Table 4 showsthe current density for the 4 chosen regions

Table 4. Current order density for 3 DCs

DC location	Delivery city	Trucks	Truck / day	Orders	Order / day	Area	Density
Monterrey	Monterrey	50	8	546	91	325	3.57
Monterrey	Matamoros	67	11	516	86	19	0.22
Tecamac	Ecatepec	76	13	1323	221	72	0.33
Culiacan	Culiacan	99	17	2753	459	64	0.14

Tables 5, 6 and 7 below show findings from increasing route length for the 4 regions. Table 5 shows the theoretical trucks required for 3 hours in zone delivery time. Table 6 shows the savings in trucks for 3.50 hours and Table 7 shows the savings in trucks for 4 hours.

Table 5. No. of trucks requiredwith a 3-hour delivery

DC (i)	City (j)	Orders/Truck (n)	Trucks	Time/hours ($T_{zone(i,j)}$)
Monterrey	Monterrey	14	6.50	2.95
Monterrey	Matamoros	23	3.74	2.93
Tecamac	Ecatepec	22	10.02	2.93
Culiacan	Culiacan	24	19.12	2.92

Table 6. No. of trucks required with 3.5-hour delivery

DC (i)	City (j)	Orders/Truck (n)	Trucks	Time/hours ($T_{zone(i,j)}$)
Monterrey	Monterrey	16	5.69	3.37
Monterrey	Matamoros	28	3.07	3.57
Tecamac	Ecatepec	26	8.48	3.47
Culiacan	Culiacan	29	15.82	3.53

Table 7. No. of trucks required with a 4-hour delivery

DC (i)	City (j)	Orders/Truck (n)	Trucks	Time/hours ($T_{zone(i,j)}$)
Monterrey	Monterrey	17	5.35	3.58
Monterrey	Matamoros	30	2.87	3.82
Tecamac	Ecatepec	30	7.35	4.00
Culiacan	Culiacan	33	13.90	4.02

Parameter for the above calculations, Time required per delivery 0.1 hours, Circuity factor for Mexico 1.46 and speed in urban driving 25Km/h.

All these areas are dense and could be used for a pilot as described below:

- Select one region and get geocoordinates for delivery addresses.
- Build n clusters or regions based on the distance between points. K-Means clustering or some other clustering method can be used for this. Improved data from January to April 2019 will help build accurate clusters
- Pilot the routes with the added time for one week and monitor KPIs – average orders per route, the total number of trips and total fuel usage.

Some anticipated challenges with running the pilot:

- Address quality is poor. We found that only 60% of the addresses provided by Coppel could be geocoded by Google API.
- Google Geocoding API has bandwidth constraints. Can only geocode addresses at the average rate of 1.5 addresses per second. We suggest limiting the data set to 15-20K addresses and using them for the geocoding and clustering.

Taking the Monterrey distribution center as an example, we ran K-means clustering on the delivery base. We chose six clusters to represent all the delivery areas in the city, with each cluster being a delivery zone. The number of outer clusters can be modified easily in our code. The output of K-Means for the Monterrey distribution center is shown in Figure 17.

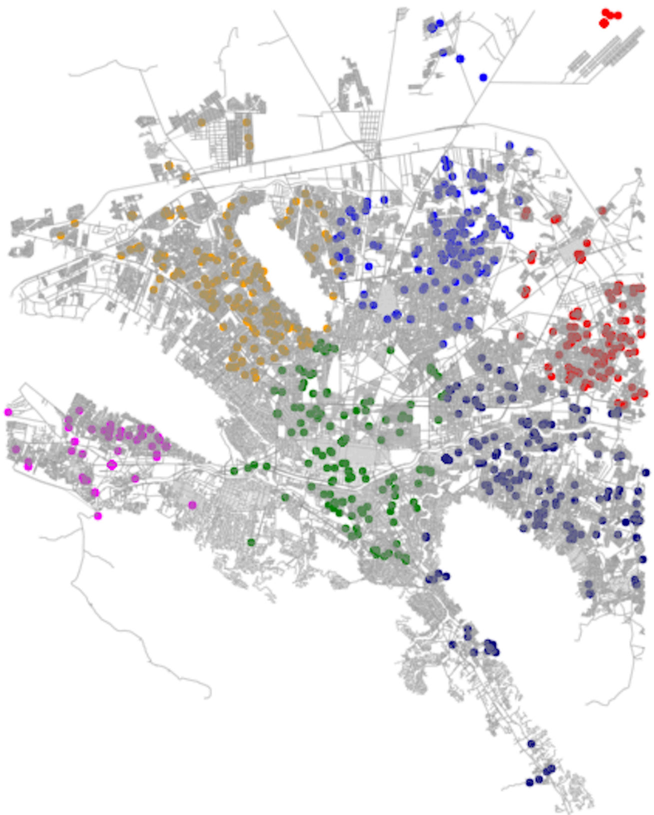

Figure 17. K-Means output for Monterrey DC

Next, we ran the resulting six clusters through a model that calculated the area of each polygon. Each of the above-mentioned larger clusters is being serviced every day. Now it is limited by the time each truck could spend on last mile delivery after store delivery, loading, and unloading.

5.5 Impact on Upstream Inventory Policy

An increase in customer lead times can provide opportunities to improve upstream inter-DC traffic. We did not receive any data from Coppel about their inventory and replenishment policies, so we were unable to complete a deeper analysis of inventory placement and warehouse transfers. However, we found opportunities to reduce inter-warehouse trips by some operational changes.

SKU Segmentation

Coppel can look to implement product segmentation and modify service levels based on the segmentation. ABC SKU segmentation for fast, middle and slow movers would be a good starting point. Today Coppel is using the same push policy to deploy inventory for all products to each regional DC or store. SKU segmentation will, in turn, enable inventory pooling, which can lead to a reduction in inter-warehouse trips. By implementing ABC classification and reducing the variability of warehouse moves, we found that we could reduce about 15% of truck moves while maintaining service levels.

Inventory Pooling

Another recommendation for Coppel to explore is pooling inventory in a few (the suggested number is 6) central locations and move inventory to the distribution centers based on the classification of the SKU. To reduce inter-warehouse moves, we recommend the policy as shown in table 8

Table 8. Recommended Inventory Policy

	Class A	**Class B**	**Class C**
Push / Pull	Partial Push to all DC, replenish from the hub	Push to Hub only	Stay at receiving DC or supplier delivery to Hub
Expected Inventory Impact	Safety stock reduces at DC	Safety stock reduces at DC	Safety stock reduces at DC
Expected impact on Lead time	Expected lead time for replenishment will be 2 days	Expected lead time for replenishment increases to 4 days	Expected lead time increases to 15 days

This product segmentation strategy should reduce the number of replenishments needed and enable more efficient use of trucks and allow them to maintain their current service level to customers.

5.6 Quantifying the Savings and Emissions Impact

We suggest using the reduction in the truck moves as a proxy for transportation cost and fuel usage and therefore for emissions reduction.

To further illustrate, we find that reducing the frequency of deliveries to a zone to once every 2 days, will reduce the number of trips by 19%. In addition, adding one hour to total route time will theoretically result in about 26% fewer trips. Both recommendations, if combined with level 1 6% efficiency gain, could reduce trips by up to 32%. We used the results from the hypothesis to calculate saving because, in the practical scenarios, we only looked at a few examples, and we believe that at a network level, the potential savings will be more aligned with the theoretical findings. This is illustrated in table 9.

On inter-DC traffic, we estimated that inventory pooling and SKU classification can save 15%on trips. The results from our analysis are in table 10.

Table 9. Fuel use and emissions for last mile delivery

Measurement	**Current Baseline**	**Level 1 6%**	**Level 1 + Level 2 (25)%**	**Level 1 + Level 3 (32)%**
Fuel (million liters)	6.69	6.29	5.02	4.55
Emissions (million kgs)	17.99	16.91	13.49	12.23

Table 10. Fuel use and emissions for inter-DC moves

Measurement	**Current inter-DC Baseline**	**After pooling and classification**
Fuel (million liters)	14.80	12.58
Emissions (million kgs)	39.81	33.84

Table 12 shows the combined impact of the last mile and inter-DC operations on fuel usage and emissions. The best-case scenario represents a savings opportunity of 11.42 million liters of fuel and 30.71 million kg in emissions. Assuming a cost of $1 / liter (Global Petrol Prices, 2019), this represents a savings potential of $12MM annually.

Table 11. Best Case Reduction in Fuel and Emissions

Measurement	**Current Baseline**	**Best Case**	**Best Case Saving**
Fuel (million litres)	21.46	17.13	4.36
Emissions (million kgs)	57.80	46.07	11.73

5.7 Other Operational Improvements

Better loading operation

Today, Coppel spends an average of 1 hour each for loading a vehicle for the store and home delivery. If the loading time is reduced by 15 mins for both store and home delivery operations, the 30 minutes saved could be used for additional home deliveries. In the same way, if the efficiency is improved by 30 mins each, the 60 mins saved could be used for additional home deliveries. Some suggested ways to improve the efficiency of the loading process:

1. Pallet loading
2. Cart loading
3. Overnight loading

6. Conclusion

In conclusion, Coppel's current home delivery operation has fairly low utilization by volume and/or weight. The current limiting factor is the total route time per truck and the service level promised to the customer of next-day delivery. If the customer is willing to wait up to 4 days to reduce carbon footprint, Coppel can lower delivery costs by up to 32%, as shown in section 5.

In addition, there are incremental savings opportunities by increasing lead times for home deliveries. Our approach aims to minimize the number of trucks required to meet total customer demand from each DC. As shown in our analysis, modifying the delivery zones, reducing the delivery frequency and increasing the time available for home deliveries will improve route density and result in fewer trips overall to meet customer demand. This represents a win-win for Coppel because fewer trips will also result in reduced emissions, thus creating a reinforcing loop for cost and emissions.

We also identified a potential 15% saving on inter-DC truck moves with increased delivery lead times to customers. However, the data set provided is missing key information on inventory policy and replenishment, which prevents us from completing a deeper analysis in this area. A future study could focus on the impact of longer lead times on inventory policy and inter-DC transportation cost.

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8. Appendix

Table 12. Number of SKUs explained by μ + 1 σ based on empirical distribution from SKU data

	Weight	Volume
Positive count	65,381	64,955
CDF	93.41%	92.80%
Total count	69,995	

Picture 1: Coppel Last Mile Truck

Picture 2: Last Mile Vehicle Utilization

Picture 3: Home Delivery Route Example