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CASE STUDIES IN CARBON-EFFICIENT LOGISTICS

Caterpillar: Light-Weighting and Inbound Consolidation

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Case Study Highlights
In this case study, we analyzed the inbound shipping operations of Caterpillar’s North American large mining truck facility to determine – based on weight, packaging, routing, and scheduling – opportunities to streamline shipping protocols and thus reduce carbon emissions associated with the supply chain. When combined, the streamlined shipping and packaging efforts could reduce Caterpillar’s overall carbon emissions by 340–730 tonnes of CO₂ per year.

Switching Shipment Packaging from Steel to Light-Weight Plastic: At present, Caterpillar uses steel containers to transport parts. Caterpillar has been working for the past four years to phase out these steel containers and replace them with plastic containers, which weigh considerably less. To determine the cost savings and CO₂ emission reduction potential associated with this switch, we had to:
- Estimate the current total CO₂ emissions of the inbound shipments.
- Estimate the CO₂ emissions of the current inbound logistics if the containers were plastic, not steel.
- Compare the two calculations to determine the total CO₂ emission reduction potential for full-scale “light-weighting” of all inbound shipments.

Analyzing Inbound Shipments to Identify Potential Consolidation: To construct the very large vehicles used in the mining industry, parts are shipped from all over the globe for assembly at Caterpillar’s manufacturing facility in Decatur, Illinois. We analyzed historical shipment data to identify areas where shipments could be consolidated to save fuel and reduce vehicle CO₂ emissions. More specifically, we analyzed:
- How the parts are packaged, to determine which shipments could be combined based on packaging requirements.
- The distance from suppliers to Caterpillar’s assembly plant.
- The timeframe within which the parts needed to arrive.
- The distance between supplier warehouses, to determine which shipments could be combined.
About Caterpillar

Caterpillar is the world’s leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives. The company also is a leading services provider through Caterpillar Financial Services, Caterpillar Remanufacturing Services, and Progress Rail Services. Headquartered in Peoria, Illinois, Caterpillar employs nearly 130,000 people globally, with 2011 annual sales and revenue of $60.138 billion.¹

The Global Mining Division of Caterpillar manufactures specialized trucks for the mining industry (Figure 1). Over the past 30 years, Caterpillar has produced nearly three times as many trucks as its closest competitor. Caterpillar assembled its 50,000th rigid-frame construction and mining truck in 2009. In this case study, we focus on North American inbound parts logistics for Caterpillar’s manufacturing facility in Decatur, Illinois.

![Two mining trucks manufactured at the Caterpillar Decatur plant](image)

**Figure 1. Two of the mining trucks manufactured at the Caterpillar Decatur plant**

Light-Weighting Returnable Containers

In order to take delivery of the thousands of parts required to manufacture a mining truck, Caterpillar uses a large assortment of returnable steel containers. These containers are specially designed to protect and transport parts during inbound logistics. They vary in shape and size and can hold loads ranging from 3,000 to 6,000 pounds.

These containers have been in circulation for more than 50 years. There is an ongoing initiative to replace them with plastic versions that can hold similar loads, but weigh significantly less. For example, while a steel tote box weighs 235 pounds, a comparable plastic container weighs only 70 pounds. Caterpillar’s internal studies have determined that the fuel savings from light-weighting inbound containers will offset the capital expenditure within two years. Added benefits that are harder to measure financially are the lighter containers’ ease of handling, and the opportunity to further standardize inbound shipments.

Since reducing packaging weight translates into lower shipment weight, less fuel will be consumed transporting parts by truck to Caterpillar’s Decatur plant. In order to estimate the expected CO₂ emission reductions due to using lighter containers, we first need to estimate the CO₂ emissions of the current inbound logistics operations and compare them with the light-weighting option.
Estimating Inbound Logistics CO₂ Emissions

To determine the total CO₂ emissions of the inbound Caterpillar logistics operations, we analyzed 16 weeks of transportation data that included detailed information about North American² suppliers for three of the flagship mining trucks, including location, number of parts shipped, and delivery dates. The data included over 15,000 truck deliveries of 1,400 different parts from more than 200 suppliers that ship directly to the Decatur manufacturing plant. These suppliers are represented by red dots, in relation to the Decatur location (blue dot) in Figure 3.

![Figure 3. Location of suppliers in North America. Geocoded using Google Maps³](image)

We used the following formula to estimate the shipment CO₂ emissions:

\[
\text{CO}_2 \text{ Emissions Inbound Shipment} = \text{Shipment Weight} \times \text{Road Distance} \times \text{Road Emission Factor}
\]

The Road Emission Factor represents the amount of CO₂ generated by moving one ton⁴ of cargo one mile using road transportation. We used 78.5 grams of CO₂ per ton-mile as the

² For this case study, only North American suppliers were included. International deliveries require other modes of transportation such as air and ocean, which are outside the scope of this project.
⁴
road emission factor. This emission factor corresponds to the average emissions of flatbed trucks as reported by the EPA SmartWay Shipper Tools.\(^5\) Even though Caterpillar uses a wide range of truck configurations, it was determined that estimates from flatbed truck carriers accurately represent the emissions from inbound logistics operations. Since Caterpillar has detailed specifications for each part number, we were able to estimate the weight (including the packaging) for each of the 15,000 inbound supplier shipments by combining the data. The baseline CO\(_2\) emission was estimated at 127 tonnes for these 15,000 deliveries over the 16 week period we chose for analysis.

Using the packaging information master data for each part, we were able to identify 9.5% of shipments as eligible for packaging light-weighting. For each of those shipments, we recalculated the CO\(_2\) emissions for the total network, assuming a plastic container instead of a steel container, using the same formula as above.

We were able to determine that light-weighting has the potential to reduce CO\(_2\) total emissions by 16.5%. In fact, the CO\(_2\) abatement potential may be higher, since we did not analyze any of the container repositioning logistics. Carriers transporting Caterpillar parts also will save fuel due to lighter

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\(^4\) In this document, we will use the word “ton” as commonly used in the United States: one ton is equal to 2,000 pounds. This is internationally referred to as a “short-ton” to differentiate it from a “tonne” or “metric-ton,” which is equivalent to 2,204 pounds.


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### Selecting the Correct Emission Factor

One of the most confusing decisions when computing CO\(_2\) emissions in transportation is choosing the correct emission factor. For example, the GHG Protocol freight tools list 1717.12 grams of CO\(_2\) per mile, while the average across all carriers reporting to the EPA SmartWay program was 1798.64 grams of CO\(_2\) per mile. Ton-mile emission factors vary even more. For example, the GHG Protocol lists an emission factor of 297 grams of CO\(_2\) per ton-mile, the average EPA SmartWay carrier reported 149.7 grams of CO\(_2\) per ton-mile, while a flatbed fleet within the same program reported an average of 78.5 grams of CO\(_2\) per ton-mile. Here are some guidelines:

- Whenever possible, use carrier-specific numbers. The EPA SmartWay program in the United States publishes self-reported values for almost 3,000 carriers and 3PLs. These numbers are computed using estimates on fuel consumption, total cargo, and distance traveled. They are rounded to pre-determined ranges, but are a good starting point. Remember that the EPA does not audit these numbers and that small fleets are under-represented in this data.

- Make sure you understand how empty miles and load utilizations are accounted for in the emission factor. For example, the GHG Protocol CO\(_2\) per ton-mile factor only includes loaded miles and assumes a 5.9-mpg fuel efficiency, which implies a heavily loaded truck.

- If possible, understand how data was collected to come up with the emission factor. The GHG Protocol ton-mile factor was computed using representative aggregate US statistical data (top-down approach) compared to the EPA SmartWay program, which uses less representative but carrier-specific information (bottom-up approach).

- More detailed approaches are available but require more data and potentially more assumptions. The non-profit organization NTM in Europe publishes a comprehensive reference on CO\(_2\) calculations at various levels of detail that includes data requirements.

- Finally, always keep good records of your assumptions, and be ready to adjust your calculations as new data becomes available. Changes in emission factors will always impact absolute emissions reported, may or may not impact percentage emission reductions, and very rarely change final carbon-efficient logistics decisions.
shipments; some of these savings will be passed through to Caterpillar in lower fuel bills and lower fuel surcharges.

The main operational barrier for Caterpillar to adopt the plastic containers has to do with internal organizational and budgetary constraints. Even though the return on investment (ROI) of 2 years is relatively fast, the company still needs to allocate capital to replace the steel containers. Also, it will take time to roll out the new plastic containers across all suppliers, and the current steel containers need to be properly disposed of. Due to the light weight of the containers, there is a higher risk of misplacing a container. As a result, tracking mechanisms need to be put in place. Finally, product designers need to take into account the new containers as they develop new features in each truck model, to maximize the reuse rates of the containers. All these changes are within Caterpillar’s control, and the additional CO₂ emission savings may motivate the various stakeholders to adopt light-weight packaging sooner.

**Inbound Consolidation**

One opportunity for improvement to lower CO₂ emissions from Caterpillar’s internal logistics operations is the consolidation of shipments headed for the Decatur facility. Currently, most suppliers ship directly to the manufacturing plant in Decatur, regardless of geographical proximity. Figure 4 shows an opportunity for geographical consolidation—by bundling shipments together based on the shipment type and location.

![Figure 4. Example of a potential inbound consolidation opportunity](image-url)
A number of requirements and constraints come into play when considering consolidation of inbound shipments. First, each part requires a certain type of packaging and handling to ensure its safe delivery. At the same time, the weight of the shipment and the capacity of the shipping vehicle limit the number of shipments eligible for consolidation. Many of the parts required for the mining vehicles are sizeable. Storing these parts for long periods of time is not a viable option. Shipments need to arrive in a timely manner according to their scheduled assembly process to minimize storage costs and optimize production. Finally, adding stops to an existing route increases time and costs, and must be offset by a total cost savings and emission reduction.

Taking these factors into account, and in order to estimate the cost and environmental reduction potential of inbound supplier consolidation, we developed a shipment-clustering algorithm as follows:

- Identified suppliers within a 30-mile radius. (Taking a shipper significantly off-route negates the carbon emission savings gained by combining shipments.) Each of these suppliers was placed in a cluster.
- For each of the suppliers in a cluster, we analyzed all shipments to the Decatur plant within the same week.
- For each of these shipments, we identified parts that used the same type of transportation container (e.g. totes, racks) to ensure equipment compatibility.
- We then identified pairs of compatible shipments that could be consolidated while keeping the extra distance traveled to pick up the shipment at no more than 50%.
- Finally, we chose only the shipments that were profitable after taking into consideration the extra stop-charge and extra travel distance.

Since these changes would affect not only the parts shipped for the three selected mining trucks, but all the parts shipped from those suppliers to Decatur, we used the following formula to estimate CO₂ emission savings potential due to consolidation:

\[
\text{CO}_2 \text{ Savings} = (\text{Route 1} + \text{Route 2} - \text{Consolidated Route}) \times \text{Truckload Emission Factor}
\]

In this formula, the first term represents the total distance saved after consolidating the two shipments: \(\text{Route 1}\) represents the total round-trip distance of the first shipment received directly from the first supplier; \(\text{Route 2}\) represents the total round-trip distance of the second shipment received directly from the second supplier; and \(\text{Consolidated Route}\) represents the total distance of the consolidated route, stopping at both suppliers and returning back to the cluster. This distance is then multiplied by the \text{Truckload Emission Factor}, which is the amount of CO₂ generated per mile by the truck. We used 1788 grams of CO₂ per mile as the road emission factor, which corresponds to the average emissions of flatbed trucks as reported by the EPA SmartWay Shipper Tools.⁶

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We applied the above formula to the Caterpillar inbound logistics network. Figure 5 shows the range of cost and CO₂ savings we concluded could be gained by implementing an inbound consolidation program. The chart demonstrates that Caterpillar would get a 3% cost reduction and a 9% CO₂ reduction when the consolidation generates no more than 20% out-of-route miles. Although the number of shipments eligible for consolidation grows as the amount of out-of-route miles allowed increases, everything above the 20% point begins to show decreased profitability. The results level out at 2,300 shipments, when 20% out-of-route miles are allowed. If non-profitable inbound consolidation opportunities are allowed, the CO₂ reduction potential increases to 11%.

Figure 5. Example of a potential inbound consolidation opportunity

This type of sensitivity analysis allows us to better analyze the environmental and economic decisions associated with inbound consolidation. For example, we can see in Figure 5, that by consolidating 500 shipments, a cost reduction of 2% and CO₂ reductions of close to 4% can be achieved. This is a relatively modest proposition that would affect less than 5% of total shipments. However, if a more aggressive CO₂ reduction goal were set, Caterpillar could consolidate up to 2,300 shipments, doubling the CO₂ savings but increasing cost savings by only 1%.

It is important to clarify that the CO₂ savings calculation is a rough approximation. First, the fuel efficiency of the vehicle is much higher with less weight than with more weight. The current calculation assumes that the fuel efficiency of the vehicle is not significantly
changed if more shipments are added to the truck. Depending on the amount of weight added, there could be noticeable fuel efficiency changes.

Summary
By analyzing several components of Caterpillar’s inbound shipments, we were able to identify two key areas that would reduce costs and carbon emissions: packaging and consolidation of shipments. By reducing the shipping containers from 130–200 pounds each to 20–40 pounds each, there is an annual reduction potential of 130 tonnes of CO₂ emissions across the Caterpillar North American network. Additionally, by identifying the ideal balance between environmental impact and profitability, clustering inbound shipments will allow for an additional reduction of 210–530 tonnes of CO₂ emissions.

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