ALLOCATING CARBON EMISSIONS FROM OCEANGOING VESSELS

Ana Yanes and Grant Guenther
Transport Canada

Introduction

Knowledge of emissions per shipment for specific trade routes contributes to more informed decisions from industry, policy makers, and consumers. However, arriving at the appropriate average emission intensities for specific routes implies an allocation process to attribute fuel use to specific locations.

This type of allocation is one of the requirements when estimating, for example, the average carbon footprint of the Asia-Pacific gateway and corridor. A carbon footprint is a measure of greenhouse gas emissions resulting from a set of activities. In this paper the average carbon footprint of transportation activities in a corridor is expressed as the average greenhouse gas emissions per unit of containeraized freight.

Following the example above, a share of emissions from oceangoing vessels per trip between Asia and North America needs to be allocated to each container that entered the ports of Vancouver and Prince Rupert. To do this, a simple ratio of emissions per container should suffice when the trip has only one destination. However, when more than one port is visited on the same distribution route, emissions must be allocated to each container based on a set of criteria.

This paper presents a theroretical solution to the allocation problem. The allocation criteria applied are based on the literature on allocation of costs and emissions on a distribution route.

The first section explains the allocation of oceangoing vessel emissions in the context of estimating the carbon footprint of the Asia-Pacific gateway and corridor. The next describes the allocation problem. The third section presents the allocation criteria and the sets of equations that define the proposed solution to the allocation problem. The paper concludes with a brief discussion of the next steps to explore alternative solutions and implementation strategy.

Project Rationale and Description

This section explains the context and contribution of the work presented in this paper. Estimating the carbon footprint of the Asia-Pacific gateway and corridor provides the context for applying a methodology of marine emissions allocation. The underlying principle of the exercise is to set a neutral and independent system-wide carbon footprint calculator for a gateway and corridor.

The final purpose of the emissions allocation is to estimate the average carbon footprint of inbound container movements for the Asia-Pacific gateway and corridor. Individual transportation companies that operate in the corridor estimate their own carbon footprint to help improve the fuel efficiency of their operations or to contribute to their marketing strategies. Estimating the carbon footprint of a gateway and corridor contributes to measure the corridor performance.

In this paper the context is to define the carbon footprint of the Asia-Pacific gateway and corridor as the average greenhouse gas emission intensity of inbound container movements from Hong Kong and Shanghai to Calgary, Toronto, Montreal and Chicago via the ports of Vancouver and Prince Rupert. The emission intensity can be measured in kilograms of CO_2 per Twenty-Foot Equivalent Units (TEUs) as an average for each route.

This problem requires the allocation of marine emissions to each of the Canadian ports visited on the same trip when more than one port in North America is visited on the same route.

Marine Allocation Problem

This section presents the marine emissions allocation problem. The problem is to estimate average emissions per TEU for routes from Asia to North America that include the origin ports of Hong Kong and/or Shanghai in Asia and the destination ports of Prince Rupert and/or Vancouver in Canada.

Transportation activities are complex, several ports are visited on the same distribution route, transloading activities occur at each port and data availability on these activities is limited. In order to arrive at a solution, this paper makes simplifications. This problem assumes that containers are shipped in sets that are handled in one origin port and one destination port. Emissions will be allocated to each set of containers that leaves the same origin port in Asia and is handled in the same destination port in North America. In this sense, emissions are allocated to origin-destination pairs and to matching sets of containers that travel from the same origin to the same destination.

A set of containers shares the same trip that may visit one port or more in Asia, one port or more in Canada, and one port or more in the rest of North America. Trips are the movements of various sets of containers from Asia to North America. All trip emissions must be allocated to the North American destination ports visited on the same route. Allocation per container starts by allocating emissions to each set of containers that are headed to one North American port.
The notation of the concepts involved is:

C	is the observed amount of cargo (number of TEUs) per trip
c_i	is the observed amount of cargo in a set of containers i
D	is the observed distance of the entire trip
d_{-i}	is the observed trip distance when port i is not included in the trip. Alternatively, it is the observed trip distance when all ports except port i are included in the trip. In the 2-port case, this is the direct trip distance to the other port, for example, is the observed distance to port 2 when the trip does not include port 1

$d_{-i,-j}$ is the observed trip distance when ports i and j are not included in the trip. Alternatively, it is the trip distance when only the set of ports that are different than i and j are included in the trip

$d_{-i,-j,-k}$ is the observed trip distance when ports i, j and k are not included in the trip

E is the observed total emissions (kilograms of CO_2) from a trip

e_i is the emissions from a trip to port i

m_i is the increase in distance to the trip by including port i in the trip. In other words, the portion of the trip that port i is solely responsible for.

$m_{i,j}$ is the increase in distance to the trip by including ports i and j that is not accounted for in either mi or mj. In other words, the portion of the trip that ports i and j are jointly – not including the portion of the trip that they are each solely – responsible for.

$m_{i,j,k}$ is the increase in distance to the trip by including ports i, j, and k that is not accounted for in i, j, and k's respective individual or 2-pair combination increases in distance.

m_o is the trip distance that all ports are jointly responsible for.

S_i is the share of the distance that is attributed to port i

Allocation Criteria and Proposed Solution

This section explores the allocation criteria and solution to the problem described in the second section. The emissions allocation problem must answer the question of which factors are to be taken into account to allocate fuel use. The main factors that affect fuel use and emissions are trip distance, speed, weight, as well as the technological and operating characteristics of the vessel. A rational allocation is based on the parameters that influence fuel use.

According to the rationality criterion, the relative impact of the parameters on the allocation should resemble the relative impact of the parameters on the actual CO_2 emissions. If distance travelled has the largest impact on emissions, distance travelled is the parameter that will have the largest impact on the allocation. However, if speed is the factor that has the largest impact on emissions, variability on speed required for the delivery of containers should be considered instead.

In addition to the rationality criterion, there are five allocation criteria to be considered, which are applicability, cost effectiveness, clarity, acceptability, and fairness. First, there should be enough data and resources to apply the proposed methodology on a regular basis. Second, the cost of obtaining the data and applying the methodology on a regular basis should not exceed the benefits of the knowledge created. Third, the allocation methodology should be clear to stake-holders. Fourth, stakeholders must accept it. Finally, the allocation outcome must be fair, which means that the joint delivery of sets of containers to various ports on the same trip will make sense from the point of view of emissions allocation.

The applicability and cost effectiveness criteria limit the complete application of the rationality criterion as described above. For this problem, we have assumed that distance is the factor that will be possible to measure. The problem below allocates emissions based on the shares of distance travelled to each of the ports visited.

The convenience of a joint delivery of sets of containers expressed in the fairness criterion is determined by four conditions described below.

A fair allocation occurs when the following conditions are met: efficiency, individual rationality, marginal rationality, and kick-back. The conditions that relate to the fairness criterion are explained in more detail below in the context of the allocation of marine emissions to ports visited on the same distribution route.

Efficiency
The efficiency condition requires that the total amount of CO_2 emitted on a trip should be allocated among the sets of containers

transported on that trip. The efficiency condition could be broken for the sake of providing incentives to carriers. For example, an increasing share of the total CO_2 emissions from a trip can be discounted to the carrier based on improvements observed in the fuel efficiency of their vessels compared to an external benchmark. This would provide an incentive to the carrier to invest in higher fuel efficiency by improving operations, or investing in new vessel technology.

Individuality

The individual rationality condition requires that the amount of CO_2 allocated to a set of containers that shares the same distribution route with other sets of containers that are headed to other ports should not exceed the amount of CO_2 that would be emitted if the trip was visiting only one port.

An allocation method follows the individual rationality condition if there are no incentives for trips to visit one port only.

Marginality

The marginality condition requires that the amount of CO_2 allocated to a certain set of containers should not be less than the marginal amount of CO_2 emitted by including this set of containers in the trip. The marginal amount of CO_2 emitted for a certain set of containers "s" is the difference between the amount of CO_2 emitted when all sets of containers are distributed to ports on a trip (including the set of containers "s") and the amount of CO_2 emitted when all other sets of containers (excluding the set of containers "s") are distributed on a trip.

Kick-back

The kick-back condition requires that none of the sets of containers distributed on a trip gets a negative emissions allocation.

The solution to the problem can be expressed by the solution for the marginal distance in the following equations. The cases of 2 ports, 3 ports and 4 ports visited on the same route are presented below.

The following set of equations express the problem when only 2 ports are visited on the same trip:

1: $E = e_1 + e_2$

7: $e_i = E * S_i$

2: $C = c_1 + c_2$

3: $D = m_0 + m_1 + m_2$

4: $1 = S_1 + S_2$

Emissions, cargo, total distance and direct distances are observed. The solution is found by solving the system of linear equations defined by (5). This is to solve for the shares of the distance that ports are jointly responsible for, and the marginal distances that each port is individually responsible for.

5: $S_i = \frac{1}{D}\left[m_0 \frac{c_i}{C} + m_i\right]$

The distance added to the total distance travelled by adding port i to the trip equals the total distance minus the distance that would be travelled when removing port i. In the 2-port case, removing port i means the direct distance to the other port.

6: $m_i = D - d_{-i}$

The following equations express the problem when 3 ports are visited on the same trip:

1: $E = \sum_{i=1}^{3} e_i$

2: $e_i = E * S_i$

3: $C = \sum_{i=1}^{3} c_i$

4: $D = m_0 + \sum_{i=1}^{3} m_i + \sum_{i=1}^{3} \sum_{j=i+1}^{3} m_{i,j}$

5: $1 = \sum_{i=1}^{3} S_i$

6: $S_i = \frac{1}{D}\left[m_0 \frac{c_i}{C} + m_i + \sum_{\substack{j=1 \\ \forall j \neq i}}^{3} \left(m_{i,j} * {}^{c_i}/_{c_i + c_j}\right)\right]$

7: $m_i = D - d_{-i}$

8: $m_{i,j} = (D - d_{-i,-j}) - (m_i + m_j)$

The following equations express the problem when 4 ports are visited on the same trip:

1: $E = \sum_{i=1}^{4} e_i$

2: $e_i = E * S_i$

3: $C = \sum_{i=1}^{4} c_i$

4: $D = m_0 + \sum_{i=1}^{4} m_i + \sum_{i=1}^{4} \sum_{j=i+1}^{4} m_{i,j} + \sum_{i=1}^{4} \sum_{j=i+1}^{4} \sum_{k=j+1}^{4} m_{i,j,k}$

5: $1 = \sum_{i=1}^{4} S_i$

6: $S_i = \frac{1}{D}\left[m_0 \frac{c_i}{C} + m_i + \sum_{\substack{j=1 \\ \forall j \neq i}}^{4} \left(m_{i,j} * \frac{c_i}{c_i + c_j}\right) + \sum_{\substack{j=1 \\ \forall j \neq i}}^{4} \sum_{\substack{k=j+1 \\ \forall k \neq i}}^{4} \left(m_{i,j,k} * \frac{c_i}{c_i + c_j + c_k}\right)\right]$

7: $m_i = D - d_{-i}$

8: $m_{i,j} = (D - d_{-i,-j}) - (m_i + m_j)$

9: $m_{i,j,k} = (D - d_{-i,-j,-k}) - (m_i + m_j) - (m_{i,j} + m_{i,k} + m_{j,k})$

When more than four ports are visited on the same trip, the computation of the solution becomes cumbersome due to the number of combinations involved.

Conclusion

Estimating the carbon footprint of transportation activities requires allocating fuel use to individual sets of activities that share common trips.

This paper proposes a theroretical solution to the problem of allocating emissions of oceangoing vessels by choosing a set of conditions that relate to the fairness criterion as well as considering a set of criteria. Fairness is interpreted as the desirability of a joint delivery of sets of containers. The solution presented also uses limited available data on observed distances.

Future empirical work may include testing the solution presented here for robusteness, or the ability of the method to allocate similar amounts of emissions to the same ports under slightly different conditions. Improvements on data availability may lead to more complex solutions that reach a closer estimate to the carbon footprint of transportation activities.

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