Australasian Transport Research Forum 2023 Proceedings
29 November – 1 December, Perth, Australia
Publication website: http://www.atrf.info

Opportunities for backloading as a logistics measure to improve freight sustainability

Fanny Boulaire [1], Stephen McFallan [1], Nick Smolanko [2], Ben Price [1], Andrew Higgins [1]

[1] CSIRO Environment, Brisbane, Queensland

[2] CSIRO Environment, Adelaide, South Australia

Email for correspondence (presenting author): Fanny.Boulaire@csiro.au

Abstract

Freight in Australia travels long distances between cities and regional centres, leading to high costs for many critical commodities and to high transport emissions. To improve their sustainability, freight operators often use higher productivity vehicles, multi-modal transport where available and efficient logistics practices. One such practice is to optimise freight routes, including minimising empty return trips. However, while such practice is possible for operators who service their own fleet, it can be a challenge for others, especially those who service many customers that rapidly change over time, those who operate over long distances with uncertainty in arrival times, or those transporting commodities that require specialised vehicles. Understanding the potential for non-empty return opportunities at the national level could benefit such stakeholders.

To this end, the work presented in this paper estimates the capacity for trucks to return with a payload, including less than truckload, to their origin location based on information available in TraNSIT (Transport Network Strategic Investment Tool) (Higgins et al., 2018). A model, named backloading model, was added to TraNSIT. It uses a mix of heuristics, based on domain expertise, and optimisation techniques, and provides metrics that quantify opportunities at the national level for various truck/trip categories, as well as information regarding round-trip opportunities. For example, next trip opportunities for refrigerated trucks were found for about 50% of the trips that are less than 400km and trips that are over 1,200km, while the container fleet had the best next trip opportunities for trips over 400km. Round-trip opportunities were determined based on the kilometre ratio, defined as the new distance (with backloading) divided by the initial distance (with empty return) and average kilometres avoided over all trip legs. An example is given for a round-trip with three trip legs, where overall costs, time and distance were halved through this process. While a first attempt at estimating the capacity for return trips with payload at the national level, this model demonstrates that opportunities exist, potentially improving the sustainability and resilience of our transport resources.

Keywords: *Supply chain, efficient logistics, sustainable freight, TraNSIT*

1. Introduction

Australia is characterised by long distance freight between the cities and regional centres, with road trips often over 2,000km and costing in excess of $300 per tonne of payload freight. This not only represents a large portion of the market price of many critical commodities (Kavussanos et al., 2014) but can put pressure on fleet capacity at different locations. Freight operators use multiple strategies to improve their operation, including higher productivity vehicles, use of multi-modal where available, and more efficient logistics practices including minimising empty return trips, through picking up loads on their way back, also called backloading.

Many fleet operators, especially large operators, attempt to optimise vehicle routing, using software platforms that optimise problems referred to as Vehicle Routing problems (Toth and Vigo, 2014). These algorithms are well suited to operators who service their own trailer fleet or a narrow set of customers, operate over small distances such as between depots and final users, and with clear constraints on delivery times. As such, they are often well suited to urban environments. However, many freight operators service a large number of customers that rapidly change over time or operate over long distances with uncertainty in arrival times. For these operators, the opportunities to optimise their routes is more complex and often leads to many trucks coming back to their origin location empty. While some might be able to pick up an opportunistic load on their way back through commercial connections or via bidding platforms (Peltan, 2015), such opportunities are difficult to plan for as there is little information publicly available. For many stakeholders, understanding their potential for non-empty return opportunities could mean they remain competitive (e.g., small fleet operators that can increase their revenue by reducing empty truck movements), or they can promote greater sustainable transport practices (e.g., for government or industry at large who have net-zero emissions targets), that will give them a competitive advantage. Considering that 72% of truck operators own 1 truck, and 17% own 2 trucks (Commonwealth of Australia, 2018), a coordinated approach to facilitate collaborating with one another in the view to optimise their transport logistics would need to be implemented, if it is to benefit all. Not unlike the mechanism that large fleet operators use, operators could coordinate their trips, while maintaining the competitivity of the trucks. However, before any such mechanism, which is often time-consuming and costly, could be put in place, an indication of the potential opportunities for backloading at the national level, as well as over different industries and locations, is required.

In this vein, we have used TraNSIT (Transport Network Strategic Investment Tool) (Higgins et al., 2018) to estimate the capacity for trucks to return with a payload, possibly less than their maximum truckload, to their origin location. The objective was to estimate the potential maximum load factor achievable across sectors leading to a more efficient use of resources, and therefore a more sustainable and resilient industry at the national level. TraNSIT currently models over 180 commodities, representing over 45 million vehicle trips per year, across 750,000 supply chain paths equivalent to over 450 billion tonnes-km across Australia (benchmark.transit.csiro.au). With about 85% of Australia's current freight movements represented in TraNSIT, the TraNSIT model was extended to provide a measure on next potential trip that would lead trucks back to base with a payload, rather than empty. This model, named backloading model, is described in this paper. A range of metrics are presented to quantify the potential for return trips for independent trips in Australia. These are compared to one-way trips, highlighting the benefits for different truck types, and trip lengths.

2. Method

The backloading model consists of a mix of heuristics, based on domain expertise, and optimisation techniques to find the best available next trip with a payload. This section describes in the first instance the problem, followed by the algorithm workflow.

2.1 Problem definition

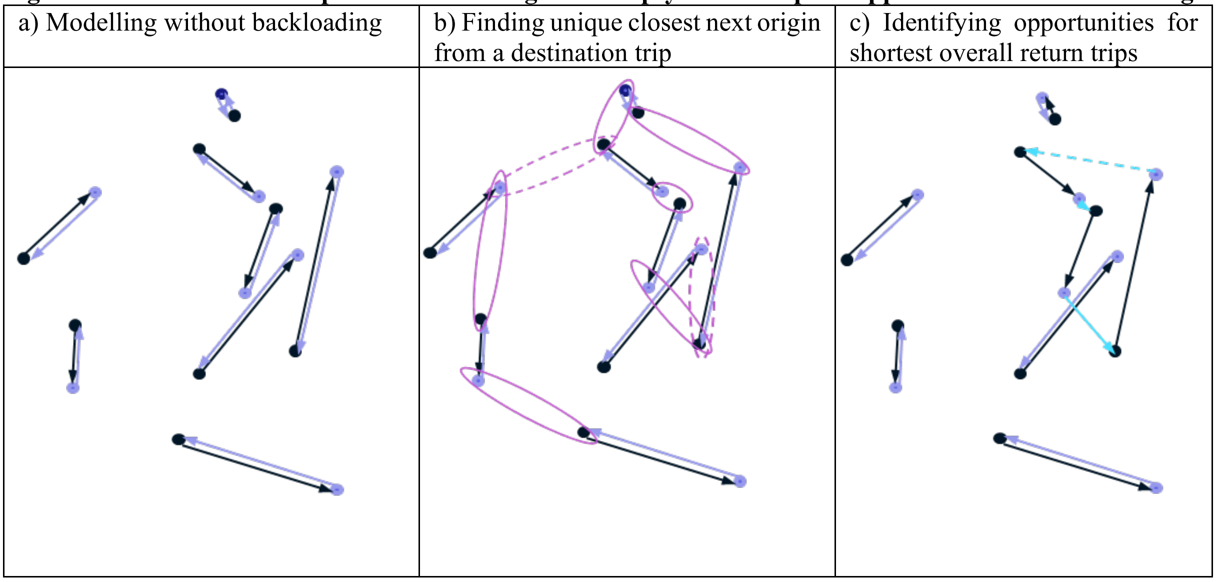
Given a set of origin-destination trips, we are looking for opportunities for a next trip with a payload whose origin is closer than the initial origin location. These sets of next trip opportunities can then be chained together to find sequences of trips that lead to an overall trip distance less than the sum of the distances of the return trips.

Based on this definition, the algorithm aims at finding the closest origin neighbours to any destination point over the whole set, and then finding the shortest path back to the origin of the first trip in the chain. An illustration of the different steps that the process is doing is given in Figure 1.

In the first instance, we have information about all the trips, with their origin and destination locations (Figure 1 a). This picture shows the base case for the modelling, where all trips return empty to their origin location. We then look for all possible next origin points from any destination (purple ovals in Figure 1 b) and select only the next trips that lead to the minimum overall distance over the set of trips (solid purple ovals in Figure 1 b). The overall distance is then defined as sum of all the original trips and their next one (whether it is a return trip to its origin location or a trip to another origin location that is closer than returning to origin). In some cases, there might be a shorter next origin trip (dashed ovals in Figure 1 b) but over the whole set, only those in solid lines will uniquely lead to the minimum overall distance. Based on these next trips, only those for which the next trip distance is shorter than the return trip (bright blue arrows in Figure 1 c) are kept. In some cases, these next trips opportunities will lead to a round trip; in other cases, they might not. However, returning to the first origin empty might still lead to an overall shorter trip than the series of individual trips (as illustrated in Figure 1c with the dotted line). The steps leading to the output of Figure 1 b) and c) are of interest such that output illustrated in Figure 1 b) gives an overall understanding of the capacity for next trip opportunities, while output illustrated in Figure 1 c) gives an understanding of round-trip potentials over a set of trips.

Details of these steps are given in the next 2 sections, along with the workflow of the algorithm (Figure 2).

Figure 1: Illustration of the process for moving from empty return trips to opportunities for backloading



2.2 Heuristics based on domain expertise

While the problem definition is applicable to any movement in theory, there are a few practical considerations that need to be considered. These are outlined below and were implemented in the model:

- Trucks are of different type depending on the commodity they are transporting.
    - 11 truck types were defined in the TraNSIT database. All trips were then allocated a truck type according to the commodity transported. Table 1 lists these truck types and gives some statistics on their trips, where distance covered and trip length refer to one-way trips, not accounting for empty returns.
- Not all truck types are candidates to our class of problem. For example, milk or fuel trucks are better suited to the vehicle routing algorithms as they are managed by one operator and done over short distances.
    - The set of truck types was reduced, removing those transporting milk, fuel, concrete, construction material; as well as all the trips going to a supermarket.
- Backloading might be happening differently depending on the trip lengths. Short distance trips are often not candidates for backloading as this would require more effort than the costs of coming back to the origin location empty. For long distance trips, some might be able to pick up a load on part of their return trip
    - Trips shorter than 50km were removed for some classes of trucks
    - From the profile/distribution of the trip lengths for each truck type, these were grouped in similar trip length groups to look for backloading opportunities.

These heuristics not only brought some realism to the way backloading might be happening, but they also led to a reduction in the search space for the next trip origin location to any destination location. This consequently had the advantage to reducing computational complexity.

Table 1 gives some information about the statistics regarding the trips of the different classes, whether the backloading model was applied to it, and the sub-groups of trip length.

Table 1: Breakdown of the trips according to truck types with their corresponding statistics

Truck Type	Number of supply chain paths	Total distance covered (million km)	Average trip length (km)	Apply model	Groups of trip lengths
General container	258,907	70.6	272	Y	up to 50km, between 50 - 200, between 200-400, beyond 400
Refrigerated	160,218	122	761	Y	up to 100km, 100- 400, 400-1200, 1200+
Livestock	114,647	45.8	399	Y	up to 120km, between 120 - 250, between 250 and 500km, beyond 500km
Grains	108,506	16.8	155	Y	up to 180km, between 180 - 780, between 780-1340, beyond 1340km
Bulk construction	27,076	2.9	105	N	-
Concrete	22,450	2.5	109	N	-
Dangerous tanker	19,931	10.8	543	Y	up to 220, between 220 and 420, between 420 and 900km, beyond 900km
Fuel tanker	15,996	2.6	159	N	-
Timber vehicle	15,393	4.3	278	Y	up to 70km, between 70km and 200km, between 200km and 400km, beyond 400km
Milk tanker	8,483	1.4	165	N	-
Flat bed	6,948	6.4	923	Y	up to 200km, between 200-800, between 800 = 1500, beyond 1500

2.3 Backloading algorithm workflow

Having defined these truck type/trip distance subgroups, the next step was to find the unique closest next origin location to any initial destination, which was done by calculating the shortest distance matrix. While the subsets created in the previous step led to smaller search spaces, in some cases the number of trips was still large. To obtain reasonable computational times, the search space was further reduced according to geographical locations, such that origin points within geographical proximity of destination points were considered for the shortest distance matrix. This was done using k-means clustering such that:

- 2 subsets of locations (origin location subset, destination location subset) are created. Within each of these groups, the points are clustered into *n* (*n= number of points / 15,000*) clusters; with the division by 15,000 selected following a large set of experiments that led to reasonable computational times.
- Using the centroid location of each cluster, pairs of origin and destination clusters are created.
- Within each of these cluster-pairs, the closest unique distance from each destination to any other origin is calculated and populates the distance matrix for the cluster pair.
- The overall distance for each matrix is minimised leading to unique pairs of destination location to next origin location.

- Only pairs for which the distance from the destination location to the origin of the next trip is smaller to the return trip, are kept as closest next trip opportunity.

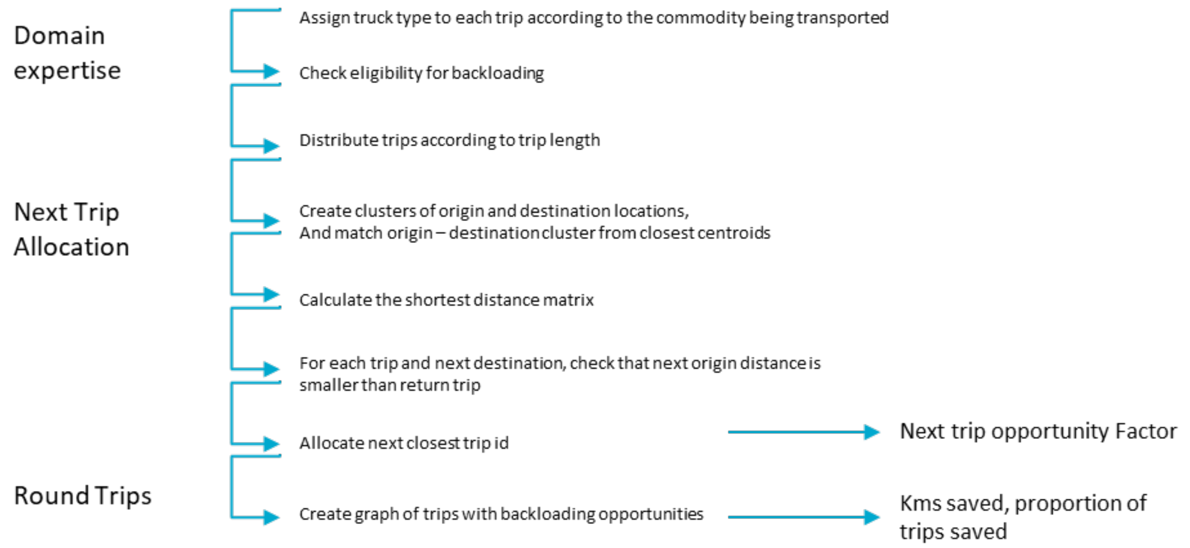
While the aim of this step is to find all destination-next origin pairs, there exists some cases where not all points have a corresponding closest distance from another origin movement. This is because the points are divided in several clusters which can be of different sizes. In practice, this would show when there are many trips going to a given location, with few going the other way. Such an example could be for a remote mining community for which refrigerated trucks supply a local distribution centre, while the only commodities leaving the area are minerals. In this case, the closest next origin location would become the origin of that trip, that is it is an empty return trip. In other cases, some candidate backloading trips could be overlooked. This would be the case when the closest trip's origin might be a member of another cluster, adjacent to the current one.

Using the output of the steps described above, the next trip opportunity factor for all truck type/trip distance was calculated. It is defined as the proportion of all trips that have a next valid origin location.

The output was further used to understand round-trip opportunities and their characteristics. This step is important to understand if from all these next identified trips, the truck would be led sufficiently closely to the initial origin location rather than further away from it. For this, a graph of all trips, including the intermediary trips to the next closest origin location, was created. Using such graph, different metrics were derived to indicate some of the backloading benefits within the Australian network supply chains, such as the average portion of avoided kms, the corresponding number of avoided kms overall, or CO_2 emissions avoided.

Figure 2 shows the algorithm workflow as described above, along with the types of metrics derived in the last two steps.

Figure 2: Backloading algorithm workflow



3. Results

This algorithm was applied to all the subgroups of truck types/trip distances; however, for brevity, only the results relating to two truck types (refrigerated, and general container) are shown in this paper. These also correspond to the truck types with the largest number of trips.

As mentioned above, two types of metrics were defined and are displayed here. The first one, called the next trip opportunity, is the proportion of trucks for which a next origin trip has been found that is closer than returning to base. It is essentially the opportunity for a truck type to pick up a next load.

Other metrics relate to round-trip characteristics, including possible use of multiple trips to efficiently return to the origin location. For this we are looking at the average distance ratio, and its corresponding avoided empty return distance.

3.1 Next trip opportunity factor

As described in section 2.3, each initial trip destination is associated with a next trip origin, where the next distance over all points in the set is minimised. These next trip distances are then compared to the original trip return distance, which reduces the whole set to potential next trip opportunities. The proportion of all trips for which next trip opportunities exist, called next trip opportunity factor, is calculated for each truck type/trip distance sub-group and displayed in the last column of Table 2.

Table 2: Backloading capacity (ratio of number of trips, and km) for each truck type according to distances

Truck type	Distance Group (km)	Number of next trip	Initial number of trips	Next trip opportunity factor
Refrigerated	**0-100**	4,705	9,396	0.5
	100-400	12,610	27,251	0.46
	400-1200	7,134	35,016	0.2
	>1200	16,414	31,232	0.53
Container	**50-200**	1,661	45,895	0.04
	200-400	4,204	49,903	0.08
	>400	13,209	54,651	0.24

Table 2 shows that the next trip opportunity factor differs greatly between the sub-groups. For truck types ‘refrigerated’ in most trip lengths, the next trip opportunity factor is around 0.5, meaning that it is possible to find a next trip for about 50% of the trips, except for those between 400-1200km that show fewer opportunities (0.2). For truck type Container, trips over 400km are those for which there are more opportunities for a next non-empty trip.

3.2 Round trips benefits

One of the limitations in considering the next trip opportunity factor only is that trips might lead to a next destination further away from its origin location. Using the graphs of all trips including their potential next trips, information regarding the kilometre ratio, defined as the new distance (with backloading) divided by the initial distance (with empty return), and average km avoided over all the trips was calculated. Results are shown in Table 3 for truck types ‘refrigerated’ and ‘general container’, where for each truck type- distance group, the number of round trips is given, with their average kilometre ratio, that is the average proportion of initial return trips over the new round trips with backloading. The average avoided empty return distance is also given for each group in the last column.

Table 3: Backloading metrics to describe potential benefits of practice.

Truck type	Distance Group (km)	Number of trips	Average kilometre ratio	Average avoided empty return distance (km)
Refrigerated	**0-100**	2,069	0.96	19
	100-400	6,682	0.97	35
	400-1200	3,895	0.87	374
	>1200	7,632	0.82	2,131
Container	**50-200**	2,584	0.84	64
	200-400	6,884	0.86	163
	>400	1,009	0.85	452

Using the above metrics, it can be noted that while the average kilometre ratio is not as great as the next trip opportunity factor, it is however still around 0.85 in most cases, which represents between 10-15% km reduction, especially for long-distance trips. In terms of costs savings, with an average cost of $2.60 per km for a B-double equivalent, Table 3 results would translate to a $1,201 saving for an average trip for a truck type 3 for trips over 400km, and to $5,540 for truck type refrigerated for trips over 1,200km. This is promising in the sense that for those trips identified with a next trip opportunity, doing so is worthwhile.

An illustration of the types of round trips is given in Figure 3 for a truck type 'container' and distance group '400+km'. Each trip leg shown in the map had its route optimised between their origin and destination location, as defined in the cost model in TraNSIT (Higgins et al., 2018). Additional optimised routes were calculated that correspond to those empty trips that go to the next closest origin location. The TraNSIT model provides information about the time, transport cost dependent on load transported (full/empty), and length of trip.

Information for this round trip is given in Figure 3 and Table 4. In Figure 3, three trips are connected in a single round trip, starting and finishing on the east coast after traversing the country to the west coast. Trip 1 is between West Sydney and Adelaide, Trip2 is between East Adelaide and North Perth, and Trip 3 is between South Perth and West Sydney. Table 4 provides output data from running TraNSIT regarding 4 metrics for each leg of the round trip, where the status (full/empty) is specified in the second column.

Using this data, the benefits of identifying the next opportunity are clear. If all trips returned empty, the overall distance would be 16,122km, the costs $86,333 and the travel time 165 hours. With the opportunities for next trip identified, these are reduced by nearly half, where the total distance is 8,436km, the costs amount to $46,592, and the time to 87 hours. Details for these calculations are given in Table 5, based on numbers from Table 4. While such opportunities might not be available on all routes, this shows that given information about other trips in the country, there exists interesting opportunities to incorporate additional freight movements as part of a truck's return journey to base. Of note, the time reported in Table 4 considers transport-related time only; however all times and costs related to logistics (including loading and fatigue management),are available in TraNSIT, but were not considered for the purpose of this paper.

Figure 3: Example of a round trip for a long-distance trip (400+km) for truck type 'container'.

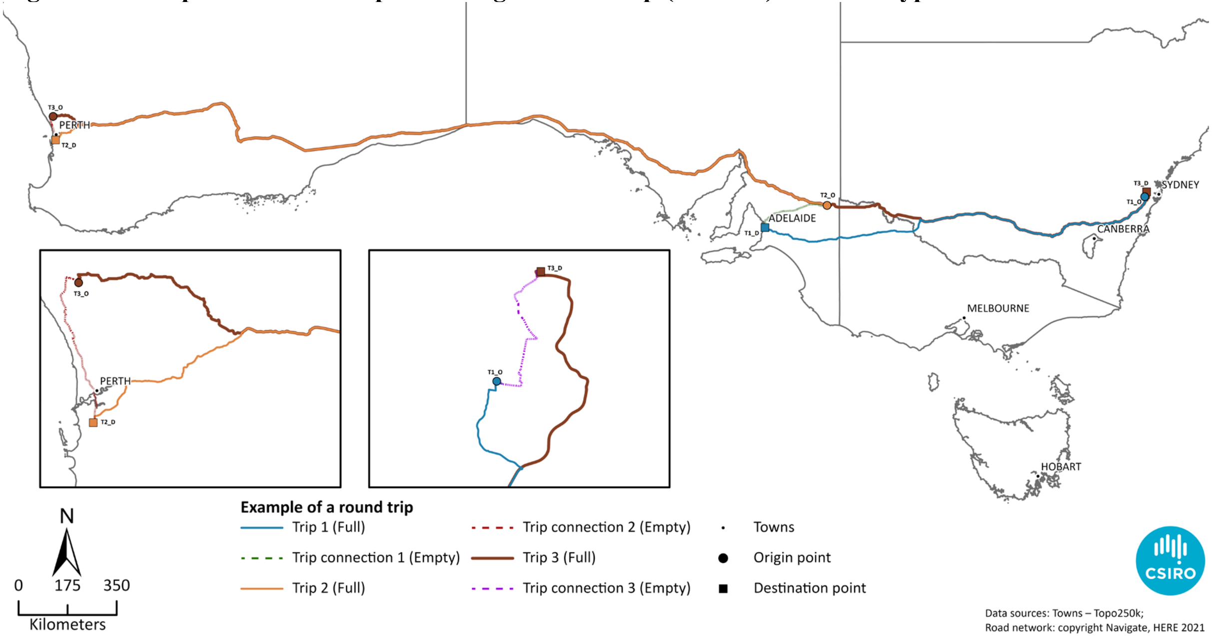


Table 4: Trip information from using TraNSIT for each leg of the round-trip example displayed in Figure 3

Trip Leg name (from Figure 3)	Trip status (full/empty)	Time * (hours)	Cost full (A$)	Cost empty (A$)	Distance (km)
Trip 1 (T1_O – T1_D)	Full	14.1	7,452	6,981	1,339
Trip connection 1 (T1_D – T2_O)	Empty	2.6	-	1,270	240
Trip 2 (T2_O – T2_D)	Full	28.3	15,347	14,368	2,781
Trip connection 2 (T2_D – T3_O)	Empty	1.2	-	581	109
Trip 3 (T3_O – T3_D)	Full	40.4	21,784	20,398	3,941
Trip connection 3 (T3_D – T1_O)	Empty	0.4	-	158	26

*Time reported in this table includes transport-related time only, not including loading and fatigue management.

Table 5:` Summary of the metrics quantifying the benefits when a round trip (example from Figure 3) is identified. Time, cost and distance are given for the 3 return trips with no backloading, and when they integrated as a round trip.

Trip type	Time (hours)	Cost (A$)	Distance (km)
Return trips with no backloading. **Trip 1 (full + empty) +** **Trip2, (full + empty +** **Trip3 (full + empty)**	2*14.1 + 2*28.3 + 2*40.4 **= 165.6**	7,452 + 6,981 + 15,347 +14,368 +21,784 +20,398 **= 86,330**	2*1,339 + 2*2,781 + 2*3,941 **=16,122**
Round trip **Trip1 +trip_connection1 +** **Trip2 +trip_connection2 +** **Trip3 +trip_connection3**	14.1 + 2.6 28.3 + 1.2 40.4 + 0.4 **= 87**	7,452 + 1,270 + 15,347 +581 +21,784 +158 **= 46,592**	1,339 + 240 + 2,781 + 109 + 3,941 + 26 **=8,436**

4. Discussion

The results presented above support the idea that there is a potential to reduce empty running by trucks in Australia. While the model output shows that the potential for a next trip opportunity might be interesting for some of the truck / route types, with opportunities up to 50%, these reduce greatly in many cases when enforcing the truck to come back to its location of origin. However, for those for which a round-trip is possible, the benefits can be great as highlighted in Figure 3 and Table 4.

Such problem has been investigated by very few other researchers but includes the work presented in (McKinnon and Ge, 2006) for which a backloading algorithm was applied to a dataset of grocery supply trucks in the UK. While the methods employed show some similarities, the application of the current work is broader with trucks carrying goods over all supply chains in Australia. The larger sample of truck types available in the current dataset shows that opportunities differ depending on the truck types, therefore leading to varying opportunities over the different sectors they service. One of the limitations in the current work, however, is that scheduling constraints are not considered. TraNSIT being a planning tool, as opposed to a scheduling tool, contains data regarding freight movements on a monthly basis, without information about scheduling windows. As such, opportunities for next trips are based on locations only with no consideration of short time windows, which if implemented might reduce the opportunities identified above.

Future versions of this model will consider alternative algorithms for the selection of the next trip, such as considering all trips within a radius smaller than a fraction of the return trip, widening the opportunities for the next trip, including picking up loads that are over a small portion of the trip. This would especially be beneficial to estimate capacity for very long-distance trips. Further extensions will also be used to better understand the availability of empty containers at different parts of the country, which is a problem of importance for many jurisdictions in Australia (Nine-Squared Pty Ltd and Neil Matthews Consulting, 2020); and how such containers can be accessed at lowers costs.

5. Conclusion

This paper presented a model to assess the backloading capacity of freight trucks in Australia. Heuristics and algorithms are presented, followed by metrics derived from the application of the model to data in TraNSIT. Overall, the results showed that for some trip categories, there are opportunities for return trips with a payload, highlighting the benefits for long-haul transportation.

While this model is a first attempt at estimating the capacity for return trips with payload at the national level, and therefore contains limitations, it demonstrates that opportunities exist. This reinforces the idea that stakeholders, especially those small truck operators, might benefit from putting in place a mechanism to provide visibility and potentially coordination of trips. Operators, could have a better understanding of their non-empty return potential, helping with the costs of their operation, and in the long-term their resilience to economic shocks. In addition, with the increasing requirements in reducing greenhouse gas emissions, operators with reduced emissions might be favoured by compagnies reporting on their scope 3 emissions. With the transport sector responsible for 94 Mt of CO_2 emission in 2020, 21% of which is attributable to trucks and buses (Climate Change Authority, 2021), even a 5% reduction in kms travelled thanks to backloading would lead to 1Mt of CO_2 emissions avoided on a yearly basis. Overall, better use of transport resources will lead to a more sustainable and resilient nation.

6. References

CLIMATE CHANGE AUTHORITY. 2021. *Transport* [Online]. Available: https://www.climatechangeauthority.gov.au/sites/default/files/2021-03/2021Fact%20sheet%20-%20Transport.pdf [Accessed 2023].

COMMONWEALTH OF AUSTRALIA 2018. Inquiry into National Freight and Supply Chain Priorities.

HIGGINS, A., MCFALLAN, S., MARINONI, O., MCKEOWN, A., BRUCE, C., CHILCOTT, C. & PINKARD, L. 2018. Informing transport infrastructure investments using TraNSIT: A case study for Australian agriculture and forestry. *Computers and electronics in agriculture,* 154**,** 187-203.

KAVUSSANOS, M. G., VISVIKIS, I. D. & DIMITRAKOPOULOS, D. N. 2014. Economic spillovers between related derivatives markets: The case of commodity and freight markets. *Transportation Research Part E: Logistics and Transportation Review,* 68**,** 79-102.

MCKINNON, A. C. & GE, Y. 2006. The potential for reducing empty running by trucks: a retrospective analysis. *International journal of physical distribution & logistics management,* 36**,** 391-410.

NINE-SQUARED PTY LTD & NEIL MATTHEWS CONSULTING 2020. NSW Empty Container Supply Chain Study.

PELTAN, T. 2015. Haulier’s Portal: A web-based GIS service for freight connection search. *SGEM2015 Conference,* 1**,** 653-659.

TOTH, P. & VIGO, D. 2014. *Vehicle routing: problems, methods, and applications,* Philadelphia, Society for Industrial and Applied Mathematics : Mathematical Optimization Society.